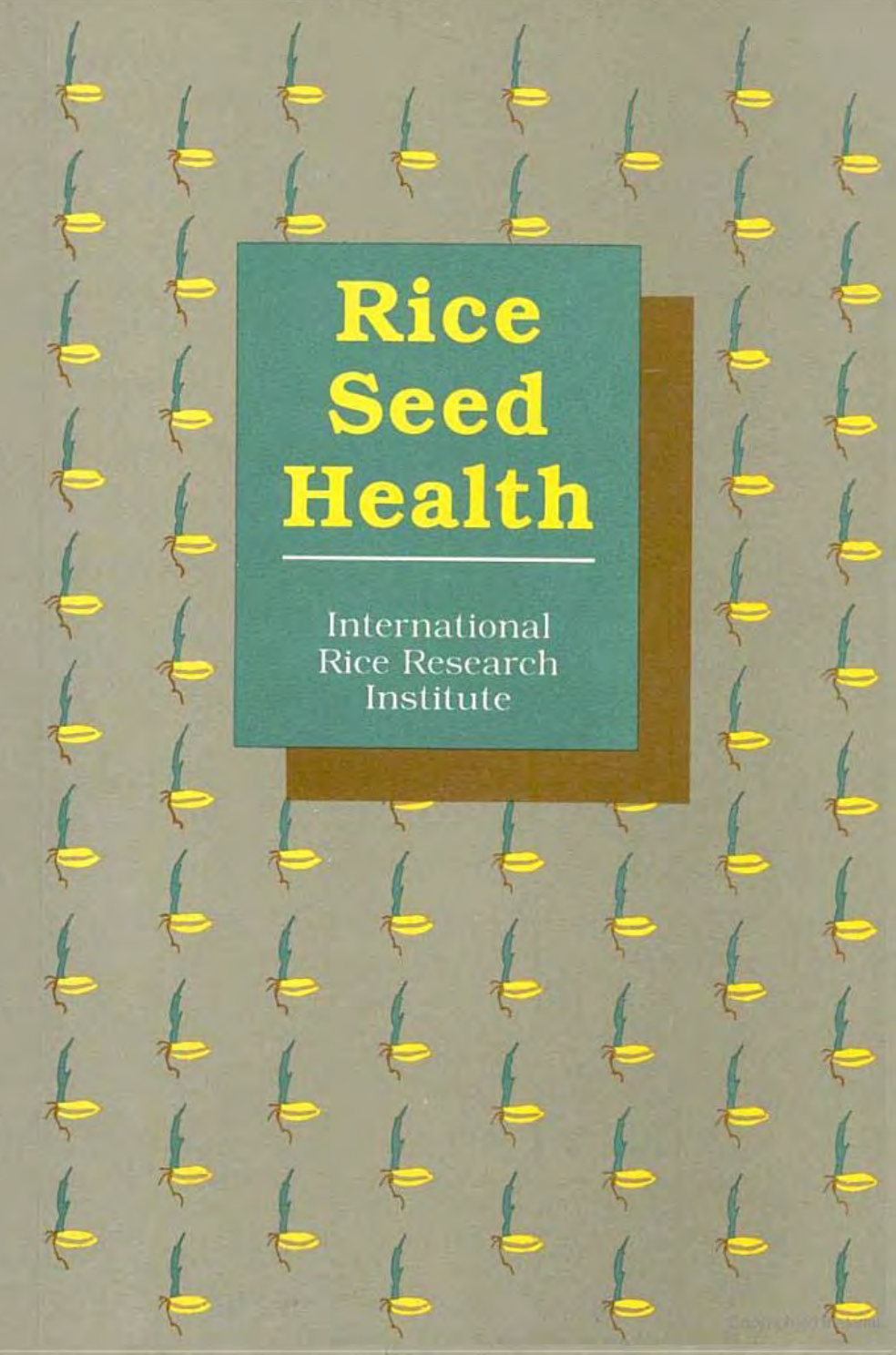
Rice
Seed
Health
International
Rice Research
Institute

Rice Seed Health

Proceedings of the
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on Rice Seed Health
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The International Rice Research Institute (IRRI) was established in 1960 by the Ford and Rockefeller Foundations with the help and approval of the Government of the Philippines. Today IRRI is one of the 13 nonprofit international research and training centers supported by the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). The CGIAR consists of 50 donor countries, international and regional organizations, and private foundations.

IRRI receives support, through the CGIAR, from a number of donors including the Asian Development Bank, the European Economic Community, the Ford Foundation, the International Development Research Centre, the International Fund for Agricultural Development, the OPEC Special Fund, the Rockefeller Foundation, the United Nations Development Programme, the World Bank, and the international aid agencies of the following governments: Australia, Belgium, Canada, China, Denmark, Finland, France, Federal Republic of Germany, India, Italy, Japan, Mexico, The Netherlands, New Zealand, Norway, the Philippines, Saudi Arabia, Spain, Sweden, Switzerland, United Kingdom, and United States.

The responsibility for this publication rests with the International Rice Research Institute.

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Foreword

The success of modern rice improvement and production programs is attributable partly to extensive international collaboration in germplasm conservation and utilization. The free exchange of breeding material and germplasm has greatly enhanced national rice improvement efforts. The International Rice Research Institute (IRRI) plays a catalytic role in these activities, and to further the joint endeavors, IRRI organized this lnternational Workshop on Rice Seed Health and invited scientists from national and international research centers to

- examine quarantine procedures to enhance domestic seed production and international seed exchange, and
- promote seed health and genetic purity in varietal identification and release.

In the past, IRRI's research centered on favorable environments for irrigated rice. IRRI research in the future, hand in hand with that of national programs, must pay greater attention to the less favorable environments encountered by many of the world's rice farmers, in addition to maintaining the ongoing efforts in favorable environments.

With this expanding demand for gene sources to meet the varietal needs of diverse environments, the global exchange of rice germplasm and breeding material is essential to make headway in rice improvement. Accompanying this large flow of seed among rice-growing countries is the inevitable need to maintain high levels of both seed purity and seed health. Plant quarantine has become a topic of concern among policymakers in national systems. Many developing countries are currently upgrading their quarantine arrangements, leading to closer scrutiny of incoming seed.

IRRI established its Seed Health Unit (SHU) in 1983 in cooperation with the Plant Quarantine Service of the Bureau of Plant Industry (BPI) of the Republic of the Philippines. The functions of the SHU are to ensure a high level of seed health to meet standard plant quarantine requirements around the world, and to provide training in seed health maintenance and testing procedures for the speedy and safe exchange of rice germplasm and breeding material.

Several important pathogens are associated with rice seed, and there are two basic problems in relation to plant quarantine in rice. One is to recognize disease organisms of quarantine importance; the other is to determine how much of a seed lot must be sampled to follow quarantine regulations. The answers are not always

straightforward. Sampling methods appropriate to large or small consignments of seed are often determined by the diseases that are of concern, and they require both statistical and common sense approaches. Standard testing procedures and sampling techniques are not always available. For rice in particular, no detailed and reliable information is available on disease occurrence resulting from seedborne pathogens.

This workshop was held in March 1987 to coincide with the inauguration of IRRI's Seed Health Laboratory. IRRI staff and scholars are grateful to the United Nations Development Programme for its generous financial support of the workshop. We are also thankful to all the participants who either presented papers at the workshop or were actively involved in the discussions.

We hope that the recommendations formulated during the workshop will be helpful to institutions and individuals engaged in seed health testing and in research on rice seed pathology.

I am especially grateful to the members of the organizing committee for their efforts to develop the programs: T.W. Mew (Chairman), T.P. Chang, G.S. Khush, S. Merca, and D.V. Seshu—all from IRRI—and E. Tuazon of Plant Quarantine Service, BPI.

The book was edited by S.J. Banta with the assistance of E. Cervantes. T. W. Mew served as technical editor. They are grateful to R.L. Gabrielson for his assistance.

Klaus Lampe
Director General

Welcome address

Good morning, ladies and gentlemen. May I extend to you a very warm welcome. I am happy to see here so many from different parts of the world — Latin America, Africa, Asia, the Near East, Oceania, Europe, and North America — all concerned with good-quality seed. I am particularly happy that we have a mixture of scientists: those from national research systems who have the responsibility for ensuring the quality of seed, both locally produced and imported; those from the international agricultural research centers; those from the Food and Agriculture Organization and other United Nations bodies; and those from other outstanding agencies like the Danish Government Institute of Seed Pathology for Developing Countries. We have a large contingent from our own host country, the Philippines, from the Plant Quarantine Service, the Seed Testing Laboratory, the University of the Philippines, and the private sector. I am particularly happy to welcome Dr. Robert Kahn. who did an extensive study in 1981 of the whole international agricultural research system for the Technical Advisory Committee of the Consultative Group on International Agricultural Research. Dr. Kahn's paper was very useful to the international centers in further strengthening their facilities for seed health, because it was a starting point for a more intensive examination of arrangements and collaboration with the national agricultural research systems. Many of our collaborators from the major rice-growing countries are here, and we are equally happy to see experts from developed nations like Denmark, France, Japan, the Netherlands, the United Kingdom, the United States, and New Zealand. We owe a great deal to Drs. Paul Neergaard and S.B. Mathur for training many scientists in seed pathology, including staff of IRRI. We are grateful for their valuable contributions.

1 hope at the end of the week, when you look back, you will find that this time has been fruitful. We will try to make it as productive a meeting as possible. Four working groups will soon be formed so that interested scientists can discuss relevant issues and come to some conclusions to be presented on the last day. We will visit the Bureau of Plant Industry and the national quarantine facilities in Manila so that you can have an idea of how international centers and national systems work together. You will also visit IRRI's seed facilities, and we welcome your comments on their further improvement.

The financial support for this meeting comes entirely from the United Nations Development Programme (UNDP). Drs. T. Rothermel and K. Satyapal of UNDP send their greetings to you and hope that our gathering here will be very beneficial to the International Rice Testing Program and other global cooperative activities. I want to express my gratitude to Dr. T. W. Mew and his organizing committee, to Mr. S. D. Merca and his group, and to Ms. V. Segovia, the conference organizer, and her associates. They all worked together extremely well to put the program together, both logistically and scientifically. I trust their efforts will be rewarded by a meaningful dialogue and a worthwhile set of workshop recommendations. Thank you.

M. S. Swaminathan
Director General

The role of the international agricultural research centers in seed research and improvement

M. S. SWAMINATHAN

The international agricultural research centers (IARCs) deal with two clients — farmers and scientists — both of whom need healthy seed, for the seed is the starting point for achieving sustainable high yields. Because breeding programs place more emphasis on less favorable environments, scrambling of genes from several environments to solve diverse problems will necessitate moving more seed; such shuttle breeding has major quarantine implications. Hybrid rice, which has become important in China, requires an efficient system to produce and transport large quantities of seed. The IARCs are at the foretront of the conservation of a wide array of genetic variability in crop plants for current and future use. Such genetic resources are regarded by IAKCs as a public resource to be used for public good. Scientists must follow the most stringent rules in transporting seed. The IARCs should promote the development of regional centers in contiguous agroecological areas that would be responsible for evolving standards, devising disease detection methods, and training. The national programs and international centers must determine the most important pests and diseases on both national and regional bases and develop ways to prevent their transmission by seed.

The international agricultural research centers (IARCs), of which the International Rice Research Institute (IRRI) is a prime example, cooperate with three levels of research programs: national, regional, and global. They have two major clients: farmers, who need healthy seed for crop cultivation, and scientists, who desire healthy seed for experimental purposes. The requirements of the two groups may differ, with different standards for seed health. Moreover, countries have a variety of quarantine arrangements for checking and monitoring seed health. In large countries with distinct agroecological regions, like India and China, quarantine arrangements exist within the country itself. What further strengthening should the IARCs do at the national level? What kind of regional collaborative programs can they take up? And what type of global programs are appropriate?

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Recent years have seen a gratifying growth of regional cooperation in quarantine and in seed movement, like the Inter-African Phytosanitary Commission, organized in 1962; the European and Mediterranean Plant Protection Organization, founded in 1965; and the Association of Southeast Asian Nations (ASEAN) Plant Quarantine Center and Training Institute (PLANTI), established in Kuala Lumpur in 1981. These organizations have provided mechanisms for more viable regional relationships. At the international level, the International Plant Protection Convention of 1951 provides an overall umbrella under which IARCs can cooperate with many countries. There is also superb cooperation among genebanks in various parts of the world — such as the collaboration in Asia among the Japanese genebank in Tsukuba, IRRI's genebank, the new Chinese genebank, and the Indian Bureau of Plant Genetic Resources — even though each group has its own requirements for seed health.

The 13 IARCs under the Consultative Group on International Agricultural Research (CGIAR) and the many other non-CGIAR centers such as the Asian Vegetable Research and Development Center carry out an enormous amount of activity in plant and seed exchange. Yet the IARCs constitute only about 3-4% of global agricultural research investment. More than 95% of the agricultural research in developing countries occurs within the national research systems. The IARCs and the national systems constitute a genuine global family of cooperators.

The CGIAR redefined its goal in 1986 as contributing toward increasing sustainable food production in developing countries in such a way that the nutritional level and general economic well-being of low-income people will be improved. Seed health has a very important relation to sustainability: the seed is the starting point of sustainable high yields. In operation, the goal of sustainability has three major thrusts:

- *Managing and conserving resources.* How can we conserve the basic life support systems of land, water, flora, fauna, and the atmosphere, and utilize them in such a way that they promote sustainable yields?
- *Increasing productivity.* The land is a shrinking resource in agriculture, but we have to produce more for the world's increasing population. For example, the Philippines will require at least 12 million t of rice annually by the year 2000 from only 3 million ha because the available land in the country is very limited. In Egypt, only 3% of the land area is available for farming, which not only makes seed technology critical but also implies the need for sound policies concerning seed development and trade.
- *Strengthening national research capabilities.* Agriculture is by and large location-specific. Whether we can stimulate and sustain high productivity in a country will depend on the vitality of the national research organization. The task cannot be done only by the IARCs. The national systems must develop the ability to solve the problems faced by their farmers.

Seed health is particularly relevant in relation to research networking. IRRI's principal networks — the International Network on Soil Fertility and Fertilizer Evaluation in Rice (INSFFER), the Asian Rice Farming Systems Network (ARFSN), and the International Rice Testing Program (IRTP) — are all wide-

reaching activities. Through these and similar mechanisms, IARCs and the national programs are brought together. The networks have enlarged the frontiers of cooperation in seed exchange and seed testing, which correspondingly deepens our obligation to attend to seed health and quarantine problems with great rigor.

At IRRI, we have decided that, having done something for irrigated and favorable rainfed areas, we should now turn in a much more integrated and multidisciplinary manner to the less favorable environments: upland, deepwater, rainfed lowland, tidal wetland, and problem soil areas. Rice breeders are trying to employ shuttle breeding — growing one generation, for example, at the National Rice Research Institute in Hangzhou, China: growing the next at IRRI; then back to China; and so on. Dr. Norman Borlaug used shuttle breeding from one environment to another in Mexico to develop photoperiod-insensitive wheat with lower temperature sensitivity. By this technique, broad resistance to pests and diseases, as well as broad-spectrum tolerance to soil stresses, can be incorporated. But shuttle breeding has implications for the movement of seed, from the quarantine viewpoint and from the seed health viewpoint. As we use more and more of these kinds of techniques, seed health work becomes much more important.

The same principles hold for gene rotation, which Korea has used successfully in breeding resistance to blast. One of the reasons the multiline system of breeding could not take off is the problem of whole seed composition. Gene rotation techniques involve a considerable degree of orchestration among scientists, seed agencies, and the farming community, all of whom should know what they are supposed to be doing. As agriculture becomes more knowledge-intensive, the broad spectrum of resistance that breeders are able to assemble becomes more important. Largely because of access to a wide range of test environments, genes from many locations can now be combined. China has gone one step forward in developing hybrid rice, which now occupies large areas. To cover 8.4 million ha, as hybrid rice did in China in 1985, an economical and efficient system of F_1 seed production is a prerequisite.

Finally, we come to the field of biotechnology. IRRI is the coordinating center for a global research cooperative on genetic engineering in rice supported by the Rockefeller Foundation. The cooperative's major aim is to transfer across sexual barriers those genes that we could not transfer before, by using vectors like *Agrobacterium tumefaciens* as well as techniques such as electrophoresis and microinjection. All this has implications for seed processing, storage, and transfer.

The IARCs are therefore in the forefront of facilitating the free exchange of seed and genetic material. They treat seed as a public rather than a private resource. The whole concept of IARCs is to share information and material freely. But how can they be shared without creating problems? And what about the millions of tons of food grain moving about?

Scientists should set an example. We must follow the most stringent methods of seed health management in our own exchanges. Our orientation should be toward helping countries get seed carefully and safely. We must develop both national and the international capabilities to do this properly. The IARCs should promote the growth of a lead center in each contiguous agroecological region for training, for

developing standards, and for deciding what pests and diseases are most important and what detection methods should be used. We need to involve and train seed producers, as ASEAN is doing at PLANTI.

The quarantine services of many countries today have excellent relationships with the IARCs. Examples are the International Crops Research Institute for the Semi-Arid Tropics and the Indian National Quarantine Services, and IRRI and the Philippine National Quarantine Service. An IRRI staff member has been deputized as a national plant quarantine officer for rice in the Philippines; that officer reports faithfully whatever is done and whatever is not done. This mutual confidence and strengthening of the relationship is exceedingly important, because both parties working together help the national breeders and scientists get the best possible genetic material. Recognizing special pests and pathogens of quarantine importance and developing sampling techniques are key tasks for each region. The quarantine services require a wide variety of expertise. How can such a variety of expertise be built into national quarantine services, and how can we all work together in harmony? Most rice-growing countries now have quarantine acts and services, but they are phenomena of the last 30-40 yr. Even in the United States, the first legislation, the Insect Pest Act, was passed only in 1905. There are few international plant protection conventions.

In the next phase of rice improvement, rice germplasm is going to play an even greater role than in the past. How can we help the breeders accomplish their tasks and at the same time not create new problems within a country? That is the very important question to be addressed at this meeting.

The importance of seed health in international seed exchange

R. P. KAHN

Plant pests and pathogens of quarantine importance can be moved along natural and man-made pathways depending on the life cycle of the pest, the environment through which it moves, and man's activities. At the end of each pathway, establishment of the pest or pathogen in a new area depends on three factors: 1) the number of individuals that survive the journey (inoculum or population), 2) the presence of hosts in a susceptible condition, and 3) a favorable environment. When pests or pathogens move through a pathway along with their hosts, the chances that these three factors will act in concert are increased. Plant protection and quarantine services at the national level exist to block man-made pathways, particularly for those organisms that have no natural means for moving long distances. The principal regulatory actions, or safeguards, implemented by quarantine services are the permit system, the phytosanitary certificate, and inspection (and treatment if necessary). These safeguards are considered adequate for low- or medium-risk plant material. More drastic actions, such as prohibition of the host, may be taken if the host can be infected or infested with an organism for which inspection and treatment are not adequate safeguards. Plant material imported for scientific purposes is often exempt from such drastic actions. This paper discusses the importance of seed health in the international exchange of seeds as viewed from a plant quarantine perspective — with emphasis on rice seed — and reviews the biological basis for establishing regulations, rules, guidelines, instruction manuals for quarantine officers, and policies that govern the entry status of germplasm imported as seed. Liberal and conservative attitudes about the entry status of germplasm are discussed. Emphasis is placed on the use of independent safeguards to lower the risk associated with the importation of germplasm. Risks, hazards, safeguards, and pest risk analysis as related to the international transfer of seed as germplasm are covered, as well as the impact of quarantine regulations and regulatory actions on the international exchange of rice seed.

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Seed health is a highly significant aspect of agricultural production, with both domestic and foreign implications. From a domestic point of view, seed health is an important factor in the planting of seed by farmers, gardeners, and researchers, including genetic resource scientists involved in the collection, evaluation, and conservation of plant germplasm. From an international point of view, seed health relates to the potential hazards and risks of introducing pests and pathogens of quarantine importance along with imported seed. From both points of view, seed health is the basis for seed certification conducted by the seed industry or by government agencies in the production of seed for domestic or export purposes and in the issuance of phytosanitary certificates by government agencies.

Seed health may be considered from two viewpoints: 1) qualitatively — whether seed is infected with plant pathogens, infested with pests, or otherwise contaminated by such organisms — and 2) quantitatively — the level of such infection, infestation, or contamination in a seed lot. In commercial seed lots, quantitative aspects may relate to the setting of tolerances for the presence of certain lower-risk pests and pathogens. The qualitative aspects provide the main thrust of this paper.

The paper reviews, in a plant quarantine context, the qualitative aspects of seed health in relation to the international exchange of crop seed in general and rice seed in particular, concentrating on the international transfer of seed for scientific purposes rather than on commercial seed.

In most countries, commercial seed and scientific seed of the same crop are judged by different quarantine standards. Often, when a country prohibits the importation of foreign seed because of the potential threat of introducing pests or pathogens not known there, the prohibition applies only to seed imported by the commercial or general public. Seed imported for scientific purposes may be exempted from the prohibition, but only after an assessment of the hazards, risks, and benefits, and the issuance of a special permit that specifies the conditions and safeguards to be followed. The justification for this double standard is the favorable risk/benefit ratio for scientific material and the much less favorable ratio for commercial material — when the agricultural production of the country as a whole is considered.

To define the role of plant quarantine in the international transfer of plant germplasm, the review begins with the concepts of hazards, risks, pathways, safeguards, pest risk analysis, and risk/benefit considerations used by quarantine officers in determining the entry status of high-risk plant germplasm and in setting safeguards. Quarantine restrictions as well as safeguards may have an impact on the international transfer of plant germplasm by international agricultural research centers (IARCs) (Kahn 1982b, 1983b, 1983c).

DEFINITIONS

Quarantine terms used in this report are listed here because they may have different meanings in different countries.

Hazard. The danger that a specified pest is known or perceived to present to the agriculture of the importing country should the pest gain entry on imported items and subsequently become established.

Risk. The chances that a hazardous organism will enter and become established. Since quarantine risks have not often been quantified, quarantine officers generally refer to the level of risk as low, medium, or high.

Safeguards. Actions taken to lower the risk of introducing hazardous organisms. Safeguards include rules, regulations, permits, phytosanitary certificates, inspection, treatment, isolation, passage through a quarantine greenhouse (Kahn 1983a), seed health testing, and other pest and pathogen detection tests.

Plant pests. All biotic agents that damage or injure plants (Table 1). The term, as used in the quarantine regulations of most countries, includes not only insects, which most scientists regard as pests, but also microorganisms, which most scientists regard as pathogens. However, in this paper, the separate terms "pests"and "pathogens" are used because, for imported seed, the risks associated with pathogens are generally higher than those with pests. Consequently, the emphasis in this paper is on pathogen hazards and risks.

Entry status. The entire range of decisions or policies that serve as guidelines for procedures, regulations, or regulatory actions governing whether imported articles such as seed are enterable and, if enterable, under what conditions. Attitudes toward

Table 1. Plant pest and pathogen groups and their associations with seed.

Pest or pathogen group	Association with seed[a]	
	Pests	
	Seed may be infested	Seed containers may harbor "hitchhikers"
Insects	+	+
Mites	–	+
Snails and slugs	–	+
Nematodes	+	–
Protozoa	–	–
Rodents	–[b]	–[c]
Bats	–[b]	–
Birds	–[b]	–
	Pathogens	
	Seed may be infected	Seed may be contaminated
Fungi	+	+
Viruses	+	–[d]
Viroids	+	–
Bacteria	+	+
Spiroplasma	–	–
Mycoplasmalike organisms	–	–
Parasitic plants	–	+
Weeds	–	+

[a] + = groups in which some members are associated with seed, – = groups in which no members are associated with seed. [b] Seed may be transported by animals. [c] Rodents are not generally associated with seed as germplasm but may be present in seed storage areas or in carriers such as ships. [d] Rarely; some viruses may contaminate the outside of seed but may be removed by special treatment, e.g., acid seed treatment.

entry status may range from "liberal" to "conservative," but liberal in this context does not mean "lax."

LEGAL BASIS FOR PLANT QUARANTINE

Quarantines are regulations promulgated by governments to reduce the risk of inadvertently introducing hazardous pests and pathogens on articles, including seed, imported from foreign areas. The legal basis of quarantine comprises 1) legislation enacted by national and sometimes state or provincial governments; 2) enabling legislation that directs the Minister of Agriculture to issue necessary rules, orders, or directives; or 3) legislation enacted by a regional parliament representing groups of countries, such as the European Community or the Andean Pact nations. The quarantine regulations for most countries have been summarized (USDA 1939-87).

In addition, biological standards or guidelines for promulgating rules are often suggested by regional plant protection organizations (e.g., the European and Mediterranean Plant Protection Organization, South Pacific Commission, Caribbean Plant Protection Commission), but such recommendations are not binding on member countries.

The legal umbrella that covers international plant quarantine matters is the International Plant Protection Convention of 1951 (often referred to as the Rome Convention). Most countries either are signatories of the Rome Convention or follow its mandates. For signatory nations, the Convention has the full force of a treaty under which disputes may be arbitrated in an international court of law. The treaty is administered by the Food and Agriculture Organization of the United Nations. Phytosanitary certificates, such as those that accompany international shipments of germplasm seed, are instruments of this treaty.

PATHWAYS

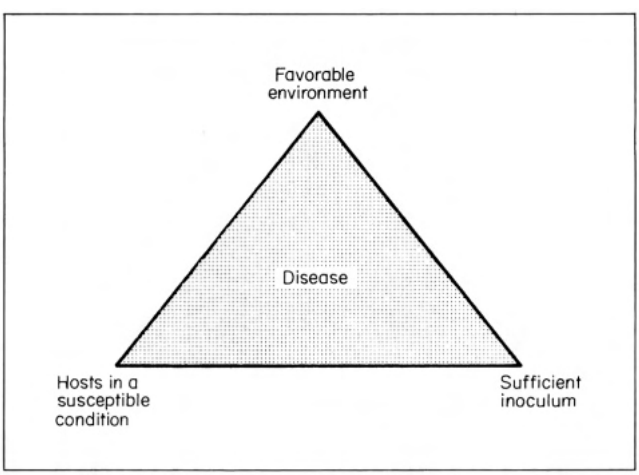
Pests and pathogens may move along natural or man-made pathways (Table 2) (Kahn 1977, 1982b, 1983b, 1983c, 1986). Whether a pest or pathogen becomes established at the end of the pathway depends on the synchronization of three factors: 1) sufficient viable inoculum (or population threshold), 2) the presence of susceptible hosts, and 3) a favorable environment. At the end of the pathway, if any one of the factors is not operative, an organism, although it may have gained entry, does not become established. In theory, countries are "bombarded" by exotic organisms entering on natural pathways; yet, there is usually no establishment if the three factors are not operating in concert when the pest or pathogen arrives. The three factors are often referred to as "the disease triangle" (Fig. 1).

The means by which seed is moved along natural and man-made pathways are shown in Table 2. To the extent that the seed is infected, infested, or otherwise contaminated with pests or pathogens, it is a carrier or, by stretching the meaning, even a vector of biotic agents. The types of agents associated with the transfer of seed along pathways are listed in Table 1. Countries that import seed are also "bombarded" with exotic organisms entering along man-made pathways; yet, as

Table 2. Natural and man-made pathways for the movement of pests and pathogens and the association[a] of seed with these pathways.

Natural pathways	Man-made pathways
+ Winds, storms	#Containers, crates
+ Air currents	*+Mail
+ Ocean currents	*+Baggage
+ Surface drainage	#Used bagging
+ Seed dispersal	*+Smuggling
Root grafting	#Used vehicles
Fliers (insects, mites)	#Common carriers (ships, etc.)
Migratory species (birds, locusts)	+Agricultural cargo including commodities and raw materials
Self-locomotion (spores, cells, nematodes)	#Nonagricultural cargo
Vectors (insects, nematodes, fungi, etc.)	*+Air freight
+ Other carriers (birds and other animals)	#Packing materials
	#Importation of soil
	*+Importation of plant or plant parts
	#Importation of microorganisms as scientific cultures
	#Goods manufactured from agricultural materials

[a] + = direct pathways for the movement of seed and, consequently, pathways for the movement of seedborne organisms, # = indirect pathways, or possible contamination by seed and, consequently, pathways for the movement of seedborne organisms, * = pathways for the importation of plant germplasm as seed.



1. The disease triangle, showing the interaction of host, environment, and inoculum on disease development. If all three factors are not synchronized, establishment of a disease agent in a new area and development of the disease do not take place.

with natural pathways, there is no establishment if the three factors are not operating together.

RISKS

Risks associated with germplasm collection sites

The risks associated with germplasm vary with the collection site. For example, rice collected as seed from the wild is likely to be of higher risk than rice collected from a research station. Rice collected as whole plants may be of higher risk than rice collected as seed, since not all rice pathogens are seedborne. Plants in the wild may grow in regions lacking studies or surveys of pests and pathogens. Table 3 lists collection sites according to estimate of potential risk.

Risks associated with seed introduction

Whether seed moving along a man-made pathway constitutes a risk depends on the genus or species of plant, the presence of seedborne or seed-associated pests and pathogens of quarantine significance in the exporting country, the known geographic distribution of those pests, the life cycles of the pests, the volume and

Table 3. Some collection sites for plant germplasm arranged in the order of highest risk first.

Source of germplasm	Hazard- or risk-related factors
Collected in the wild	Pest and pathogen occurrence is often unknown
Tubers, seeds, etc. collected in marketplaces	Health status of mother plants is unknown; pathogens may be latent; tubers or seeds may be symptomless; origin uncertain
Farms	Minimal pest control activities, or none
Orchards, plantations	Often a high level of pest and pathogen control and surveillance
Commercial or research nurseries	Usually a high level of pest control and inspection; commercial nurseries often associated with government certification
Experimental fields	May have high level of pest control; personnel are usually aware of pests, pathogens, and symptoms
Plots in areas isolated from commercial plantings or where specified pests are not known to occur	Risk is reduced by absence or lower incidence of specified pests; pest and pathogen control and surveillance
Greenhouses at research stations	Plants isolated from many pests and pathogens; high level of pest control and surveillance
Plant tissue cultures	Most pests and pathogens except fastidious bacteria and obligate parasites (e.g., viruses) are eliminated during processing and subsequent culture; isolated from contamination
Approved certification	Pathogen-tested plants (assuming procedures are adequate and there is no recontamination); pest and pathogen control and surveillance programs in place; inspection safeguards
From other quarantine stations, third-country quarantine, or other high containment facilities	As with plant tissue cultures; plants maintained under high levels of phytosanitation; wide spectrum of pest and pathogen detection tests; quarantine treatments

frequency of plants and seed moving in international traffic, and the favorableness of environmental factors. The association of a pest or pathogen with its host during transit along a pathway favors the dissemination of pests and pathogens that have an obligate relationship with their host such as viruses or others that depend on the presence of their host during most of their life cycle.

However, not all of the organisms found in or on seed are economically important, and not all are of quarantine significance. Many are ubiquitous and therefore already established in the importing country. Some seedborne fungi such as *Penicillium* spp. grow slowly on stored seed and affect its quality but are not considered plant pathogens because they are usually not found as pathogens in the field. However, others are economically important, and some may be of quarantine significance to the importing country.

The numbers of pathogens reported in the scientific literature for 23 crops, including rice, are shown in Table 4. The totals may include some synonyms. The organisms have been classified into three groups: Group A includes pathogens that

Table 4. Number of seedborne pathogens reported in the world scientific literature for 23 crops and the classification of these organisms into groups based on their occurrence in the United States.[a]

Scientific name	Common name	Total	Number in group[b]			Percent in group		
			A	B	C	A	B	C
Arachis hypogaea	Peanut	156	31	73	52	20	47	33
Avena sativa	Oat	55	2	41	12	4	75	21
Brassica spp.	Brassicas	49	2	36	11	4	74	22
Capsicum spp.	Peppers	47	3	41	3	6	88	6
Daucus carota	Carrot	37	5	30	2	14	81	5
Glycine max	Soybean	112	9	89	14	8	79	13
Hordeum spp.	Barley	74	9	51	14	12	69	19
Lactuca sativa	Lettuce	30	1	27	2	3	90	7
Lycopersicon	Tomato	46	3	35	8	7	76	17
Medicago sativum	Alfalfa	36	3	28	5	8	78	14
Nicotiana tabacum	Tobacco	23	6	17	0	26	74	0
Oryza sativa	Rice	153	28	99	26	18	65	17
Panicum spp.	Panicum	25	6	19	0	24	76	0
Pennisetum spp.	Millet	50	9	38	3	18	76	6
Phaseolus spp.	Beans	85	13	63	9	15	74	11
Pisum sativum	Pea	53	5	45	3	9	85	6
Secale cereale	Rye	32	3	28	1	9	88	3
Setaria spp.	Millet	35	9	23	3	26	66	8
Sorghum spp.	Sorghum	137	21	91	25	15	67	18
Triticum spp.	Wheat	121	11	85	25	9	70	21
Vicia faba	Broadbean	39	10	28	1	26	72	2
Vigna spp.	Cowpea	116	22	77	17	19	66	15
Zea mays	Maize	130	13	81	36	10	62	28
Total		1,641	224	1,145	272			

[a] Source: P. Waterworth and R. P. Kahn, Protection and Plant Quarantine, Animal and Plant Health Inspection Service, United States Department of Agriculture, unpublished data; based on a survey of the literature as of 1984. [b] Seedborne pathogens in Group A = pathogens of quarantine significance, i.e., not known in the United States; or, if present, not widely distributed; or for which there are insufficient data to make a determination; B = present in the United States (exotic strains of domestic pathogens may exist, and some of these strains might be considered as Group A pests); C = storage or "quality-type organisms."

are not known to occur in the United States, Group B includes pathogens that are known to be present there, and Group C consists of pathogens that are considered as storage organisms.

Pest risk analysis

To assess the risk of pests and pathogens moving along man-made pathways such as the importation of seed, quarantine officers often use a pest risk analysis. Pest risk analysis is essentially a thought process whereby the entry status of seed is determined based on perceived or known hazards and risks as defined earlier in this paper. Before entering into a pest risk analysis, one first determines if there is a hazard; if so, one then estimates the risk. In general, both hazard and risk determinations are based on the life cycle of the pest as it relates to the three factors discussed in the section on pathways.

Some of the biological components and variables used in such an analysis include the life cycle of the pest or pathogen, its host range, its geographic distribution, the ecological range of the pathogen compared with the ecological range of the host, hitchhiking ability, ease of colonization, ease of establishment, potential of the pest to cause damage, and effectiveness of inspection and treatment as safeguards.

The rules and regulations governing the entry of seed should be based on a matching of risk with decisions about entry (Kahn 1979, 1983b). If the risk is known to be low, the entry status should be liberal; if it is known to be high, the entry status should be conservative. When the pest risk is unknown, quarantine officers tend to be conservative. The most liberal attitude is that specified seed may enter freely without restriction. The most conservative attitude is that specified seed is prohibited without exception. However, in high-risk situations, if effective safeguards can be brought into play, the entry status can be liberalized — provided the benefits justify taking the risk.

The policy of an importing country might be to prohibit all plants of high-risk genera and by doing so take no risk (except from smuggling), but at the cost of receiving no benefits from crop improvement — a very conservative position. A very liberal position might be to allow importation, subject to inspection upon entry, of all high-risk genera. By doing so, the country might gain maximum benefits from germplasm importation, but at maximum risk. A hazardous pest might be introduced, become established, and cancel previous and future gains obtained by crop improvement. Cost/benefit and risk benefit factors come into play in developing attitudes. Safeguards come into play in lowering risk to support a more liberal entry status.

Plant quarantine officials and plant breeders may arrive at different conclusions when given the same body of information for assessing pest risk and for setting safeguards, standards, and criteria to grant exemptions to the prohibition. Both breeders and quarantine officers are aware that the centers of origin and diversity for plants are often the centers of origin and diversity for the pests and pathogens that attack these plants. Breeders tend to be liberal, and quarantine officers tend to be conservative about entry status. They share the same goals for

improving agriculture, but their methods differ. Breeders and germplasm resource scientists are concerned with the collection, evaluation, conservation, and distribution of genes found in exotic germplasm, while quarantine officers are concerned with preventing the inadvertent collection, conservation, and distribution of hazardous pests.

SAFEGUARDS

Safeguards are put into place along pathways to block the movement of pests and pathogens (Kahn 1979, 1982b, 1983a). Such quarantine actions are more effective when man rather than nature is the prime mover of such organisms. The life cycle of the pest or pathogen is a key factor in determining, first, whether the pest or pathogen will move either actively or passively along a pathway, and second, whether safeguards can be used. The greater the number of independent safeguards, the lower the chance that the importation of seed will result in the establishment of a pest or pathogen of quarantine significance (Kahn 1979, 1982b, 1983a).

The principal features of a safeguarding program are the options of the importing country either to deny a permit for high-risk material requested for commercial purposes, or to issue a permit for plant material imported for scientific purposes. For scientific purposes, a special permit that usually specifies conditions or safeguards is issued by the importing country.

For the international exchange of seed as germplasm, safeguards may be used at origin, upon entry, and after entry to reduce to an acceptable level the chances that seed will serve as an effective pathway for the establishment of pests or pathogens of quarantine importance. Among the safeguards that quarantine officers may use are the following:

- a phytosanitary certificate that attests to the inspection, origin, and identification of the seed;
- a permit requirement for added declarations on the phytosanitary certificate that the mother plants were inspected during the growing season;
- a requirement for treatment at origin;
- the acceptance of a special certification or safeguarding program at origin such as may be practiced at an IARC;
- inspection, and treatment if necessary, upon arrival at port of entry; and
- isolation, special testing, or additional quarantine after entry (Kahn 1977, 1983a).

The author has prevously reviewed the concept of safeguarding for articles in general (Kahn 1979) and for germplasm in particular (Kahn 1977, 1982b, 1983b, 1983c, 1986).

At origin, phytosanitary actions may be taken by the exporter or the quarantine service of the exporting country. For example, the Seed Health Unit of the International Rice Research Institute (IRRI), in cooperation with the Plant Quarantine Service of the Philippines, has set high phytosanitary standards and has initiated several safeguards that have maintained a significantly high level of seed health over time.

Prohibition and the importance of seed health

Prohibition of the host is the most drastic action that can be taken by the quarantine service of the importing country. A regulation can specifically prohibit the host; but, in actual practice, several other regulatory actions can be taken that effectively result in prohibition — even though the item may not be specifically prohibited. Such actions can affect the entry status of rice. However, seed of superior health usually qualifies for exemption from prohibition.

The author reviewed the quarantine regulations of 125 countries (Kahn 1982a) and found 11 methods by which seed and other plant material are denied entry, as follows:

- *Plant genera or species are prohibited by regulation if they are known to be*
  1. hosts of pests or pathogens of quarantine significance to the importing country;
  2. alternate hosts of rust fungi of quarantine significance;
  3. parasitic plants or weeds of quarantine significance; or
  4. a variety that the government believes is genetically inferior to local varieties;
- *or if they are otherwise enterable but arrive at a port of entry and are found to be*
  5. contaminated, infected, or infested with pests or pathogens of quarantine significance against which there is no known practical and effective eradicant treatment that can be administered safely at the port of entry;
  6. mixed with or contaminated by prohibited species; or
  7. contaminated with prohibited articles such as straw, soil, or bark;
- *or if they are otherwise enterable, but at the port of entry the shipment arrives*
  8. without a permit issued by the importing country or a phytosanitary certificate issued by the exporting country or both;
  9. without the required added declarations on the phytosanitary certificate in accordance with the conditions stated on the permit; or
  10. with a phytosanitary certificate that has been erased or altered;
- *or*
  11. it is determined that the seeds are not enterable due to pest risk factors or extenuating circumstances.

The plant health of seed that arrives at a port of entry or inspection station of an importing country can be affected by these 11 restrictions. In the case of rice from IRRI, items 2, 3, 4, and 11 are not applicable, and items 5-10 are matters of seed health under the direct control of the Seed Health Unit of IRRI and the Plant Quarantine Service of the Philippines. Item 1, an outright prohibition against rice, could affect IRRI programs if the importing country did not exempt germplasm from the prohibition. The author is not aware of any country that prohibits rice germplasm for biological reasons when the origin is the best available source. However, the countries that prohibit and then exempt germplasm either accept the best-available-source concept (such as IRRI) or require additional safeguards after entry.

Prohibition of the host as a safeguard

The author also reviewed the quarantine regulations of 125 countries to determine 1) which crops were most frequently named as prohibited (corresponds to item 1 above), 2) which pests and pathogens were most frequently named (corresponds to item 5 above), and 3) the extent to which prohibition of the host was utilized as a regulatory control measure. The review showed that 246 crops or genera were prohibited a total of 1,802 times by the 125 countries. The number of genera prohibited by a country ranged from 0 to 132, the average being 15 (Kahn 1982a).

Rice was among the most frequently prohibited crops (Table 5). The extent to which rice was prohibited and the geographic areas where such prohibition was practiced are shown in Table 6 in comparison with the five most frequently prohibited crops. In Table 7, some characteristics of the regulations for rice are compared with those of three other seed-propagated and three clonally propagated crops. Of the countries that prohibited rice, 79% prohibited seed.

Table 5. Plant genera or crops most frequently prohibited in the regulations of 125 countries (Kahn 1982a).

Fruit crops	Vegetable crops	Forest crops	Other crops
Citrus	*Ipomoea* (sweet potato)	*Acer* (maple)	*Camellia sinensis* (tea)
Cocos (coconut)	*Solanum* (Irish potato)	*Castanea* (chestnut)	*Coffea* (coffee)
Fragaria (strawberry)		*Conifers*	*Elaeis* (African oil palm)
Malus, Pyrus (pome fruits)		*Crataegus* (hawthorn)	*Gossypium* (cotton)
Musa (banana)		*Juglans* (walnut)	*Helianthus* (sunflower)
Prunus (stone fruits)		*Populus* (popular)	*Hevea* (rubber)
Ribes (gooseberry, currant)		*Quercus* (oak)	*Nicotiana* (tobacco)
Rubus (raspberry, etc.)		*Salix* (willow)	*Oryza* (rice)
Vitis (grapevine)		*Sorbus* (ash)	*Rosa* (rose)
		Ulmus (elm)	*Saccharum* (sugarcane)
			Theobroma (cacao)

Table 6. The extent to which 125 countries prohibit rice, compared with the 5 most frequently prohibited crops.[a]

Crop	Countries in which crop will grow (no.)	Countries that prohibit the crop (%)	Countries (%) in 6 geographic areas prohibiting					
			North America	Europe	Southwest Pacific	South America	Africa	Asia
Rice	107	33	9	10	50	46	34	38
Coffee	79	62	56	0	66	80	74	33
Elm	50	64	40	90	33	20	15	20
Citrus	103	60	62	67	60	54	66	52
Poplar	59	54	60	59	23	20	42	0
Oak	67	54	60	52	33	0	100	80

[a] Based on a survey of the quarantine regulations of 125 countries, which delimited the most frequently prohibited crops (Table 5) (Kahn, 1982a); genera were prohibited to the general and commercial public but, when imported under permit for scientific purposes, were often exempt.

Table 7. Some particulars of the quarantine regulations of 125 countries for rice as compared with 3 other seed-propagated crops and 3 clonally propagated crops.[a]

Crop	Countries in which crop is prohibited (no.)	Countries that name pests or pathogens (%)	Countries (%) prohibiting		
			Plants only [b]	Plants and seeds [b]	Seeds only
		Seed-propagated crops			
Rice	33	42	21	61	18
Sunflower	15	40	20	80	0
Cotton	52	23	25	61	14
Coffee	49	31	24	57	18
		Clonally propagated crops			
Citrus	62	45	55	45	0
Sweet potato	23	35	61	39	0
Sugarcane	40	10	63	31	0

[a] Based on a survey of the quarantine regulations of 125 countries, which delimited the most frequently prohibited crops (Kahn, 1982a). [b] Plant parts included.

The review also showed that 1,588 different species of pests and pathogens were named a total of 5,303 times. The number of species named and the total number cited, respectively, were as follows: insects (plus mites), 614 and 2,475; nematodes, 46 and 225; fungi, 537 and 1,444; and bacteria, 96 and 514. For viruses and virus-like organisms, 295 names were cited 645 times. The number of pest species named ranged from 0 to 275, the average being 35. The 10 most frequently cited fungi, bacteria, nematodes. insects. and viruses were named (Kahn 1982a). Of the 50 organisms in the 5 top-10 listings, only 2 were pests of rice: the rice stem nematode *Ditylenchus angustus* and the rice white tip nematode *Aphelenchoides besseyi.*

Biological justification for exclusion or prohibition as a safeguard

Because prohibition is the most drastic action that can be taken, there should be a sound biological justification for exercising this regulatory action in view of potential economic, political, and biological impacts. The policy, guidelines, or regulations of the various countries govern how they view taking the most drastic action of prohibition. It is beyond the scope of this presentation to recommend policies or review existing policies. In the author's judgment, the following represents a biologically sound justification for prohibiting certain plants:

A genus or species of plants may be prohibited if it is known to be infected or infested with a pest or pathogen, or is known to be a host of such a pest or pathogen in other countries, provided that

- the pest or pathogen does not occur in the importing country, *or* if it does occur, it is not widely distributed in the ecological range of its hosts in the importing country, *or* it is under a domestic suppression, containment, or eradication program, *or* there are exotic strains of quarantine importance that do not occur in the importing country;
- the pest or pathogen causes economic damage, *or* has the potential to cause such damage, in economic or important crops; *and*

- the plant cannot be inspected for an obscure pest or pathogen at a port of entry by a plant quarantine officer using equipment and procedures found routinely in a plant inspection station, *or* it can be inspected but there is no practical, safe, and effective eradicant treatment that can be administered should a pest or pathogen meeting these criteria be encountered.

Although many countries use these criteria or similar ones as a basis for prohibition, others may be either more or less conservative.

Exclusion procedures, also referred to as prohibition, regulate the importation of hazardous articles moved by man to reduce the risk of the entry of pests and pathogens of quarantine significance. These procedures are regulatory actions to reduce the chances of inadvertently spreading pests and pathogens within or between countries.

QUARANTINE SIGNIFICANCE OF SEEDBORNE ORGANISMS

The quarantine significance of seedborne organisms can be considered from a double-standard point of view: one standard for commercial seed and another for seed of germplasm.

When quarantine officers of importing countries determine the entry status of commercial seed, the answers to the following questions may be considered:

- Do pathogen species, and in some cases, certain strains in the exporting country occur in the importing country? If such pathogens do not occur in the importing country, what is the known or perceived hazard?
- What is the risk that the organism could enter and become established as the result of the importation and planting of the seed?
- Will inspection of a sample, and in some cases testing of a sample of the seed, either at origin or upon entry, plus seed treatment, be adequate safeguards to lower the risk to an acceptable level?
- If inspection, testing, and treatment are inadequate, should the seed be placed in a high-risk category, and, therefore, should the host be prohibited because inspection, testing, and treatment are not adequate safeguards?

When quarantine officers consider the entry status of seed of germplasm, these four questions may also be asked. However, the double standard often applies to the last question. If the answer to the fourth question is “yes” for commercial seed, then the importing country is likely to prohibit it. However, for seed imported for scientific purposes, even if the answer to the last question is “yes,” most countries will accept it if safeguards are adequate at origin, during transit, and after entry. If safeguards are adequate, the risk may be lowered (Kahn 1983b, 1983c) so that the entry status may be changed from conservative to liberal.

The justification for lowering the risk is a favorable risk/benefit ratio for germplasm that is not present for commercial importation.

The bottom line is that exporters of plant germplasm who initiate and maintain a safeguarding program and attain a reputation for high levels of phytosanitation will find that quarantine officers are prepared to lower the restrictions placed on germplasm that is known or perceived to be high-risk.

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The rice seed exchange and evaluation programs of IRRI

T. T. CHANG, D. V. SESHU, and G. S. KHUSH

Seed is the base that supports much of IRRI's research activities on crop improvement, cultural refinement, and plant protection. Seed is also the vehicle through which improved genotypes are disseminated to more than 100 rice-growing countries of the world. Assembling the enormous genetic resources of rice, making seed freely available to all rice research workers either in the original or improved form, operating a collaborative network of evaluation and use, and training young researchers to collect, evaluate, and use germplasm are major thrusts of IRRI's research portfolio. The seed exchange and evaluation programs of three major research and service units of IRRI are enumerated to illustrate the scope and impact of their seed-related activities. IRRI researchers also exert efforts to ensure the purity, health, and viability of seed supplied to rice workers.

The seed is the carrier of the genetic potential of most crop plants. The perpetuation and dissemination of rice varieties depend entirely on seed. Therefore, it is not surprising that the founders of the International Rice Research Institute (IRRI) included physical facilities for refrigerated seed storage in the Institute's first building, even before scientific activities became operative. The first field planting in the 1961 wet season (WS) was the initial seed multiplication of 120 varieties that had reached IRRI earlier in the year. The 1962 dry season planting consisted of 256 foreign introductions and Philippine varieties, from which promising entries were chosen for crossing in 1962 WS. IR5 and IR8 were bred from this group of parents.

Seed acquisition, multiplication, evaluation, distribution, and local use grew steadily in subsequent years. The distribution of seed to rice researchers in various countries began in 1962 under the rice germplasm project (now known as the International Rice Germplasm Center [IRGC]). Breeding material was distributed in 1965 under the varietal improvement program (later renamed the Plant Breeding Department), and sets of nurseries in 1975 by the IRRI-coordinated International Rice Testing Program (IRTP). Other research departments such as Plant Pathology,

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Entomology, and Plant Physiology also grew and distributed small numbers of seed stocks for use in special tests. Meanwhile, a continually increasing number of regional, national, and state (provincial) centers sent their seeds to IRRI for preservation, evaluation, hybridization, and exchange.

As seed exchange continually grew in both volume and geographic coverage, the pivotal importance of seed health was recognized by IRRI administrators and scientists. A Seed Unit was set up in 1980 to inspect and select healthy seed for foreign use, ensure seed health and seed treatments that would meet the phytosanitary requirements of importing countries, and monitor and collate seed shipments by IRRI departments. In 1982, IRRI also participated in the International Consultation on Germplasm Exchange held at the Centro Internacional de Agricultura Tropical (CIAT) in Colombia. A Seed Health Unit (SHU) was organized in 1982 when the Philippine Bureau of Plant Industry (BPI) delegated to IRRI the responsibilities for seed inspection (both predispatch and postentry) and for issuance of official phytosanitary certificates to IRRI research units that initiate seed shipments. The operations of the SHU are under the administration of the Plant Pathology Department and are guided by an interdepartmental committee. The SHU reports its activities to the BPI monthly. During the past decade, the Danish Institute of Seed Pathology, Dr. Robert Kahn (formerly of the United States Department of Agriculture), Dr. C. J. Langerak of the Government Seed Testing Station of the Netherlands, and consultants of the International Board for Plant Genetic Resources provided technical assistance to IRRI on seed health matters.

This paper discusses the major activities in seed exchange and evaluation for a variety of purposes by IRRI's three major seed-related units: IRGC, the Plant Breeding Department, and IRTP.

INTERNATIONAL RICE GERMPLASM CENTER AND AFFILIATED EVALUATIONS

The enormous genetic diversity assembled by IRGC (formerly known as the germplasm bank [GB]) fuels a great variety of rice research activities at IRRI and elsewhere. The bulk of the seed produced by IRGC has been used by researchers for specific research studies or for trait-by-trait evaluations that eventually lead to varietal improvement, both at IRRI and in national programs. The operations of IRGC and the evaluation efforts under IRRI's Genetic Evaluation and Utilization (GEU) Program are discussed to indicate the scope and impact of rice germplasm resources.

Conservation, distribution, and assistance to national centers

IRGC carries out a complicated and comprehensive process to ensure the availability of rice germplasm to users: collection and acquisition, multiplication and rejuvenation, characterization and documentation, preservation (at two sites), and distribution. All these activities revolve around rice seed. Fortunately, rice seed belongs to the orthodox type (as contrasted with the recalcitrant type) in storage behavior, i.e., its viability can be effectively preserved by storing dry seed at low temperature.

The size of the rice collection has grown steadily from 256 samples in 1961 to about 82,000 in 1986. The current collection is divided equally between donations by national centers from pre-existing collections and acquisitions from extensive international field collection activities in the past 15 yr. The holdings in 1986 consisted of 76,250 accessions of *Oryza sativa* cultivars, 2,983 accessions of *O. glaberrima* cultivars, 2,268 populations of wild species, and 700 entries of mutants and testers.

In recent years, the annual plantings have amounted to about 30 ha (both inside and outside IRRI), which are grown for single- or dual-purpose work: 1) initial seed increase (if the incoming seed quantity is small), 2) characterization and regular seed increase (usually consuming two seasons), 3) separate increases of photoperiod-sensitive or difficult-to-grow germplasm, 4) rejuvenation of old or insufficient seed stocks for medium- and long-term storage, and 5) extra increase of material to meet unexpected demands or specialized requests of researchers, especially those in biotechnology. In an average year, we plant about 28,000 plots of varying sizes for seed increase.

Because the IRGC program focuses on producing from a restricted space the maximum amounts of seed that will have high quality (uniformity, health, and viability) and genetic integrity (trueness to type or representative populational structure for heterogeneous material), we pay attention to the following aspects:

- Maintenance of high seed health standards at various stages (reception, planting, and storage). The SHU staff assists in field and laboratory inspection for disease incidence.
- Precautions to minimize mechanical mixtures, wrong labeling, and confusing or duplicative designation. An accession is the basic unit, each carrying an assigned accession number. A widely grown commercial variety of some vintage may appear under multiple accession numbers because it can be differentiated into morphological variants, ecostrains, and strains no longer breeding true to the name. Wild rices are known to be hybrid swarms in nature (Chang 1976).

  A seed file consisting of a small number of original seeds is maintained for checking. During rejuvenation, an accession is reidentified by comparing its plant characteristics with the earlier characterization data. Repeated rejuvenation is minimized by storing seeds under dry and cool conditions. Rejuvenated seeds are checked against specimens in the seed file before distribution or planting.
- Planning of seeding dates and planting sites that provide favorable growing conditions and lead to high yields and good seed quality. This requires experience and expertise in targeting maximum returns, but the harvests are subject to the vagaries of weather, pest incidence, and the local security situation. The ricefields at and around IRRI generally have acombination of the following production constraints: poor water quality; Zn deficiency in the soil; high pest incidence, especially on the IRRI farm; bird damage; and flooding following storms, especially in rented fields. Most accessions are not high-yielding seed producers.

- Postharvest operations to maintain seed viability and maximize longevity. We carefully control threshing speed, initial seed drying (to 12% moisture content), fumigation, seed inspection and selection, final seed drying (to 6% moisture content), packaging (in aluminum foil envelopes or airtight glass jars containing active silica gel), canning (under partial vacuum), and storage conditions in short-term (20 °C, 50% relative humidity [RH]), medium-term (2 °C, 40% RH), and long-term (-10 °C, 37% RH) storerooms. Periodic viability monitoring of stored seed and studies on seed storage techniques and varietal patterns in seed longevity are also carried out (Chang 1986).
- Security. The security of the conserved seed stocks is provided by a structurally strong building; safety devices against earthquake, fire, and electrical failure; vigilant maintenance; backup equipment; storage of a duplicate set of seed at the National Seed Storage Laboratory, Fort Collins, USA; and computerized records and data retrieval systems.

The collaboration of national and international centers, the excellent facilities and well-trained staff at IRRI, and continuous improvements in facilities and management have enabled IRGC to efficiently carry out the dual mission of conservation and dissemination of rice germplasm. Since 1962, more than 600,000 seed samples of diverse origin, genetic composition, and quantity have been provided to numerous rice researchers, making IRGC the hub of rice evaluation and improvement activities throughout the world. (See Chang [1980] and International Rice Research Institute [1985] for historical accounts of IRGC; see Hargrove et al [1979] and Dalrymple [1986] for the global use of germplasm.) Both IRTP and IRRI's plant breeding program have drawn heavily on donor parents supplied by IRGC (International Rice Research Institute 1980, Khush 1984a). The returns from investments in rice germplasm have greatly exceeded the inputs (Chang 1984, 1985).

The extent of the seed distribution during the past 10 yr is shown in Table 1. Substantial portions of the accessions supplied were based on information retrieved

Table 1. Distribution of seed of *Oryza* cultigens and wild species by the International Rice Germplasm Center, 1977-86.

Year	*O. sativa* samples distributed				*O. glaberrima*, genetic testers, and wild rices distributed			
	Within IRRI		To national programs		Within IRRI		To national programs	
	Samples (no.)	Requests (no.)	Samples (no.)	Requests (no.)	Samples (no.)	Requests (no.)	Samples (no.)	Requests (no.)
1977	50,354	196	4,126	148	74	8	597	14
1978	31,941	182	7,316	142	942	17	343	22
1979	26,694	268	3,260	157	352	17	722	29
1980	29,743	337	3,659	156	733	23	483	51
1981	29,053	319	4,376	206	569	16	552	28
1982	33,975	279	11,075	154	378	26	438	20
1983	28,443	287	3,756	150	342	20	972	38
1984	28,170	277	6,619	146	83	17	448	29
1985	30,709	306	4,736	172	1,138	24	1,174	36
1986	39,135	327	9,897	187	2,253	13	595	28

from IRRI's two computerized files — GB-basic (morphoagronomic characteristics) and GEU-traits (biotic, nutritional, edaphic, and hydrologic evaluations); consultation with disciplinary scientists on specialized needs; and occasional consultation of publications for those traits not yet studied at IRRI or under the IRTP network. It is a time-consuming process.

In recent years, IRGC has returned samples of entire collections to requesting national rice programs in Kenya, Nepal, Pakistan, and Kampuchea (only partly accepted) and to two state rice experiment stations in India. An increasing number of rice researchers request seeds of indigenous cultivars that are no longer available in their home countries.

Despite the favorable setup, the massive operations of IRGC have encountered problems:

- no or meager information on the accession from the donor;
- mixture of several types in one incoming seed sample, especially those collected from farmers' fields by extension workers;
- many duplicate samples with similar or dissimilar names;
- poorly adapted or pest-susceptible cultivars, especially those from temperate areas;
- differential seed longevity among varieties;
- the enormous load of rejuvenating and reprocessing old seed stocks stored in medium-term storage jars for the new system of medium- and long-term storage in aluminum cans and duplicate storage in the U.S.;
- continuous inflow of new seed samples, averaging more than 3,000/ yr for the past 14 yr;
- unpredictable demands for seed; and
- meager feedback from users.

These areas present challenges for both national genebanks and IRGC to collaboratively devise remedial measures.

IRGC has also expanded its technical assistance to national genebanks on the upgrading of storage facilities and laboratory equipment and on the training of field collectors and genebank workers to provide greater security for regional, national, and state rice collections. IRGC also trains young rice workers in genebank management and seed production.

Evaluation by GEU teams of scientists

Systematic evaluation of the IRRI collection for sources of resistance to blast and stem borers began in 1963. The multidisciplinary evaluation efforts were streamlined and markedly expanded in 1973 under the GEU Program (Brady 1975). Eight interdisciplinary teams were set up to focus on agronomic and physiological characteristics, grain quality and nutritional value, disease resistance, insect resistance, drought tolerance, adverse soils tolerance, deepwater and flood tolerance, and adverse temperature tolerance. The rapid growth in evaluation experiments was reflected in the number of seed samples supplied to IRRI researchers by IRGC: from 8,275 in 1973 to a peak of 50,354 in 1977. When the computerized data storage and retrieval systems were established in 1976, the number of GEU traits totaled 36 (Gomez et a1 1979). The total now is 38, but many other small evaluation programs

have not been entered in the central database. Combined data from the GB-basic file and the GEU-traits file have been frequently used by IRGC to locate appropriate accessions for rice researchers who specify the desired traits. The computer printout is supplied along with the seeds as a free service.

Reports of outstanding sources of resistance to or tolerance for various biotic and ecological stresses may be found in IRRI annual reports, IRTP annual reports, and the following reviews:

- general — Chang et al (1982)
- diseases — Chang et al (1975), Ling (1972), Ou (1972, 1985)
- insect pests — Chang et al (1975), Heinrichs et al (1985), Pathak (1977)
- drought resistance — Chang et al (1974)
- cold tolerance — Vergara et al (1976)
- adverse soils — Ponnamperuma (1977)

Significant instances of using the rich gene-pool in the IRRI collection for crop improvement in various countries and at IRRI may be found in Chandler (1968), Chang (1980, 1985), Chang et al (1982), Dalrymple (1986), Hargrove et al (1979), Khush (1984a,b), Khush and Virmani (1985), and IRTP annual reports.

PLANT BREEDING DEPARTMENT

The Plant Breeding Department generates and disseminates improved germplasm, produces breeder seed, and trains GEU personnel.

Generation and dissemination of improved germplasm

Rice germplasm at various stages of development — including named varieties, fixed breeding lines, early-generation segregating populations, and F_1 seeds — is sent to scientists throughout the world. Many visiting scientists, scholars, and trainees request seeds of IRRI breeding lines to take home with them. Since 1964, IRRI has sent 313,895 seed packets (Table 2) of breeding material to 87 countries. Seed of IRRI breeding lines is also sent abroad through IRTP nurseries: 720,307 seed packets by the end of 1986.

These materials are evaluated under local conditions and utilized as parents in breeding programs. Some become named varieties. Often, introduced breeding materials are further selected and improved before they are released as varieties by national programs. By the end of 1986, 155 IRRI breeding lines had been named as varieties by national programs in Asia, Africa, and Latin America.

Sometimes, early-generation breeding material is sent abroad for testing and selection at hot-spot locations. This program has expanded in recent years with the establishment of shuttle breeding projects to collaboratively develop improved germplasm for adverse environments. This involves making crosses and growing F_1s at IRRI. The F_2 populations are grown in the collaborating country under stress conditions. Seed of selected plants is brought to IRRI for growing the F_3, which is concurrently evaluated for disease and insect resistance and for grain quality. Seed of selected plants is again sent to the collaborating country for growing the F_4 under actual stress conditions. The F_5 is grown at IRRI. This shuttling between two

Table 2. Number of seed samples of IRRI breeding material sent to other countries.

Year	Seed samples sent (no.)	
	Directly [a]	Though IRTP[b]
1964	2,296	–
1965	3,033	–
1966	6,000	–
1967	12,400	–
1968	12,000	–
1969	15,998	–
1970	na	–
1971	na	–
1972	6,865	–
1973	7,618	–
1974	11,492	–
1975	4,729	50,000
1976	10,365	42,867
1977	9,220	36,583
1978	14,948	69,087
1979	16,817	75,677
1980	8,240	68,769
1981	6,771	68,157
1982	8,124	53,315
1983	22,426	65,778
1984	45,705	65,778
1985	48,050	81,623
1986	40,798	42,673

[a]na = data not available. [b]Began in 1975.

locations and the growing of alternate generations under favorable and unfavorable environments allow evaluation and selection for wide adaptation and incorporation of resistance to diseases and insects. We have shuttle breeding projects for developing improved breeding material for cold tolerance (with China and Korea), for rainfed lowland conditions (with Thailand), for deepwater environments (with Bangladesh, India, and Thailand), and for tidal wetlands (with India, Indonesia, and Sri Lanka).

Breeder seed production

IRRI maintains breeder seed of all named IR varieties. We also produce breeder seed of about half a dozen elite breeding lines. Thus, when any of the breeding lines is recommended as a variety by the Philippine Seed Board, breeder seed is already available. We supply breeder seed of IR varieties to the BPI regularly. Requests for breeder seed from scientists in other national programs are similarly honored

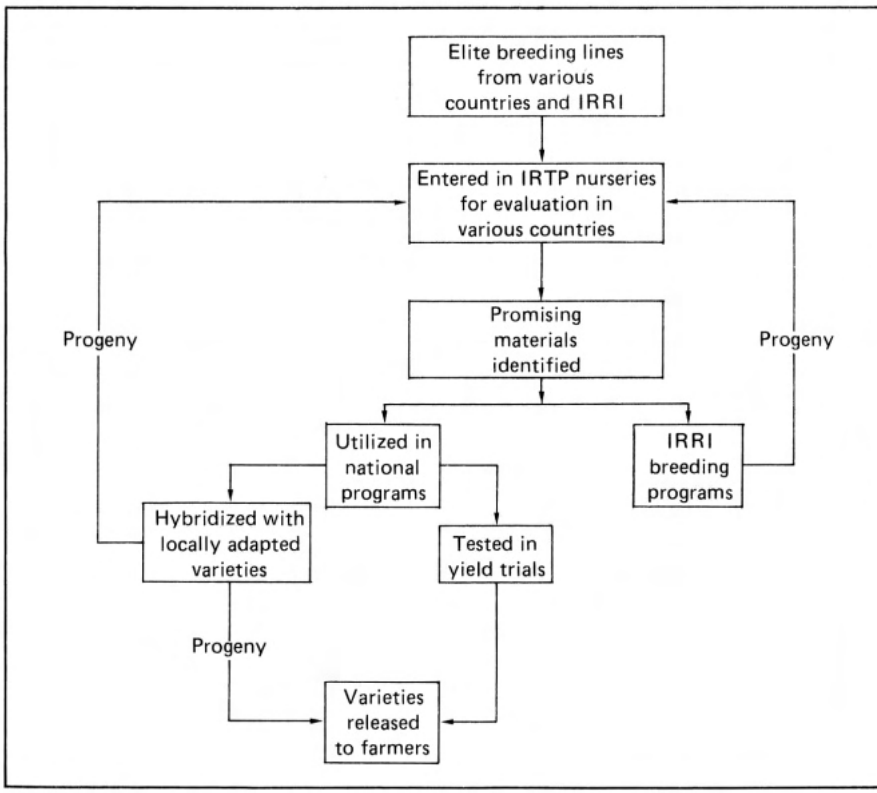
Generally, we make about 500 plant selections, which are checked for grain characteristics. After discarding the offtypes, 330 plant selections are planted in a 0.25-ha field with a 4-row, 5-m-long plot for each plant selection. These head rows are observed at several growth stages, and offtypes, early plots, and late plots are discarded. Seed from uniform plots is then bulked for use as breeder seed.

GEU training program

For the last 12 yr, we have conducted a training program for young rice breeders and affiliated researchers from national rice improvement programs. Twenty to thirty rice scientists participate in each course. Trainees are given formal lectures on crop improvement techniques. They also participate in all the field operations and laboratory work related to GEU activities and make crosses for their own programs. They are given lectures on seed health inspection and quarantine procedures and are exposed to practical problems.

INTERNATIONAL RICE TESTING PROGRAM

IRTP was established in 1975 to provide a mechanism for the international exchange of elite rice germplasm and for its evaluation and utilization in various environments. Promising breeding lines developed at IRRI and donor parents identified by IRRI GEU scientists are also evaluated through IRTP. The program thus represents an intercountry cooperative effort toward the genetic improvement of rice targeted at the many environments in which the crop grows around the world (Fig. 1). With this access to a wide range of genetic material, purchase of time is an



1. International Rice Testing Program (IRTP) flow chart.

important dividend for network scientists in their efforts to develop improved varieties.

IRTP is organized and coordinated by IRRI with funding from the United Nations Development Programme. More than 800 rice scientists from 75 countries in Asia, Latin America, Africa, North America, Europe, and Oceania participate in the network (Seshu 1985). Scientists representing some of the participating countries serve on an advisory committee to assist in program planning and implementation. About 75% of the nurseries are tested in Asia, 10% each in Latin America and Africa, and the rest in North America, Europe, and Oceania. The nurseries are distributed and tested in Latin America in collaboration with CIAT, and in Africa in collaboration with the International Institute of Tropical Agriculture (IITA) and the West Africa Rice Development Association.

IRTP nurseries fall into two broad categories:

- nurseries for identifying superior varieties for different rice cultural types, and
- nurseries for identifying genetic donors for individual biological, physical, and chemical stresses.

About 60% of the entries are contributed by national programs; the remaining originate from IRRI's GEU program and IRGC.

In 1986, 1,464 sets comprising 29 types of IRTP nurseries (Table 3) were composed and distributed to network scientists. Nearly 100,000 individual seed packets are involved in each year's dispatch. Seeds for the regional nurseries in Africa and Latin America are multiplied and distributed by IITA and CIAT, respectively.

The testing results over the past 10 yr have helped identify the following:

- varieties with high yield potential for various cultural types (Seshu 1985).
- sources of resistance to major diseases and insects and tolerance for adverse soils and adverse temperatures (Seshu 1985), and
- genetic variation across locations in rice pathogens and insects expressed as races or biotypes (Heinrichs and Seshu 1981, Seshu and Kauffman 1980).

The multilocation data also provide valuable information on genotype × environment interactions (Seshu and Cady 1984).

By the end of 1986, a total of 114 IRTP entries originating from 15 national programs and from IRRI had been released as varieties in 46 countries around the world. Furthermore, several hundred entries had been utilized as donor parents for various useful traits in national breeding programs as well as in IRRI's GEU program.

Monitoring tours, advisory committee meetings, conferences, and subject matter workshops provide forums for network participants to interact with each other and the mechanism for program planning and international cooperation in the exchange of ideas and breeding material. Monitoring tours also serve as a training mechanism.

Results from worldwide IRTP trials are analyzed and published twice annually (as preliminary and final reports), and the reports are made available to all concerned rice scientists, research administrators, and libraries. Likewise, the

Table 3. IRTP nurseries, 1986.

Nurseries for target environments			
			Irrigated
Yield	–	IRYN-VE	International Rice Yield Nursery – Very Early
		IRYN-E	International Rice Yield Nursery – Early
		IRYN-M	International Rice Yield Nursery – Medium
Observational	–	IRON-VE	International Rice Observational Nursery – Very Early
		IRON-E	International Rice Observational Nursery – Early
		IRON-M	International Rice Observational Nursery – Medium
			Rainfed
Upland			
Yield	–	IURYN-E	International Upland Rice Yield Nursery – Early
		IURYN-M	International Upland Rice Yield Nursery – Medium
Observational	–	IURON-E	International Upland Rice Observational Nursery – Early
		IURON-M	International Upland Rice Observational Nursery – Medium
Lowland			
Yield	–	IRRSWYN-E	International Rainfed Rice Shallow Water Yield Nursery – Early
		IRRSWYN-M	International Rainfed Rice Shallow Water Yield Nursery – Medium
Observational	–	IRRSWON-E	International Rainfed Rice Shallow Water Observational Nursery – Early
		IRRSWON-M	International Rainfed Rice Shallow Water Observational Nursery – Medium
		IRDWON	International Rice Deep Water Observational Nursery
		IFRON	International Floating Rice Observational Nursery
		ITPRON	International Tide-Prone Rice Observational Nursery
Nurseries for specific stresses			
Temperature	–	IRCTN	International Rice Cold Tolerance Nursery
Soil	–	IRSATON	International Rice Salinity and Alkalinity Tolerance Observational Nursery
		Acid Upland	Acid Upland Soils Screening Set
		Acid Lowland	Acid Lowland Soils Screening Set
Diseases	–	IRBN Upland	International Rice Blast Nursery – Upland
		IRBN-Lowland	International Rice Blast Nursery – Lowland
		IRBBN	International Rice Bacterial Blight Nursery
		IRTN	International Rice Tungro Nursery
Insects	–	IRBPHN	International Rice Brown Planthopper Nursery
		IRWBPHN	International Rice Whitebacked Planthopper Nursery
		IRSBN	International Rice Stem Borer Nursery
Nematode	–	IRUSS	International Rice Ufra Screening Set

observations and recommendations of monitoring tours are published and distributed to all concerned.

IRTP has established itself as an effective and powerful medium for international cooperation. In the coming years, network activities will be further strengthened with a particular focus on less favorable environments, involving increased national participation and a higher magnitude of international seed exchange.

CONCLUDING REMARKS

It is apparent from this discussion that IRRI's initial investments, followed by continuous expansion in seed and seed-related activities, have paid off handsomely (see Herdt and Capule [1983] for the production impact of modern varieties). Our experience has also shown that handling rice seed is not a simple technology in the humid tropics. Improved production, exchange, and evaluation processes will call for continuing collaboration of national rice research centers and the international centers in further exploring and using the genetic potential contained in the seed of rice cultivars and their wild relatives.

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Rice seed exchange in the Philippines

E. P. SEVILLA and N. G. MAMICPIC

The importance of germplasm in Philippine rice seed improvement and the eventual diffusion of improved varieties into the countryside have been clearly demonstrated during the past 80 yr. The roles of the international genebank, the national genebank. and the seed quality control program are discussed. Seed quality control consists of seed testing, seed certification, and seed and plant quarantine. The Seed Health Unit of the International Rice Research Institute (IRRI), the national quarantine service, and a network of seed testing laboratories were established only in the last 6 yr. Current quarantine arrangements with IRRI for seed health are interim; quick procedures for instituting plant quarantine measures at seed exchange centers are needed. Quarantine activities in seed exchange should be shared between the host country and the international genebank such that international seed exchange is through the national quarantine system. Specific suggestions are given to establish such sharing of responsibility in seed quality control for quarantine purposes and for varietal purity.

Great strides have been made throughout the world during the last decade in the movement of germplasm for varietal improvement and of seed for multiplication. Some 600 institutions in more than 100 countries have released varieties of more than 100 crop species (International Board for Plant Genetic Resources 1986). Within the national, regional, and international network of genebanks and international agricultural research centers (IARCs), there is a general awareness that plant health — and consequently seed health — is imperative (Neergaard 1984). The risk of introducing plant pathogens and pests into new regions, thereby creating new problems, may have increased with the recent expansion in the number of genebanks in the tropics (Gerard 1984). In 1981, the Food and Agriculture Organization (FAO)/United Nations Environmental Programme (UNEP)/International Board for Plant Genetic Resources (IBPGR) technical conference on genetic resources

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emphasized the importance of precautions for plant health, while the International Consultation on a System for the Safe and Efficient Movement in Global Germplasm Exchange Network held at the Centro Internacional de Agricultura Tropical in June 1982 described the plant health situation at the IARCs. Regulations on plant quarantine in the host countries of the IARCs with special reference to the import and export of plant germplasm in these centers were disseminated. The ASEAN Plant Quarantine Centre and Training Institute (PLANTI) Meeting on Seedborne Diseases in the ASEAN and Seed Health Testing in Chiang Mai, Thailand, in October 1985 likewise identified procedures and proposed guidelines for the ASEAN countries to minimize the distribution of pests, thus providing good-quality seeds to their farming communities.

PHILIPPINE RICE SEED IMPROVEMENT

A responsive seed program is a basic and vital support to profitable and effective agricultural production. Although rice had been planted in the Philippines for centuries, rice seed improvement started not more than 80 yr ago.

Varietal improvement work

Sevilla (1982) divided varietal improvement work in the country into four periods:

- Prewar, 1902-41
- Wartime, 1941-44
- Rehabilitation and reconstruction, 1945-52
- Cooperative crop improvement, 1952 to present

The Bureau of Agriculture was established in 1902. During the subsequent 3½ decades of the American regime, varietal improvement work in rice involved introduction, acclimatization, selection, and breeding (Manas and Rozul 1952). The first new introductions of rice came from Japan (1902) and the U.S. (1905). More than 400 varieties were eventually introduced from 15 countries of Asia, Australia, North America, the Middle East, Africa, and Europe (Rorja et al 1952). In 1920, rice hybridization began, and in 1935 a plant breeding section was established within the Bureau of Plant Industry (BPI) to develop high-yielding varieties with improved quality and resistance to pests and diseases (Torres and Solpico 1952). However, because of poor storage conditions and destruction during wartime, the varieties and strains collected and isolated were lost.

During the war years, varietal improvement work was nil. However, in Rizal Province, Horai rice from Formosa replaced native rice.

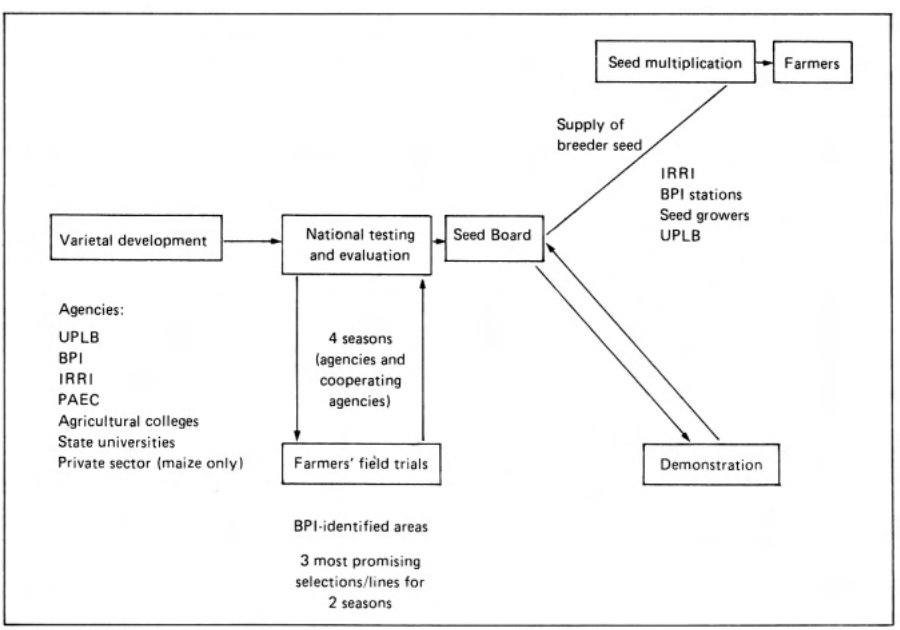
From 1945 to 1952, there was a slow resumption of breeding work. Purification of salvaged varieties was pursued, and crosses of upland varieties were made at the Central Experiment Station in Manila, followed by testing at the Santa Barbara Nursery, Pangasinan.

In 1952, an intensive rice varietal development program was initiated, resulting in the launching of the Coordinated Cooperative Rice and Corn Seed Improvement Program in 1953. This marked the transition from the limited and cloistered work of various government workers in different agencies to a multiagency cooperative

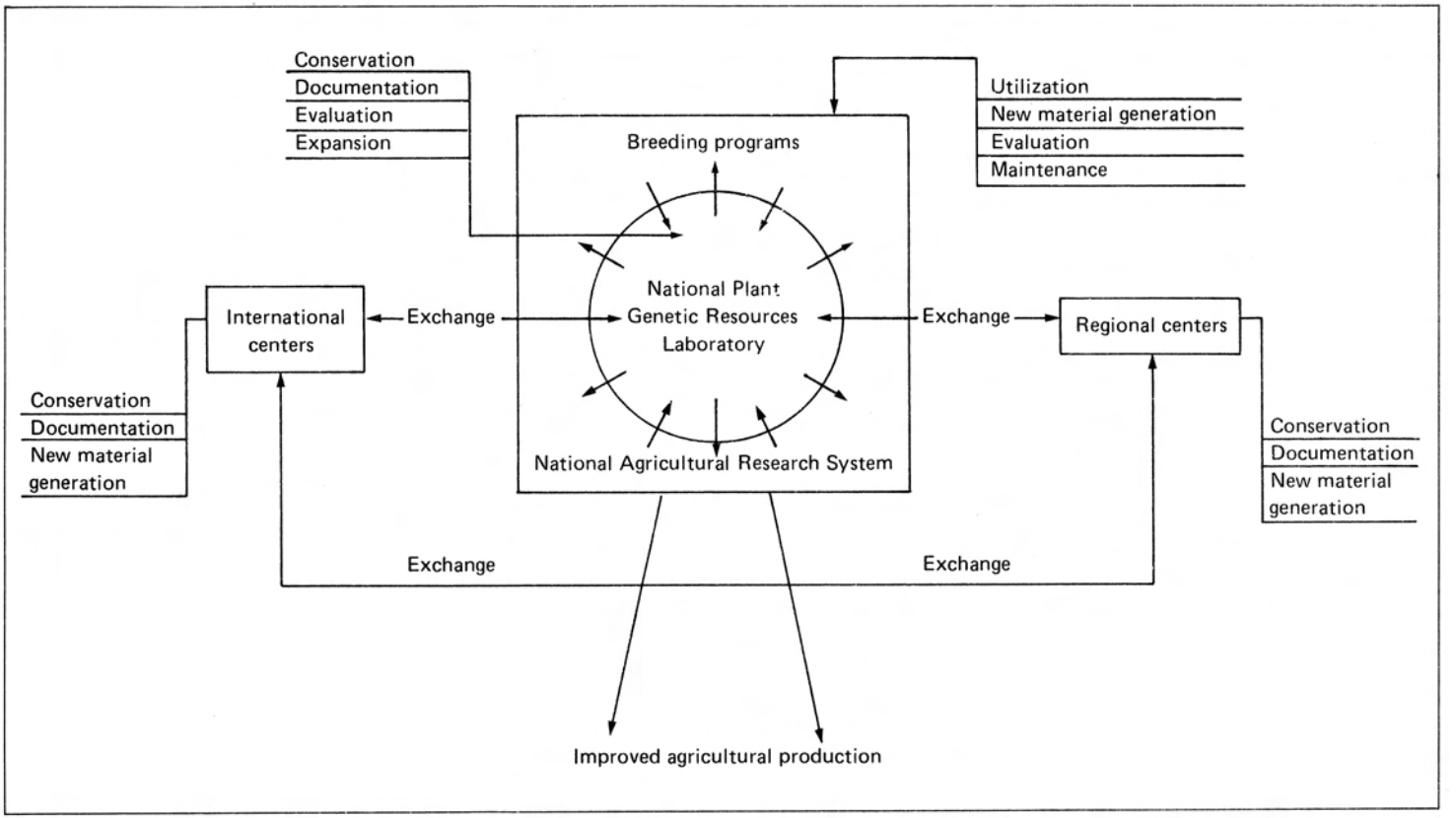
program. The objectives of the program were to breed, to test in the different regions, and to distribute rice and maize varieties to replace badly mixed and low-yielding ones. The original cooperating agencies — BPI, the University of the Philippines College of Agriculture at Los Baños (UPLB), and the Bureau of Agricultural Extension — expanded to include members of the Association of Colleges of Agriculture in the Philippines, the International Rice Research Institute (IRRI), and the Philippine Atomic Research Center (PARC). The program is currently known as the National Cooperative Testing Program, of which varietal improvement is a component. Since the start of the program, the magnitude of germplasm and seed exchange has greatly increased. Figure 1 reflects the varietal evaluation and release flow for rice and other seeds.

Germplasm program

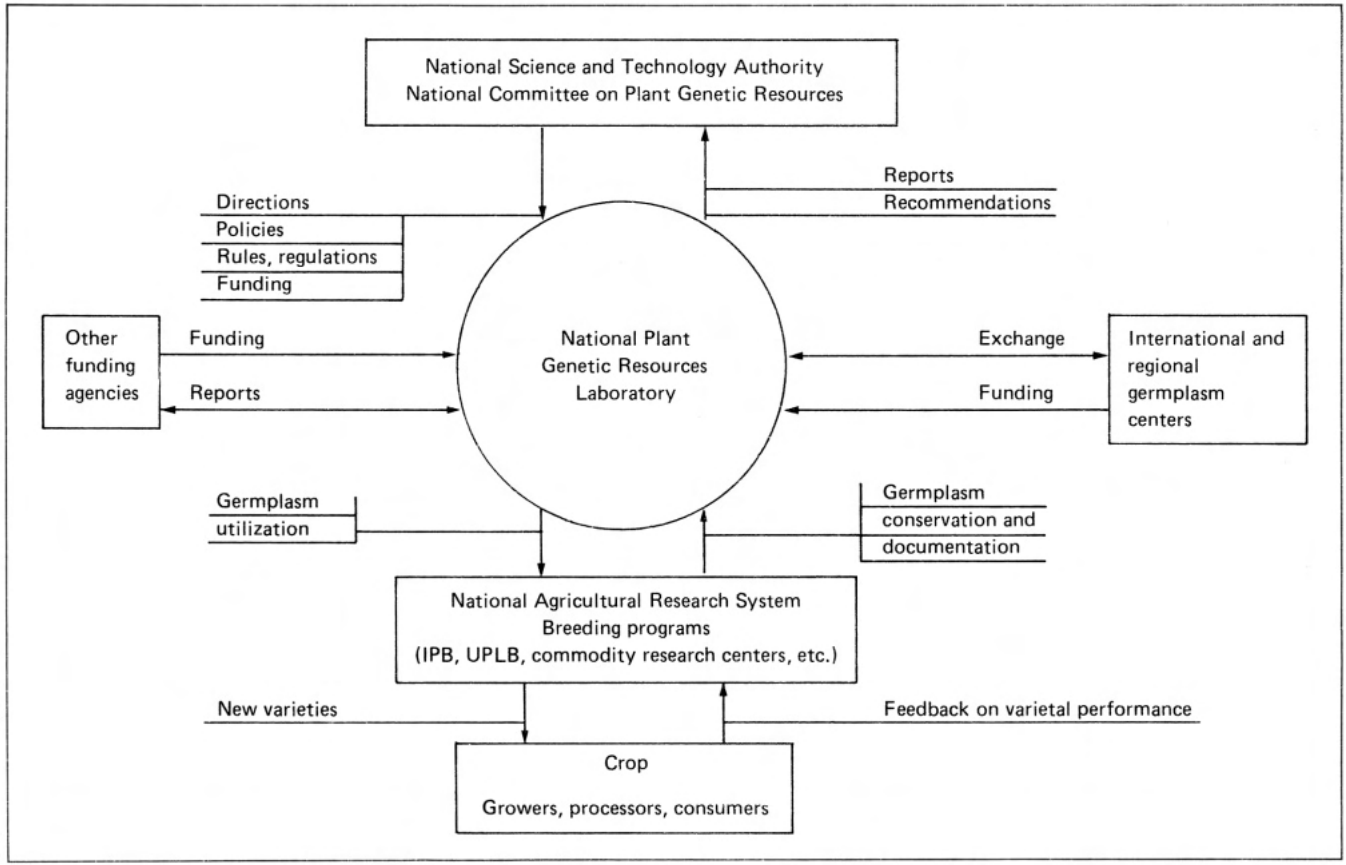
Germplasm collection, conservation, and exchange in relation to crop improvement were ad hoc before the 1970s (National Plant Genetic Resources Laboratory [n.d.]), and many valuable collections were lost. However, rice germplasm work became organized at the international level with the establishment of IRRI in the Philippines in 1960. In 1975, the Institute of Plant Breeding (IPB) was established at UPLB with a plant genetic resources program. A year later, the National Plant Genetic Resources Laboratory (NPGRL) was created at IPB with a national mandate to collect, conserve, utilize, and exchange plant genetic resources, thereby institutionalizing a full-fledged national germplasm program (Fig. 2, 3). However, rice is not included in the program because it is not within IPB's mandate.



1. Varietal evaluation flow and release scheme for rice. Philippines.



2. Conceptual model of national plant genetic resources utilization and conservation, Philippines.



3. System of operation and linkages, national plant genetic resources utilization and conservation, Philippines.

Table 1. National Plant Genetic Resources Laboratory seed exchange, 1986, Philippines.

Flow	Species (no.)	Accessions (no.)
	Collection	
Local	30	477
Foreign	16	599
Total		1076
	Distribution	
Local	30	3056
Foreign	6	312
Total		3368

NPGRL is responsible for providing researchers in the national agricultural research system coordinated by the Philippine Council for Agriculture and Resources Research and Development with highly viable seeds of low moisture content. The seeds are packed in sealed packets to preclude movement of pests into or out of the container during delivery. NPGRL is also responsible for the exchange of genetic material outside the country. NPGRL and BPI came to agreement on seed exchange (Institute of Plant Breeding 1978). NPGRL effects the quarantine of newly introduced genetic material at its facilities under the general supervision of BPI and subject to plant quarantine rules.

Table 1 shows the volume of seed exchange handled by NPGRL (1987) in 1986.

Seed production and distribution

Organization. The government and private sectors jointly participate in rice seed production. Initially, production and distribution were mostly· on government seed farms and experiment stations, but after a few years, farmer cooperators produced registered and certified seed. In some provinces, cooperators organized provincial seed growers' associations, which later federated into regional associations.

Production programming. Seed production became more organized after 1955, when the Philippine Seed Board was established with a Seed Production and Distribution Working Group composed of members from both government and the private sector (Sevilla 1982). Seed requirements for breeder, foundation, registered, and certified seed are based on targets of the national productivity programs of the National Food and Agriculture Council. The variety, quantity, seed class, and area required are determined annually. together with the institutions that will produce the seed for each wet and dry season.

Allocation of breeder and foundation seed. The Seed Production Section of the Crop Production Division of BPI allocates breeder seed from the breeding institutions to six selected stations for foundation seed production. IRRI and UPLB also produce foundation seed. The foundation seed is in turn allotted by BPI to seed growers' associations in consultation with the Regional Directors of the Ministry of Agriculture and Food based on target areas for the production of registered and certified seed in each region.

Table 2. Area planted to rice and to modern varieties, and potential area served by certified seed stocks, Philippines, 1970-85.

Year	Area planted to rice ('000 ha)	Area planted to modern varieties (%)	Area that can be served by certified seed stocks (%)
1970	3113	43.5	2.4
1975	3539	61.5	7.9
1980	3637	75.5	8.3
1985	3222	87.5	7.2

Diffusion of modern varieties and certified seed. From 1970 to 1985 the Philippine Seed Board released 28 varieties — 20 from IRRI, 4 from BPI, 3 from UPLB, and 1 from PARC.

The Filipino farming community has, by and large, adopted high-yielding rice varieties (Table 2). However, the area that can be served by the certified seed stocks produced by the program reached only 8.3% in 1980 and slightly decreased in 1985.

Seed quality assurance and control

Since 1954, seed quality control in the Philippines has been a state function as part of the cooperative seed improvement program. However, future development does not preclude private seed quality control organizations from servicing the seed industry.

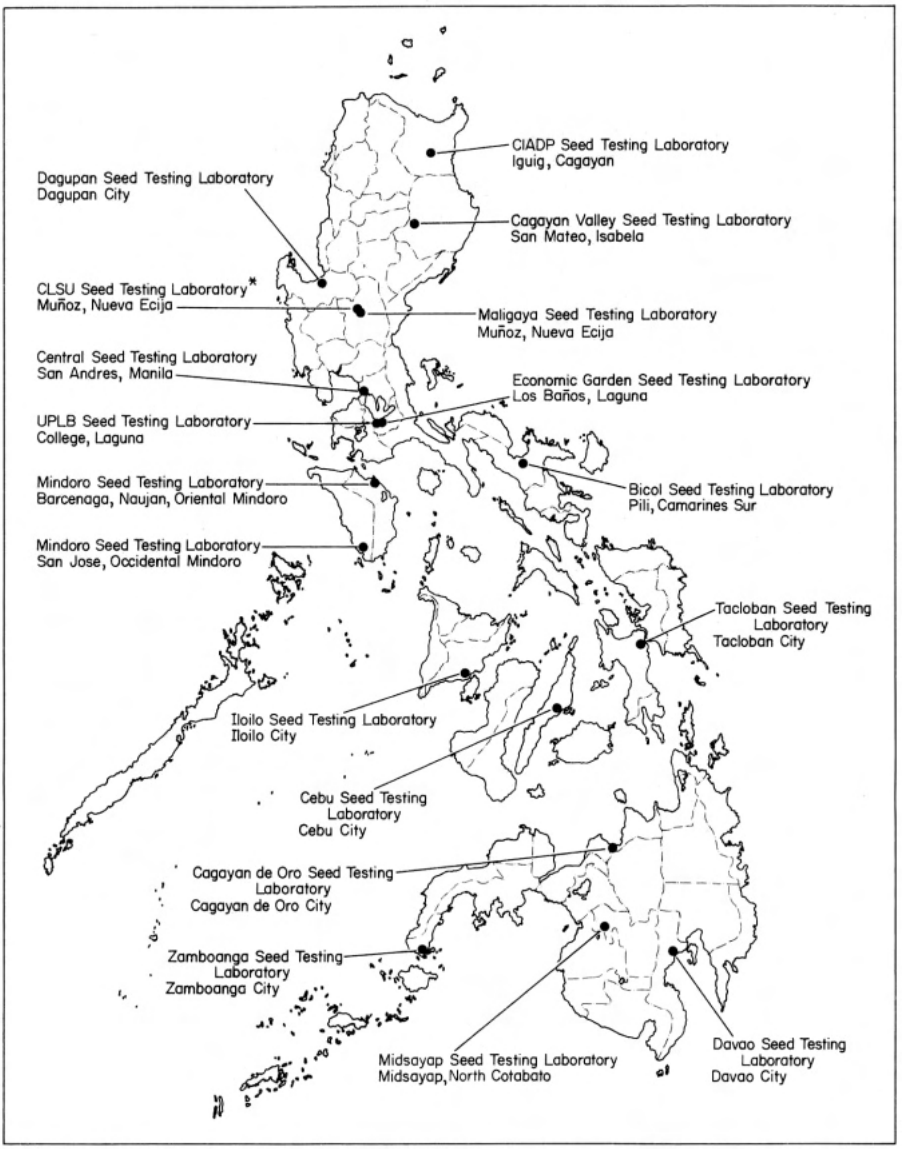
The seed quality control program started with the establishment of the Central Seed Testing Laboratory of BPI in 1954. In 1973 the laboratory became the Seed Certification Section of the Crop Production Division. In the 1980s the name Seed Quality Control Services was adopted to reflect the dual roles of seed testing and seed certification and in anticipation of a Seed Law. Figure 4 shows the regional, provincial, and research seed testing laboratories in the country. Currently, about 110 personnel are involved in seed testing in the 16 laboratories under the Department of Agriculture and Food and about 240 personnel are responsible for seed inspection in the 66 provinces.

Seed quality control measures include seed testing, seed certification, and seed and plant quarantine.

SEED TESTING FOR QUALITY CONTROL

A quality control program is pointless unless it involves seed testing. Conversely, a seed testing laboratory has little value unless it is a part of a certification and seed marketing enforcement program (Douglas 1980).

Seed testing in its broadest sense includes measuring, examining, evaluating, and checking seed for determining conformity with stated standards or requirements, or for information and advisory purposes. Seed tests provide information on pure seed, other crop seeds, weed seeds, inert matter (kind, quantity), normal and abnormal seedlings, fresh or hard seed, dead seeds, moisture content, seed health conditions, varietal purity, and other seed quality factors requested and determined



4. Seed testing laboratories in the Philippines. * = seed research laboratory.

on samples properly drawn by authorized samplers or submitted by persons wanting information on the samples.

The contribution of seed testing to the seed program from 1954 to 1985 is reflected in Table 3. Seed tests are conducted on more than 100 species of cereals, legumes, cover crops, fruit trees, flowers, vegetables, forest trees, root crops, oil crops, tobacco, and medicinal plants.

Table 3. Quality tests conducted in the Philippines, 1954-85.

Test	Tests conducted (no.)				
	Jan 1954 to Jun 1964	Jul 1964 to Jun 1975	Jul 1975 to Dec 1985	Total	Total (%)
Purity test	5,413	13,622	74,497	93,532	12.1
Germination test	34,089	40,802	246,198	321,089	41.4
Moisture test	8,344	32,973	200,842	242,159	31.2
Red rice and other varieties	5,362	15,191	69,391	89,944	11.6
Other tests	711	325	17,871	18,907	2.4
Seed health test[a]	0	0	9,960	9,960	1.3
	53,919	102,913	618,759	775,591	100.0

[a]Routine seed health testing started in 1979; only seedborne fungi determined.

Based on the comprehensive definition of seed health testing (International Seed Testing Association 1985), seed health tests currently undertaken by the program are mainly for fungi. With the recent acquisition of equipment for enzyme-linked immunosorbent assay, testing for seedborne viruses will follow, and as more trained personnel are available, tests for nematodes and bacteria will be included.

Procedures used in seed health testing by the laboratory follow the International Seed Testing Association (1985), Neergaard (1977), and de Tempe (1970). Seed pathological work in the laboratory started in 1968. The Philippines hosted the First International Seed Pathology Workshop in Los Baños, Laguna, in 1969. Seedborne fungi associated with rice as recorded by the Seed Quality Control Services from 1969 to the present are listed in Table 4. Seedborne fungi associated with other crops have also been reported by the Seed Testing Laboratory (de Guzman 1985).

SEED CERTIFICATION

The main purpose of seed certification is to maintain and make available to the public high-quality seed and propagating material of superior crop varieties to ensure varietal purity. Other attributes of seed quality such as presence of weed seeds, freedom from seedborne diseases, viability, mechanical purity, and grading are considered. Seed certification is therefore designed to maintain the genetic purity of crops and to maintain reasonable standards of seed quality.

Seed certification in the Philippines includes the following activities:

- *Field inspection.* Inspection assesses offtype plants, other varieties, weeds, other crop plants, and diseases in the field. The eligibility of seed crops for certification is also verified. At least two field inspections are conducted for seed crops — preliminary and final — to ensure good control. Table 5 shows the area inspected from 1975 to 1985.
- *Precontrol and postcontrol tests.* These field plot tests are conducted at the Maligaya Rice Research and Training Center to check the genetic purity of seed lots released for multiplication and those certified for commercial

Table 4. Fungi recorded as associated with rice seed in the Philippines.[a]

Alternaria longissima	*D. tetramera*
**A. padwickii*	*Drechslera* sp.
A. porri	*Epicoccum purpurascens*
A. tenuis	*Fusarium avenaceum*
Alternaria sp.	*F. concolor*
Arthrobotrys sp.	*F. culmorum*
Aspergillus sp.	*F. equiseti*
Botryodiplodia palmarum	**F. graminearum*
**Cephalosporium* sp.	*F. longipes*
**Cercospora oryzae*	*F. moniliforme*
Cercospora sp.	*F. nivale*
Chaetomium sp.	*F. oxysporum*
Cladosporium sp.	*F. poae*
Colletotrichum dematium	*F. semitectum*
C. gloeosporioides	*F. solani*
C. lindemuthianum	*Fusarium* sp.
Colletotrichum sp.	*Macrophoma* sp.
Corynespora sp.	*Melanospora* sp.
Curvularia cymbopogonis	*Myrothecium verrucaria*
C. eragrostidis	**Nakataea sigmoidea*
C. geniculata	**Nigrospora oryzae*
C. inaequalis	*Penicillium* sp.
C. intermedia	*Periconia* sp.
C. lunata	*Pestalotia* sp.
C. oryzae	*Phaeotrichoconis* sp.
C. pallescens	*Phoma sp.*
C. trifolii	*Phyllosticta* sp.
Curvularia sp.	**Pyricularia oryzae*
Drechslera halodes	*Rhizoctonia* sp.
D. hawaiiensis	*Rhynchosporium oryzae* (Gerlachia)
D. longirostrata	**Sarocladium oryzae*
D. maydis	*Stemphylium* sp.
D. oryzae	*Tilletia barclayana*
D. rostrata	*Ulocladium* sp.
D. sorokiniana	*Ustilagitloidea virens*

[a] * = pathogen of economic importance.

Table 5. Area (ha) of fields inspected, Philippines, 1975-85.

Year	Preliminary inspection	Final inspection
1975	1857	2279
1980	6103	5365
1985	4020	2851

planting. Precontrol and postcontrol tests were conducted from 1983 to 1986 on breeder seed from BPI, IRRI, and UPLB, including promising lines for seed increase.

In the precontrol tests, most of the lots showed 0.04 to 1.72% admixtures, indicating that more control is needed in the production of breeder seed.

Table 6. Seed stocks produced (t), Philippines, 1970-85.

Class	1970	1975	1980	1985
Foundation seed	28.7	319.0	13.5	90.4
Registered seed	203.7	996.3	2,148.3	1,373.0
Certified seed	243.2	4,523.9	12,776.3	7,674.2
Good seed	2,780.7	6,449.2	2,093.9	2,766.2

The procedure for conducting the test is given in Annex A.

- *Seed testing against quality standards.* Seed testing is the final control measure in the seed certification process. Initially, the minimum quality standard was established based on prevailing seed quality; with experience and progress, standards were raised. During exigencies like typhoons, specific standards like germination are temporarily relaxed to avoid a seed shortage.

In addition, the seed certification program carries on the following activities:

- registration of seed growers,
- registration of seed fields,
- field and bin inspection, and
- sampling seeds, and labeling and sealing seed lots.

The three decades of seed certification in the country have made possible the rapid multiplication and distribution of high-quality seeds of the new crop varieties constantly turned out by IRRI, UPLB, BPI, and other agencies. So far only 10 crops are in the seed certification scheme: rice, maize, sorghum, wheat, peanut, mungbean, soybean, cotton, tobacco, and potato. The volume of rice seed stocks produced from 1970 to 1985 is shown in Table 6.

PLANT QUARANTINE SERVICE

The introduction of pests and diseases into a country or from one area to another within a country can be attributed to the quest for new plant material, progress in transportation and communications, and disregard for quarantine rules and regulations. With the eagernes of both developed and developing countries to introduce new germplasm to improve local varieties, avenues were opened for introducing pests and diseases. A noxious weed, *Salvinia molesta,* was recently introduced into the Philippines: the golden snail is proving a menace to rice plants: and the importation of cavendish bananas brought in banana bacterial wilt or "moko" disease caused by *Pseudomonas solanacearum,* which presently threatens the banana industry. The recent report of rice black bug (*Scotinophara coarctata*) in Palawan is being closely monitored to prevent its spread.

BPI is responsible for implementing laws concerning the entry and movement of exotic plant pests and diseases and for preventing the further spread of indigenous plant pests and those already introduced. Local laws have been enacted, and international regulations of FAO and International Plant Quarantine have been implemented, but to a limited extent. Implementation of these regulations is

hindered by deficiencies in trained manpower, laboratory facilities, and financial support. The detection of pests and diseases has been limited to ocular inspections. Private farms, which isolate plant introductions, may not be strictly applying quarantine regulations.

The Plant Quarantine Service has been boosted recently with grants from international organizations for manpower training and improved facilities like a postentry station. However, much must be done to reach acceptable standards.

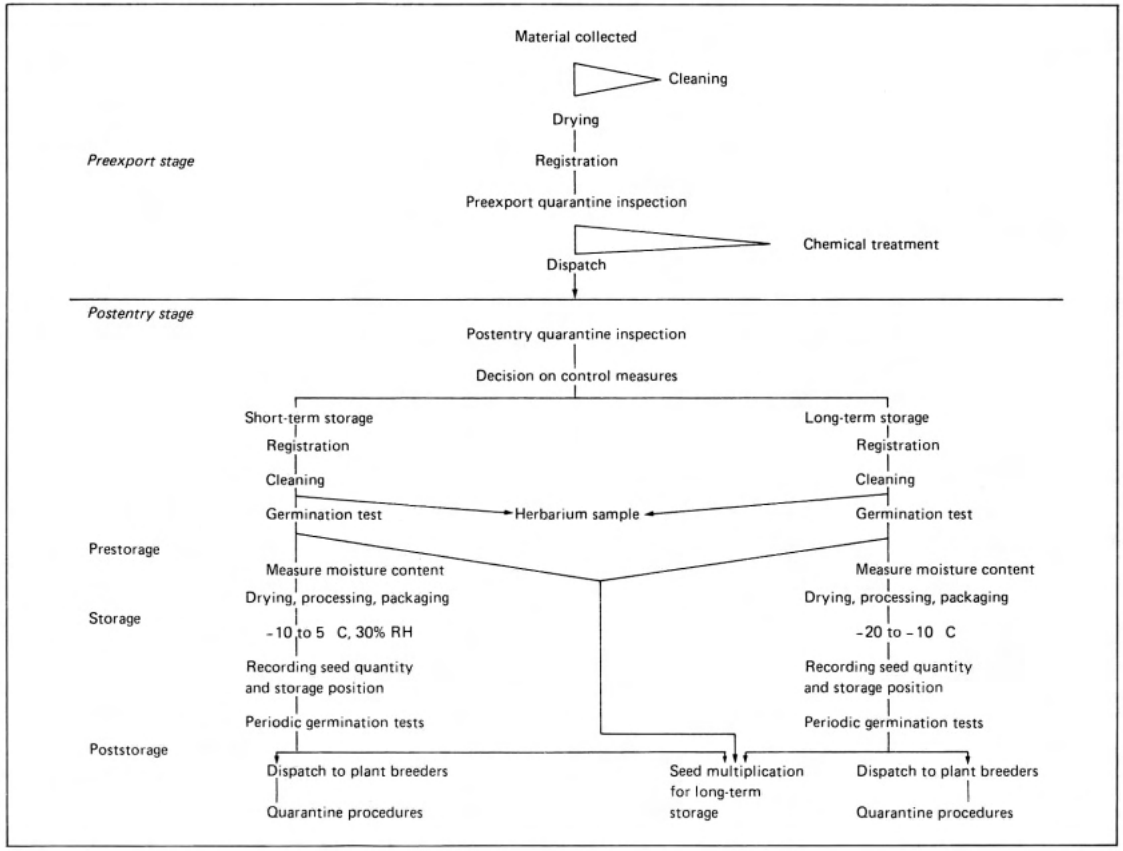
The flow of germplasm from collection to plant breeders in the Philippines is shown in Figure 5 (Gerard 1984). During the late 1970s, detection of seedborne pathogens for quarantine purposes was undertaken by the Seed Quality Control Services, and the results were submitted to the Plant Quarantine Service for the issuance of phytosanitary certificates. The process was long, and the laboratory was unprepared for the influx of seed, resulting in delays in dispatching seed, especially to the International Rice Testing Program (IRTP). The Seed Quality Control Services trained quarantine officers to conduct seedborne pathogen tests, and BPI established the Quarantine Seed Health Unit. The arrangement was still not sufficient, and IRRI established its Seed Health Unit in 1981 — one of its personnel being deputized in 1982 with the regulatory functions and powers of a Philippine plant quarantine officer. The IRRI Seed Health Unit has been servicing the plant quarantine needs of the International Rice Germplasm Center and IRTP. This is an interim arrangement; seed health testing will eventually be done by the national quarantine service.

In 1983, the IRRI Seed Health Unit distributed 2,000 seed packets from 2,000 analyzed seed lots to 57 countries, and another 30,000 seed packets of breeding lines and traditional cultivars to 63 countries (Singh 1985). Every year, on the average, 3,000 entries are received from different rice-growing areas and tested. In 1986, 3,255 entries consigned to various departments of IRRI were tested. The IRRI Seed Health Unit conducts postentry clearance, fumigation, seed inspection, seed health tests, and treatments on incoming seed before it is released to IRRI scientists, and conducts crop health inspection of all plantings of introduced material. It also attempts to detect the seedborne nematodes *Aphelenchoides besseyi* and *Ditylenchus angustus* and seedborne bacteria. The Seed Health Unit issues phytosanitary certificates for outgoing seed and administers postentry regulations for incoming seed.

Other countries have established seed health units, either within the plant genetic resources agency as in India, or within the quarantine service as in Mexico, Nigeria, and Kenya (Neergaard 1984).

OUTLOOK

The changing needs of the farmer to keep up with agricultural developments and to provide food security require continuous movement of germplasm and seed, which is accompanied by seed and crop health problems. Other likely quality problems are varietal purity, genetic identity, and seed vigor. Continuous dialogue among collectors, breeders, consumers, and quarantine services has led to the improvement



5. Flow chart of international transfer of seed to genebanks (Gerard 1984).

of quarantine regulations and international collaboration in seed exchange. Williams (1984) commented on the usefulness of many ideas and approaches, but they are geared to specific programs of IARCs or breeding institutions that are time-consuming and not relevant to the operations of genebanks in storing endangered species. There is a need for suggesting quick, acceptable quarantine procedures in such cases. We would like to reiterate the recommendations of the 1981 FAO/UNEP/IBPGR Conference, as cited by Neergaard (1984), that "all germplasm exchange should take place through national quarantine services" and the "setting up of national and regional laboratories should be considered by governments to expediate the passage of germplasm through quarantine." Furthermore, the proposals of the ASEAN PLANTI Meeting on Seedborne Diseases in the ASEAN and Seed Health Testing in 1985 also merit consideration, namely:

- All importation of economic seed should be made through main entry points.
- Seed for germplasm should be examined for pests in laboratories with the necessary equipment, manpower, and expertise.
- Each of the ASEAN countries should establish an adequately equipped seed health unit to carry out pest detection and certification of samples intended for import, export, and local distribution. The unit should also develop treatment schedules and sensitive techniques for detecting pathogens of quarantine importance.
- Where international or regional centers are available, the seed health unit should work closely with the Plant Quarantine Protection Department. The unit should be given the regulatory functions of inspection, treatment, and destruction of consignments.

These recommendations are valid and useful but will take time to implement, especially for the national systems. Immediate measures are needed. The quarantine activities in seed exchange should be a shared responsibility between the host country and the IARC or genebank, in the context that all germplasm exchange should take place through the national quarantine service. The Philippine experience can be considered an example. The cooperative performance of seed health tests for seed exchange should be guided by the developmental stage of the national system. The following general steps are suggested:

- A memorandum of understanding should be drawn up between the IARC or genebank and the national quarantine service regarding supervision, reporting systems, information dissemination, and other relevant activities. The role of each must be properly identified for smooth operation, and the quarantine activities (seed health test for fungi, nematodes, etc.) specified based on capabilities and the availability of effective seed health techniques.
- National quarantine can deputize a staff member of the IARC or genebank as a plant quarantine officer subject to meeting the required qualifications. Or, if a staff member is available from the national quarantine services, he or she may be detailed to the seed health unit of the IARC or genebank.
- Meanwhile, the national quarantine service should increase the capabilities of its seed health unit through improved facilities, manpower training, and

increased funding. The IARC or genebank should assist the national system to develop its capability to provide the needed service through equipment and financial grants, manpower training, and other technical support.

- As the level of capability in the national system increases, quarantine activities should be transferred to it from the IARC or genebank until the former can perform most activities.
- When the national system is fully developed, the seed health unit of the IARC or genebank can perform training, research, and backup functions.

The time frame for this arrangement depends on the speed of the developmental process. For other quality determinations like varietal purity, genetic identity, and vigor, a similar arrangement could be made with concerned national agencies like the National Seed Testing Laboratory and National Seed Certification Agency.

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Annex A. Precontrol test methodology

1. Source of seed for precontrol test = breeder seed and promising lines from originating agency of Seed Board varieties
2. Field operation
   a. Seed bedding = ordinary wet bed method
   b. Seedlings transplanted at 25 d
   c. Distance of planting= 20 cm between rows and 10 cm between hills and 1 seedling/hill
   d. Test plots = 2 replications
   e. Estimated population per plot = 2,350-3,000 plants; area per plot = 92.4 m^2 (22 m × 4.2 m)
   f. Fertilizer applied at 120-30-30 kg/ha for wet and dry seasons; hand weeding, crop protection, and irrigation provided when needed
3. Plot observations
   a. Close observation of all plants in every plot conducted thoroughly throughout the growing season
   b. Obvious offtype plants that exhibit morphological characteristics different from those of the standard variety labeled as admixtures
   c. Doubtful plants identified as admixtures recorded, observed closely, and all identifying characteristics different from the authentic sample noted
4. Characteristics observed
   a. Leaf color (basal leaf sheath — purple or green: leaf blade — pale green, dark green, or purple)
   b. Size and shape of leaf (slender, long; slender, short; broad, long; broad, short)
   c. Other leaf characteristics (erect or drooping, pubescent or glabrous)
   d. Tiller angle or growth habit (compact [erect], intermediate, or open [spreading])
   e. Tiller number (low, medium, or high)
   f. Flag leaf angle (erect, intermediate, or horizontal); other characteristics such as length, width, and color may be affected by environmental factors
   g. Plant height (short, medium, or tall), although it can be affected by photoperiod, temperature, water supply, and nutritional status
   h. Panicle characteristics (compact or open; exertion may be full, partial, or very poor)
   i. Growth duration or maturity (early, medium, or late); may be markedly affected by day length, temperature, and nutritional status
   j. Grain (size — long, medium, or short; USDA scale for brown rice: long = 6.6-7.5 mm, short < 5.5 mm)

ASEAN plant quarantine systems

K. G. SINGH

Plant quarantine systems within the Association of Southeast Asian Nations (ASEAN) are undergoing tremendous changes because of the consensus reached by the member countries on a common agricultural policy. Efforts are being made to revise legislation and standardize plant quarantine operations. The ASEAN Plant Quarantine Centre and Training Institute has provided the necessary impetus to develop plant quarantine technology in the region. Phytosanitary regulations and practices that impede the movement of plant materials and trade have been reviewed. More attention has been given to economic pests that pose a danger to the crops of the region. The pest risk analyses formulated for the different pests have been periodically reviewed to update information and provide justification for quarantine action. Seedborne diseases have been intercepted in cereals, vegetables, and other crops, and treatments have been evaluated. Advanced techniques are required to identify pathogens and exclude seedborne pathogens from the region. The quarantine systems of ASEAN anticipate adopting aseptic techniques for the movement of germplasm materials.

The Association of Southeast Asian Nations (ASEAN) Plant Quarantine Centre and Training Institute (PLANTI) has been charged with the responsibility of developing plant quarantine (PQ) technology in the ASEAN countries (Indonesia, Malaysia, Negara Brunei Darussalam, Philippines, Singapore, and Thailand). Since its establishment in 1980, PLANTI has carried out a range of activities relating to manpower development, research, standardization of PQ operations, and dissemination of PQ information (Singh 1983a, b). Recognizing the importance of good seed to increasing productivity in the agriculture sector, PLANTI has expanded to include seed health testing. Its activities have therefore been directed at different facets of plant protection, with the ultimate objectives of keeping the region free of exotic pests and promoting trade in agricultural produce.

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SYSTEMS AND OPERATIONS

Various PQ activities have been discussed at 14 technical meetings organized by PLANTI since its inception; topics have ranged from formulation of draft legislation to PQ treatments and emergency action plans. Some of the pertinent topics are highlighted below.

Pest risk analysis

The pests to be excluded from the ASEAN region have been categorized into two broad groups: A1 and A2, A1 pests are dangerous organisms that have not been introduced into the region. A2 pests are organisms that have a very restricted or limited distribution within the region and are present in one or more ASEAN countries. Zero tolerance has been approved to prevent further dissemination and establishment of these organisms. At least three ASEAN countries are required to express approval for designating a particular pest as A1 or A2.

The pest risk analysis is updated periodically at meetings organized by PLANTI. The list of the organisms (Singh 1987) that are important to the region also includes noxious weeds.

Legislation

The quarantine legislations of the ASEAN countries prohibit, restrict, or regulate the importation ofdifferent types of plant material. The regulations are based on the Food and Agriculture Organization Plant Protection Agreement for the Southeast Asia and Pacific Region and have generally emphasized provisions contained in Appendices I and II of that document (Singh 1987). Generally, plant produce from the South American tropics is prohibited from entry into the region. However, small consignments intended for research may be allowed entry provided they have undergone third country intermediate quarantine. This action is taken to minimize the introduction of *Microcyclus ulei,* the pathogen of the South American leaf blight (SALB) disease of rubber that is endemic in that continent. Similar types of restrictions have been imposed on other types of planting material that are of economic value to the agriculture sector of the ASEAN region. For instance, the cocoa swollen shoot virus disease has not been established in the ASEAN region, and stringent measures are taken to exclude from entry into the region planting material from countries where the disease is known to occur. In other cases, domestic quarantine has been utilized to restrict the movement of plant material from infected areas. Cocoa pods from East Malaysia have been denied entry to Peninsular Malaysia because of the presence of *Conopomorpha cramerella* in East Malaysia. Likewise, because rice is a very important crop in Thailand, the introduction of rice seed is allowed only for research purposes. The principle being followed is that planting material should be imported only in small quantities from certified sources to minimize hazards.

The quarantine services of the ASEAN countries undertake inspection of planting material intended for growing. In some cases, depending upon the status or condition of the consignment, the material is subjected to postentry quarantine. The duration of postentry quarantine for different crops and diseases varies. Generally,

for material like sugarcane, postentry quarantine may be extended to one growing season.

In recent years, the PQ legislation of the ASEAN countries has undergone tremendous change such that in some cases, plant produce from countries where dangerous diseases are known to occur is excluded. Under Malaysia's Plant Quarantine Act of 1984, plant produce may not be imported from the American tropics. Generally, while agricultural items intended for consumption do not require an import permit issued by the PQ service, all other items — including seed, bulbs, cuttings, and pollen — require import permits even if the consignments are intended for scientific or research purposes. Conditions in the form of additional declarations have been specified in the import permit to facilitate introductions.

Documents

To streamline and standardize PQ operations, 32 different PQ forms have been formulated. These forms are necessary for the smooth and effective enforcement of PQ regulations. They provide information on the type of action to be taken during introduction of plant material and give details regarding the consignment or treatment to be given.

Treatments

It has been agreed that agricultural commodities intended for consumption should be treated before loading in accordance with standard phytosanitary practices. Treatment schedules have been approved for

- plants and plant parts,
- seed,
- plant products (for consumption processing),
- commodities of plant origin, and
- material of other than plant origin.

Treatments have been proposed to protect against *M. ulei* spores, which might be carried by passengers arriving from the South American tropics. The following treatment has been found effective:

- exposure to ultraviolet light (524 nm) and fumigation with formalin (1 ml/8 m^3)
- moist heat at 55 °C or dry heat at 75 °C for 30 min
- soap solution at 40 mg/liter

It has been proposed that member countries continue to obtain bioassay results, particularly for seeds that are likely carriers of seedborne diseases. Such measures would assist the PQ services to determine and carry out effective treatments.

Seedborne diseases in ASEAN

The ASEAN countries practice voluntary seed certification schemes for rice, maize, sorghum, mungbean, soybean, groundnut, and cotton seed. The procedures are enforced upon growers to ensure high-quality seed. However, seed purity and viability are the only main criteria. Seed health conditions are examined in the field on the growing plants only but not directly on the seed. Little attention is paid to

seedborne organisms. Seed health testing, therefore, has never received sufficient emphasis, and field inspections for purity and severity of diseases are periodically carried out by inspectors to oversee minimum standards recommended by the crop production department.

Nearly all the ASEAN countries have attempted to list important seedborne organisms. Some countries have intercepted seedborne organisms such as *Phomopsis theae* from tea seed, *Cylindrocladium cohouni* from cloves, and *Phoma lingam* from crucifer (ASEAN PLANTI 1985). However, in some situations the pathogens have not been identified in accordance with approved taxonomic practices.

Seed health testing

Seed health testing activities became routine only in the early 1970s. These activities are generally carried out at selected stations to detect organisms being introduced through imported consignments. Standard methods used for detecting fungi, bacteria, and viruses have been adopted by the ASEAN countries.

Although immunofluorescent serology could provide a rapid and accurate means of determining infection by bacterial pathogens, the method must be developed in the ASEAN countries. For determining seedborne viruses, indicator plants have been used. Serological methods are being developed against specific organisms.

Advanced tissue culture techniques (Singh 1985a) have been developed for the aseptic transfer of rubber (*Hevea brasiliensis*) germplasm.

The sampling intensity stipulated by the International Seed Testing Association has been adopted by ASEAN to achieve uniformity and reproducibility. For very small samples, 10% by weight of the sample is examined for purity and pests.

Seed health units

Germplasm material originating from research institutions sometimes carries seedborne organisms despite treatment and certification. The following measures have been agreed upon in ASEAN for imported seed lots:

- All importation of economic seed should be made through the main entry point.
- Seed for germplasm should be examined for pests in laboratories with the necessary equipment, manpower, and expertise.
- Each ASEAN country should establish a seed health unit, adequately equipped to carry out pest detection and certification activities on samples intended for import, export, and local distribution. The units should work in close cooperation with the PQ services. The units should also develop treatment schedules and sensitive techniques for detecting important pathogens.
- Where international or regional centers are available, the units should work closely with them. The units should be given the regulatory functions of inspection, treatment, and destruction of seed consignments.

Threshold/tolerance levels

Within ASEAN, tolerance/threshold values for diseases for most of the economic crops have not been widely established. Although for A1 and A2 pests the tolerance should be zero, values have been established for other diseases that are likely to cause serious losses in the region. The tolerance levels for some crop diseases are given in Table 1.

DISCUSSION

Poor-quality seed could form the basis for limiting food production. The subject has therefore received considerable attention. Purity and germination have been the basic qualities subjected to intensive investigations in the past. However, because seedborne organisms can affect seed quality and ultimate development of seedlings, attention must be given to the movement of good-quality seed. The factors considered to play an important role in any seed certification scheme are analytical purity, weed content, viability, freedom from disease, moisture content, and trueness to variety. When a seed sample exhibits a satisfactory level in all these aspects, it can be considered of high quality.

Table 1. Proposed ASEAN tolerance/threshold values for some diseases.

Host/pest	Disease	Tolerance level (%)
Cocoa *(Theobroma cacao)*		
Crinipellis perniciosa (Stahel) Singer (syn. *Marasmius perniciosus* Stahel)	Witches' broom	0
Moniliophthora roreri (Cif.) H. C. Evan et al *(=Monilia roreri* Cif.)	Monilia pod rot, watery pod rot, Queredo disease, grey pod rot	0
Phytophthora palmivora (Butler) Butler	Black pod	0
Trachysphaera fiuctigena Tabor & Bunting	Trachysphaera pod rot, mealybug disease	0
Glomerella cingulata (Stonern,) Spauld. & Schrenk (syn. *Colletotrichum gloeosporioides* [Penz.] Sacc.)	Anthracnose	1
Cocoa swollen shoot virus	Cocoa swollen shoot	0
Coffee (*Coffea* spp.)		
Colletotrichum coffeanum	Blister spot	1
Colletotrichum coffeanum var. *irulans*	Coffee berry disease	0
Coffee ringspot virus		0
Maize (*Zea mays)*		
Erwinia stewartii (Smith) Dye	Bacterial wilt	0
Corynebacterium nebraskense Schuster	Leaf freckles and wilt	0
Pseudomonas syringae Van Hall	Bacterial spot, leaf blight, top rot, chocolate spot	0

Continued on next page

Table 1 continued

Host/pest	Disease	Tolerance level (%)
Cochliobolus heterostrophus (Drechsl.) (syn. *Drechslera maydis* [Nisik.] Subram. & Jain)	Southern leaf spot or blight	0
Gibberella zeae (Schw.) Petch. (syn. *Fusarium graminearum* Schwabe)	Seedling blight, cob rot, stalk rot	0
Sclerospora maydis (Racib.) Butler	Downy mildew	0
Sclerospora sacchari Miyake	Downy mildew	0
Sclerospora sorghi Western & Uppal	Sorghum downy mildew	0
Sclerospora philippinensis Weston (syn. *S. indica* Dutler)	Downy mildew	0
Claviceps gigantea Fuentes et a1	Ergot	0
Colletotrichum graminicola (Ces.) Wils.	Anthracnose, dieback, stalk rot	0-0.1
Sugarcane mosaic virus		0
Maize mosaic virus		0
Rice (*Oryza sativa*)		
Xanthomonas campestris pv. *oryzae* (Ishiyama) Dye	Bacterial blight	0
Xanthomonas campestris pv. *oryzicola* (Fang et al) Dye	Leaf blight streak/ bacterial leaf streak	0
Gibberella zeae (Schu.) (syn. *Fusarium* graminearum Schwabe)	Scabhead blight	0
Pyricularia oryzae Cav.	Blast	0
Balansia oryzae (Syd.)	Udbatta	0
Aphelenchoides besseyi Christie (syn. A. *oryzae*)	White tip	0
Bean (*Glycine max*)		
Pseudomonas syringae pv. *tabaci* (Wolf & Foster) Young, Dye & Wilkie (=*P. tabaci* [Wolf & Foster] Stec.)	Wild fire	0
Xanthomonas campestris pv. *glycinea* (Nakano) Dye (=*X. phaseoli* [E. F. Smith] Dowson)	Bacterial pustule	0
Pseudomonas syringae pv. *glvcinea* (Coerper) Young, Dye & Wikie (=*P. glycinea* Coerper)	Bacterial blight	0
Corynebacterium flaccumfaciens (Hedges) Dowson	Wilt	0
Colletotrichum truncatum	Anthracnose	0-0.1
Peronospora manshurica (Naumoff) Syd.	Downy mildew	0
Cercospora kikuchii (Mats & Tomoy) M. W. Gardner	Purple seed stain	0-1
Diaporthe phaseolorum (Cooke & Ellis) Sacc. var. *batatas* (Harter & Field) Wehm.	Stem canker	0
Diaporthe phaseolorum (Cooke & Ellis) Sacc. var. *sojae* (Lehman) Wehm.	Pod and stem blight	0
Diaporthe phaseolorum (Cooke & Ellis) Sacc. var. *caulivora* Athow.	Stem canker	0
Macrophoma phaseolina (Tassi) Goid. (syn. *M. phaseoli* [Maubl.] Ashby)	Charcoal rot	1
Tobacco ringspot virus	Budblight	0
Heterodera glycines Ichinohe	Soybean cyst nematode	0

In recent years, noxious weeds have been intercepted in substantial numbers from imported seed lots of legumes such as *Centrosema pubescens, Calopogonium mucunoides,* and *Pueraria phaseoloides.* Thirty-six weed species were intercepted (Ngizailah and Nair 1985). The PQ authorities therefore need to inspect plant material in detail, regardless of the certifications such materials carry.

PLANTI has promoted the concept of the ASEAN Plant Quarantine Ring (Singh 1983a), and through its efforts two Ministerial Understandings were approved by the ASEAN Ministers of Agriculture. Research on quarantine treatments and on the presence and distribution of certain pathogens has emphasized that there is a scarcity of information in the ASEAN region. Quarantine authorities in the past relied basically on information from reports that had not been critically reviewed or updated. This consequently prevented quarantine decisions from being based on sound biological principles. PLANTI has acted as a focal point, has provided a coordinating mechanism for PQ information, and has reported the seriousness of pests so that effective treatments or quarantine actions can be undertaken. Emergency action plans have been prepared for many pests.

The ASEAN quarantine systems are undergoing considerable changes to improve inspection procedures and techniques. Where there is a need to import germplasm material for research, the PQ systems have been flexible to accommodate importation to improve productivity. Seedborne diseases have been intercepted by a number of PQ stations. Serological and other advanced techniques are being introduced to facilitate quarantine decisions (Singh 1985b). The ASEAN region is still free of a number of dangerous organisms, a situation that must be maintained. It is heartening to note that the International Rice Research Institute has established a seed health testing unit to assist countries in acquiring certified seed samples of this crucial crop.

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The plant quarantine system for rice in the United States

F. E. COOPER

Rice is an important crop in the United States that warrants quarantine protection against foreign plant pests and disease organisms. Safeguard measures are prescribed in departmental import permits issued to rice researchers. These include selection of apparently disease-free seeds, phytosanitary certification, treatment, seed health testing, inspection of the growing plants, and measures for harvesting of seeds and disposal of vegetative parts and growing media.

Annual rice production in the United States is approximately 8.2 million t (United States Department of Agriculture 1982), of which more than half is exported. Rice is therefore an important crop to consider in plant protection.

The USDA Agriculture Handbook No. 418, *Foreign bacterial and fungus diseases of food, forage, and fiber crops,* lists 37 foreign diseases of rice, including bacteria and fungi, that could be inadvertently introduced and established in the U.S. by rice seed importation. Two of the most destructive of these foreign diseases are glume blotch caused by *Melanomma glumarum* and bacterial blight caused by *Xanthomonas campestris* pv. *oryzae. M. glumarum* may be the perfect stage of *Phoma sorgina,* a pathogen widespread in the U.S., but this has not been confirmed. Disease organisms may be found on imported seed, on the attached glumes, or on other parts of the rice plant brought with the seeds as contaminants.

In addition, there are numerous diseases caused by viruses and viruslike entities that are not reported to exist in the U.S. These diseases, although not seedborne, could enter the country on living infected plants. Taken as a group, the diseases we are concerned with are widespread in the rice-growing areas of the world. We cannot be sure of their effects on the U.S. rice crop if they were introduced, but we know that domestic diseases reduce the average annual yield by 5%. One exotic rice disease is reported to have caused 20% to more than 30% losses in Japan (Mizukami and Wakimoto 1969). The danger of introducing foreign disease organisms is too great to allow the unrestricted importation of rice seed. For this reason, rice seed is

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allowed to enter the U.S. only for experimental purposes and under strict safeguards.

The movement of plant germplasm poses a risk of moving harmful organisms along with the germplasm into areas where these organisms were unknown before. Pathologists have found spores of exotic fungi on seed imported for scientific purposes. When the Plant Quarantine Act became law 75 yr ago, this avenue of entry for exotic parasites was recognized (Title 7, United States Code 1912). Therefore, U.S. quarantine regulations include restrictions on importing germplasm as well as other plant material intended for propagation, whether for experimental use or not (Title 7, Code of Federal Regulations 1974). The organization given the responsibility for carrying out these restrictions is the Plant Protection and Quarantine (PPQ), a part of the Animal and Plant Health Inspection Service (APHIS), U.S. Department of Agriculture (USDA).

When seeds or plants are planted, exotic pathogens can often find suitable conditions for growth and spread. Therefore, we consider that plant material for planting poses a high risk of introducing exotic pathogens. Because rice germplasm is in the form of seeds, and seeds must be planted for increase, germplasm collections from foreign countries definitely fall into this high-risk category. The risk is also to the collection itself, a portion of which may be destroyed by severe disease outbreak, resulting in a reduction in the amount of usable germplasm or at least in the loss of the time taken to plant and grow the increase crop. Commercial plantings of the same or similar crops are also threatened by the presence of new pathogens in the country. Unforeseen factors such as windstorms, hail, tornadoes, and vandalism could result in the escape and establishment of exotic pathogens, even from a secure greenhouse.

PREVENTING THE ENTRY OF RICE PATHOGENS

How can we prevent the entry and establishment of exotic pathogens with rice germplasm? The usual quarantine measures of inspection and treatment are insufficient to eliminate all fungal spores, bacteria, and viruses. Countries without an established safeguard system usually prohibit high-risk imported seeds, the most drastic action that can be taken. In the U.S., we have set up a system of safeguards that lowers the risk associated with imported rice seeds.

Applying for permit to import rice germplasm

An import permit is required by law for all importations of rice seed into the U.S. The researcher in the U.S. who wishes to import rice seed and who will be responsible for the rice germplasm applies for an import permit by writing to the Permit Unit, PPQ, APHIS, USDA, Room 638, Federal Building, Hyattsville, Maryland 20782.

In the application, the researcher describes the kinds and quantities of rice seed to be imported, the country where the seed was produced, the means of transportation into the U.S., the expected port of entry, the geographic location of the proposed research, and a general outline of the work to be performed with the seed. The researcher also includes a description of the site where the work will be

carried out (whether in a growth chamber, laboratory, greenhouse, field plot, etc.); what precautions are planned to prevent the escape of disease organisms; and how the seed, the plants grown from it, and other associated imported material will be disposed of. If possible, the researcher also provides the name of a rice pathologist who will examine the growing plants for evidence of plant diseases.

PPQ determines whether the proposed work can be carried out without significant risk of introducing and establishing exotic diseases and pests. Specific conditions or safeguards for importing and growing the rice are listed on the permit.

Prescribed safeguards

The safeguard conditions for growing out imported rice seed are designed to prevent the escape of plant disease organisms that may have been brought undetected with the seed. In the country of origin, the seed must be selected from an apparently disease-free and pest-free source, securely packaged to prevent loss in transit, and sent to the Plant Germplasm Quarantine Center in Beltsville, Maryland. Pre-addressed mailing or shipping labels are provided.

Only the minimum amount of seed necessary for the research will be admitted. The consignment should be accompanied by a phytosanitary certificate issued by the plant protection service of the exporting country. No fungicides or insecticides should have been used on the seed before shipment.

All seed intended for growing must be inspected at the Plant Germplasm Quarantine Center in Beltsville by pathologists and entomologists familiar with pests and diseases of normally prohibited plant material. The rice seed is hot-water treated at 56-57 °C for 15 min. An alternate treatment is removal of the hulls and dipping in a solution of 1 part 5.25% NaOCl to 4 parts water plus a wetting agent for 5 min. After drying, the rice seed is forwarded to the researcher.

Imported seed must be planted and the plants grown in a growth chamber, laboratory, or greenhouse, and the growing plants must be inspected periodically for symptoms of plant disease. Inspections are conducted by the researcher, by a designated rice pathologist, or by a Federal or State quarantine officer as specified on the import permit. Plants showing disease symptoms are rogued and destroyed.

The greenhouse or laboratory, as well as the seed and plants, are subject to inspection by one of our officers and by the quarantine office of the Department of Agriculture of the state in which the work is done. All seed imported and the plants derived from it are considered to be under quarantine and may not be removed from the designated laboratory or greenhouse without prior written approval.

Seeds produced from healthy plants, and which do not show discoloration or deformation, may be released without further restriction.

If the seed is to be grown in a rice-growing area of the U.S., we also require that, before planting, the imported seed be subjected to seed health testing in the laboratory of a rice pathologist using the agar method (potato dextrose agar or Wakimoto's medium). Germinating seeds that test negatively for pathogens are transplanted. Contaminated seeds and agar media are autoclaved or incinerated prior to disposal. Seeds not passed through seed health testing by the agar method are placed in sealed storage and not used until passed later through seed health testing. All growing plants must be inspected by a rice pathologist.

PPQ may request a written report on the inventory and health status of the importations of rice seed from certain locations.

These are the usual conditions prescribed for the importation of rice germplasm. However, if the researcher cannot observe one or more of these conditions, we work with the researcher to develop alternatives that offer the same or better protection against the introduction of exotic plant pests and disease organisms.

Less stringent requirements are prescribed for the importation of rice seed for laboratory analysis. When the seed will be destroyed in the process of analysis, and any remaining plant material will be autoclaved or incinerated, the risk of plant disease introduction is small. Nevertheless, a permit is required for these importations to inform laboratory scientists of the conditions that must be observed to minimize the risk of introducing plant pests and disease organisms.

EXPORT OF RICE GERMPLASM

Researchers in the U.S. also export rice germplasm to colleagues in other countries. PPQ provides inspection and phytosanitary export certification for these shipments as a service, on the request of the exporting scientist. However, a certificate can be issued only if the country of destination does not prohibit the entry of rice seed or, in case it does, if a permit specifically authorizing the shipment is presented to us. Phytosanitary export certification is provided by Federal inspectors, and by approved State inspectors in most of the states.

Researchers in any country wishing to receive rice germplasm from cooperators in the U.S. should first determine what their country's quarantine requirements are for rice germplasm from the U. S. This information should be available from the Ministry of Agriculture in most countries.

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The Brazilian plant quarantine system for rice germplasm introduction

A.C.R. LINS

The introduction of plants and plant material for research purposes is carried out in Brazil by the National Genetic Resources Center — CENARGEN—under a special mandate of the Ministry of Agriculture. Quarantine measures are adopted at CENARGEN in accordance with Brazilian phytosanitary legislation. CENARGEN's activities include the exchange of germplasm with national and international research institutions. A total of 8,529 rice accessions have been exchanged since 1979, the International Rice Research Institute being the most common partner. An arriving rice consignment is first inspected in an insect-proof room, fumigated, and registered on a computer. Samples are later simultaneously examined for fungal, bacterial, viral, and nematode contamination. So far, the only exotic rice pathogen intercepted in CENARGEN's laboratories has been the fungus *Clasterosporium* sp.; however, many pathogens that already exist in Brazil have been intercepted. Where there is contamination, the accessions are treated and re-inspected before release. Treatments are either by thermotherapy, chemotherapy, meristem-tip culture, or a combination.

The majority of the successful cash crops in Brazil are the result of introductions made many years ago (Rocha et al 1984), such as coffee, sugarcane, soybean, and black pepper. But there are numerous examples of agricultural disasters caused by the introduction of exotic pathogens (Kahn 1970, Morschel 1983). Citrus canker caused by *Xanthomonas campestris* pv. *citri* (Hasse) Dye, found in 1957 in Sao Paulo State, cost more than US$5 million to eradicate there but remains in other states (Galli et al 1968). The citrus virus "tristeza" was probably introduced to Brazil in 1937 with material from South Africa or Argentina. The destructive coffee rust caused by *Hemileia vastatrix* Berk & Br. has spread throughout Brazil and other South American countries and could mean about US$500 million of annual loss for the Brazilian economy alone if fungicide spraying were suspended. The cotton boll weevil (*Anthonomus grandis* Baermann) was introduced to Brazil in 1983, causing great economic damage.

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Although a large number of insect pests and diseases are already established in Brazil, many others pose threats to various crops. Therefore, special attention is needed at least to delay their introduction. *X. campestris* pv. *oryzae* on rice, *Tilletia indica* on wheat, *Globodera rostochiensis* on potato, bunchy top virus on banana, and cocoa swollen shoot virus are just a few important pathogens not yet reported in Brazil (Warwick 1982). Even within the country there are some diseases of important crops that are so far restricted to certain regions. Cocoa witches' broom (*Crinipellis perniciosa*) and moko disease (*Pseudomonas solanacearum* race 2) on banana are at present limited to the Amazon region; but they represent a permanent threat to the main cocoa- and banana-producing areas in the country.

Brazil produces 62% of the rice in South America, but only 1.9% of world production. Brazil's total production is about 9 million t/yr from an area of 5.5 million ha. This production is not sufficient for domestic demand; hence Brazil is a potential rice importer, even though the planting area is expanding (Teixeira 1987).

As a result of modern technology, Brazilian production and productivity have increased substantially in the last two decades. The enrichment of genetic resources has played an important role in this process, particularly the accelerating introduction of genetic material from different parts of the world stemming from cooperative programs with national and international agricultural research centers. On the other hand, this has exposed Brazilian agriculture to significant risks from exotic insect pests and diseases (Rocha et al 1984).

The National Genetic Resources Center (CENARGEN) was created in 1974 by the Brazilian Agricultural Research Corporation (EMBRAPA) to systematize germplasm introduction. Under the Ministry of Agriculture, CENARGEN has a mandate to import germplasm for research purposes. It centralizes all activities related to genetic resources: introduction, exchange, inspection, treatment, and quarantine; collection; characterization and evaluation; conservation; and documentation. More recently, biotechnology, particularly genetic engineering, has been incorporated.

The major aim of the plant quarantine system adopted at CENARGEN is to evolve methods of introducing new varieties of agricultural, horticultural, and forestry plants into Brazil without contamination by exotic insect pests and diseases.

QUARANTINE PRINCIPLES IN BRAZIL

Quarantine in Brazil is based on biological evidence. It is expected to involve the active cooperation of the community in obeying the restrictions imposed by the law; it is not expected to be looked on as a barrier, especially against germplasm introduction and breeding programs. Its chief aim is to act as a filter to prevent the introduction of insect pests and diseases associated with the germplasm. Quarantine measures in Brazil are not static; they are altered as new facts become evident.

Germplasm introduction as seed should have preference whenever possible. The seed itself can function as a filter for many plant diseases. Nevertheless, several pathogens can be transmitted by seed, and in some cases their detection is even more difficult than in vegetative material (Kaiser 1983).

In general, the breeder's point of view in relation to germplasm introduction is liberal, whereas the plant quarantine officer's tends to be conservative (Kahn 1982, Rocha 1985). CENARGEN has adopted a balanced view in relation to germplasm introduction and quarantine, based on biological evidence of risk (Rocha 1985).

BRAZILIAN PHYTOSANITARY LEGISLATION

Brazilian phytosanitary legislation is based on Law No. 24 of 14 April 1934 (Ministerio da Agricultura, Departamento Nacional de Producao Vegetal 1976), which promulgates guidelines and safeguards concerning the introduction of plants and plant material. Special regulations can be issued at any time as required (Alves 1977).

All plants and plant material to be imported fall into one of three categories, described as follows.

Category one: import prohibited

Material in this category can be introduced only for research purposes by an official agency and under special license. It includes

- plant and living vegetative material, from all countries, of *Citrus* spp., *Coffea* spp., *Fortunella* spp., *Gossypium* spp., *Herrania* spp., *Hevea* spp., *Musa* spp., *Saccharum* spp., *Sorghum* spp., *Theobroma cacao,* and *Zea mays* L.;
- seeds of *Calopogonium, Canavalia, Centrosema, Crotalaria, Glycine, Leucaena, Macroptilium, Macrotiloma* or *Dolichos, Neonotonia, Pachyrhizus, Pueraria, Stylosanthes, Vicia,* and *Vigna* when originating in Australia, Burma, China, Costa Rica, Finland, India, Indonesia, Japan, Kampuchea, Korea, Laos, Malaysia, Nepal, Papua New Guinea, Philippines, Puerto Rico, Sri Lanka, Soviet Union, Taiwan, Venezuela, Vietnam, or any other country where the fungus *Phakopsora pachyrhizi* Syd. (soybean rust disease) has been reported;
- seeds of *Glycine, Lespedeza, Lupynus,* and *Phaseolus* when originating in China, Korea, United States, or any other country where the soybean cyst nematode (*Heterodera glycines* Ich) and *Corynebacterium flaccumfaciens* (Hed) Dow (soybean wilt disease) have been reported; and
- soil, mites, insects, weeds, and microbial cultures.

Category two: conditional restriction

Material in this category can be introduced only if there is a special additional statement in the phytosanitary certificate certifying that it is free from particular insect pests, diseases, or weeds. For example:

- *Medicago* must be free from cuscuta seeds.
- *Cydonia, Fragaria, Malus, Prunus, Pyrus,* and other genera of the Rosaceae must be free from *Erwinia amylovora* and *Nectria galligena.*
- *Olea* spp. must be free from *Pseudomonas savastonoi.*
- *Pisum sativum* (pea) must be free from pea seedborne mosaic virus; the result of an enzyme-linked immunosorbent assay made with samples of the material to be shipped to Brazil must accompany them.

- *Allium* spp. must be free from *Ditylenchus dipsaci.*
- *Solanum* spp. must be free from *Corynebacterium sepedonicum, Globodera rostochiensis, Pseudomonas solanacearum, Synchytrium endobioticum,* and necrotic races of the Y virus.
- *Helianthus annuus* (sunflower) must be free from *Plasmopara halstedii* and sclerotia of *Sclerotinia sclerotiorum.*

Category three: import free

Any material not included in categories one and two falls into this category. The only requirement is a phytosanitary certificate that must accompany the material. The International Plant Protection Convention requires that the phytosanitary certificate be issued by an official institution of the exporting country.

CENARGEN PROCEDURES FOR HANDLING IMPORTED GERMPLASM

CENARGEN has two postentry glasshouses and two screenhouses. Four inspection laboratories have all the necessary equipment, including a transmission microscope. Soil sterilization is hot-vapor based, and fumigation is carried out using tightly closed drums within an isolated compartment. One cold chamber is available exclusively to store seed material while samples are being inspected in the laboratories. The scientific staff consists of I1 plant pathologists.

CENARGEN follows these standard procedures:

Inspection at point of entry

As a consignment arrives at an airport, seaport, or post office, a visual inspection is carried out by a quarantine officer of the Ministry of Agriculture. If the material already has CENARGEN's import permit label, it is immediately forwarded there. If the material does not meet the necessary requirements, it is either destroyed or kept in strict quarantine (Rocha 1984).

Preliminary procedures at CENARGEN

When the material arrives at CENARGEN, it is opened in an insect-proof room, and a preliminary inspection is made for insects. This room is equipped with germicide lights to catch and kill flying insects at night.

All seed lots are fumigated with phostoxin, which is unlikely to cause damage to most plant species. The opened consignment is fumigated in its original package, and the germplasm is then registered in a computer according to codes given by the crop curator.

Laboratory inspection

The original package is destroyed and a new CENARGEN bag is used. Samples are taken from each accession and sent simultaneously to the mycology, bacteriology, virology, and nematology laboratories. The bulk of the seed material is kept in a cold chamber (5-10 °C, 10% relative humidity) until the laboratory reports are issued.

For fungi, direct examination, the blotter test, and plating methods are used, followed by careful examination under a light microscope (Neergaard 1973, 1978;

Tuite 1969). Other methods, like centrifugation (International Seed Testing Association 1966), can be used according to specific needs.

For bacteria, plants are grown in humid chambers in the glasshouse and tests are performed using plating techniques with specific media (Schaad 1982), the paper towel method (International Seed Testing Association 1966, Singh and Rao 1977), and serological methods (Schaad 1979).

For viruses, the most common test is the growing-on method. The infectivity test is also used by inoculating host extracts in virus test plants whenever virus symptoms are expressed. Serological tests are also used, the most common of which are Ouchterlony gel diffusion and sensitive latex-agglutination techniques. Leaf dip and immunosorbent electron microscope techniques are used when further information on the virus particles is needed (Hampton et al 1978, Kitajima 1965, Ouchterlony 1968).

For nematodes, the most common techniques are trituration, sieving techniques, modified Baermann funnel, and flotation for cysts (Byrd et al 1966, Jenkins 1965, Thorne 1961).

The fact that a pathogen already present in Brazil comes associated with introduced germplasm does not justify overlooking precautions at CENARGEN with regard to that particular pathogen, because most pathogens exist in several physiological forms or races; the introduction of a new strain or race can mean the initiation of a serious outbreak.

Postentry quarantine

The main purpose of postentry quarantine is to intercept serious pathogens that may be present in high-risk materials but not evident at the time of entry. The plants are established in appropriate glasshouses built exclusively for this purpose and are provided optimum conditions for vigorous growth. Virus indexing and tests for pathogenic fungi, bacteria, and nematodes are carried out. Basic fertilizers are added to the soil mixture after sterilization, and automatic watering is used. Insects are excluded to ensure that no vectors are present for any kind of transmission.

Planting material from CENARGEN's postentry quarantine is not released until after at least one growing season and unless the four inspection laboratories have issued pathogen-free reports.

CENARGEN'S GERMPLASM EXCHANGE

Since CENARGEN's emergence in the national agricultural research system, germplasm exchange has considerably increased. In 1978, the number of accessions handled by CENARGEN was less than 2,000, whereas in the first 7 mo of 1986, more than 13,000 accessions were inspected (Table 1). Germplasm handled at CENARGEN is classified as imported, exported, or in internal transit. Inspection of germplasm in internal transit, although difficult to implement, is necessary when diseases of important crops are limited to certain regions. The great majority of germplasm handled by CENARGEN is, in fact, imported. Because modern agricultural research has been gaining momentum, the need for advanced lines and varieties in most crops has become evident. The breeding programs are anxious for

Table 1. Germplasm movement at CENARGEN, 1978-86.

Year	Accessions (no.)			
	Imported	Exported	Internal transit	Total
1978	1,158	633	169	1,960
1979	2,508	1,266	1,529	5,303
1980	8,675	2,045	1,651	12,371
1981	9,457	2,287	1,922	13,666
1982	3,696	1,230	2,943	7,869
1983	6,978	1,712	5,606	14,296
1984[a]	23,554	1,503	4,175	29,232
1985	4,765	3,233	4,573	12,571
1986[b]	11,057	1,039	1,490	13,586
Total	71,848	14,948	24,058	110,854

[a] Includes a barley collection of 19,353 accessions. [b]January to July.

variability that in most cases can be obtained only through germplasm exchange with large germplasm banks at national and international institutes, necessitating warnings about plant health safety. An important issue in the majority of the international crop institutes is the large amount of samples handled and their diverse sources of origin. Sometimes the emphasis on collection of plant material, rather than on disease-free germplasm, may unwittingly serve to spread plant diseases.

Table 2 shows the number of accessions handled by CENARGEN per major crop. Rice germplasm represents 16.5% of the imported accessions. The increasing importance of rice can be seen in the number of accessions introduced: from 175 in 1979 to 1,432 in the first 7 mo of 1986.

Table 2. Accessions of major products in germplasm exchange inspected at CENARGEN, 1979 through July 1986.

Crop	Imported		Exported		Internal transit	
	No.	%	No.	%	No.	%
Cotton	1,852	4.5	52	0.4	853	5.1
Rice	6,736	16.5	1,793	13.5	2,541	15.3
Cowpea	444	1.1	741	5.6	185	1.1
Oil palm	10	< 0.1	3	<0.1	520	3.1
Beans	3,901	9.6	1,044	7.9	1,476	8.9
Cassava	326	0.8	1,364	10.3	1,227	7.4
Maize	5,135	12.6	1,997	15.1	808	4.9
Soybean	2,345	5.8	2,630	19.9	2,197	13.2
Sorghum	3,946	9.7	326	2.5	54	0.3
Wheat	2,078	5.1	212	1.6	30	0.2
Forestry crops	2,330	5.7	90	0.7	61	0.4
Forage crops	6,447	15.8	1,699	12.8	3,700	22.3
Fruit crops	1,800	4.4	599	4.5	1,652	10.0
Vegetables	3,336	8.2	673	5.1	1,269	7.7
Rubber	43	0.1	20	0.2	3	<0.1
Total	40,729	100	13,243	100	16,582	100

POTENTIAL RISKS IN RICE GERMPLASM INTRODUCTION

A remarkable feature of Brazilian rice production lies in its sensitivity to climatic conditions, because only 19% of the total rice area is irrigated. In the 1970s, the rice-producing area began moving from the south toward the northern and middle west regions, because rice is traditionally a frontier crop. After establishment, it gives way to more valuable crops as the region develops. This behavior enhances the risks of spreading rice diseases in new regions.

Rice germplasm exchange has been handled principally through seed material, enabling safer exchange, because the seed itself can function as a filter for many plant pathogens. Apart from new strains, races, or pathotypes of the pathogens already established in Brazil, several exotic ones pose a constant threat to rice culture.

Table 3 shows important rice pathogens not yet reported in Brazil. There is no clear evidence of virus transmission by seeds, but some fungi, bacteria, nematodes, and mycoplasmalike organisms (MLOs) of economic importance require special care to avoid or delay their introduction (Ou 1984). Special attention has been drawn to bacterial blight (*X. campestris* pv. *oryzae*), which, although reported in other South American countries, so far has not reached Brazil.

PLANT DISEASE INTERCEPTIONS AT CENARGEN

Table 4 shows some exotic plant pathogens that have been intercepted through routine inspection at CENARGEN's laboratories. They represent a fraction of the

Table 3. Important rice diseases not yet reported in Brazil.

Pathogen	Common name
Fungi	
Sclerophthora macrospora	Downy mildew
Drechslera gigantea	Eyespot
Monographella albescens	Leaf scald
Sarocladium oryzae	Sheath rot
S. attenuatum	Sheath rot
Gaeumannomyces graminis var. *graminis*	Crown sheath rot
Balansia oryzae-sativae (Ephelis oryzae)	Udbatta disease
Bacteria	
Xanthomonas campestris pv. *oryzae*	Bacterial blight
X. campestris pv. *oryzicola*	Bacterial leaf streak
Pseudomonas syringae pv. syringae	Bacterial sheath rot
Viruses and mycoplasmalike organisms (MLOs)	
RDV	Rice dwarf
Tungro virus	Tungro
GSV	Grassy stunt
MLO	Wrinkled stunt
MLO	Witches' broom
MLO	Yellow dwarf
Nematodes	
Ditylenchus angustus	Stem nematode
Heterodera oryzae	Rice cyst nematode
Tylenchorhynchus annulatus	Stunt nematode

Table 4. Exotic plant pathogens intercepted at CENARGEN.

Pathogen	Host	Source
	Fungi	
Clasterosporium sp.	Rice	Indonesia
Pyrenochaeta sp.	Soybean	Nigeria
Phyllosticta sp.	Sorghum	Mexico
	Viruses[a]	
Bunchy top	Banana	Philippines
Potyvirus	Sweet potato	USA (Louisiana)
Clover yellow mosaic	Clover	USA (Washington)
	Nematodes	
Ditylenchus dipsaci	Potato	Canada
Aphelenchoides besseyi	Panicum maximum	Ivory Coast
A. bicaudatus	Grape	France
Globodera rostochiensis	Potato	Netherlands

[a]Other unidentified viruses were found in soybean from Japan; mungbean from Taiwan; sweet potato from Nigeria; apples from USA; and plums from South Africa (Warwick et al 1983).

significant contribution to Brazilian agriculture made by the relatively recent quarantine work developed at CENARGEN. In rice, only the fungus *Clasterosporium* sp., which so far has not been shown to be a primary rice parasite, has been detected at CENARGEN — in material introduced from Indonesia in 1983.

When a pathogen is intercepted in highly important germplasm that is difficult to obtain, only the plants showing symptoms are destroyed. The apparently healthy ones are kept in the glasshouse for treatment by thermotherapy, chemotherapy, meristem-tip culture, or a combination.

- Thermotherapy may be administered by hot water, hot air, or another source of heat. The temperature is raised, killing the pest or pathogen without killing the plant or plant part. The margin between the two threshold temperatures is usually very narrow, so temperature control and pretesting must be accurate.
- Chemotherapy is based on the use of chemicals with selective activity against the pest or pathogen. The chemical must kill the organism without killing the host.
- The technique of culturing meristem tips harvested from infected plants can produce pathogen-free plants. Sometimes, depending on the host/pathogen involved, hot-air treatment is added to eradicate the organism.

DISCUSSION

Because of the great speed of modern transport and the accelerating international traffic in plant material, it has become necessary to consider plant quarantine as an international issue rather than as a matter affecting only the domestic affairs of individual countries. The need for an improved scheme of germplasm exchange must be reinforced, whereby the risks of moving insect pests and diseases can be

diminished by careful procedures in the exporting country, complemented by a thorough examination by the importer.

Although germplasm exchange implies the movement of small samples of each accession, two factors interact to increase the risk of insect pest and disease introduction: 1) usually a broad spectrum of varieties is exchanged, increasing the total amount of plant material involved; 2) as a result of greater variability, the risk of the emergence of new physiological races or strains of a pathogen is proportionally increased.

Because germplasm exchange operations in Brazil have increased substantially, greater quarantine interventions by CENARGEN have become necessary. However, quarantine activity is not always well understood and fully accepted, often because it is very time-consuming. Nevertheless, the time spent by any delay is well rewarded by the savings in time and money that would be lost in the control and eradication of a new plant pest or disease outbreak. Although CENARGEN's quarantine activity was started only a few years ago, its performance in intercepting some important diseases has proved worthwhile.

Although a significant amount of rice germplasm has been exchanged, no economically important rice pathogen has yet been intercepted. Nevertheless, it is advisable that stricter precautions be taken by both the exporters and the Brazilian quarantine staff to prevent diseases such as bacterial blight from entering the country.

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The rice plant quarantine system in China

LIU SONGLIN

In light of the stipulations in the Quarantine Regulations for the Import and Export of Animals and Plants, the introduction and exchange of rice germplasm resources in China are conducted in a unified way by the Institute of Crop Germplasm Resources under the Chinese Academy of Agricultural Sciences. The Chinese National Rice Research Institute organizes isolation trial planting for the germplasm introduced. The plant quarantine services at the point of entry carry out quarantine inspection. When the germplasm is proved to be free from important quarantine objects, dangerous diseases, and pests, it can be distributed and grown in other parts of China. This paper describes China's plant quarantine organization and regulations, and international cooperation in plant protection and plant quarantine, and makes suggestions for strengthening rice plant quarantine work.

Rice is the most important cereal crop in China. The area sown to rice amounted to 32.1 million ha in 1985, and its total output was 16.9 million t, amounting to 29.5% of the country's total agricultural area and 44.5% of the total cereal output.

New cropping systems, cultivation techniques, and varieties — especially hybrid rices — have caused the emergence of new diseases and pests. The rice borer was the primary object of control throughout the country in the 1950s and 1960s. Since the 1970s, other pests and diseases — planthoppers, leaf rollers, sheath blight, blast, bacterial blight, and stripe disease — have become more serious in some regions and have markedly affected the rice output; in addition, some of minor importance — for example, thrips and false smut — occur locally and may spread. The losses caused by pests and diseases amount to 15% of the total rice output, half of which could be salvaged through control.

China, one of the sources of the rice plant, has rich germplasm resources. To breed high-yielding, good-quality, resistant varieties, China has introduced large quantities of rice germplasm from abroad, especially from Southeast Asia. The Institute of Crop Germplasm Resources under the Chinese Academy of Agricultural Sciences (CAAS) and the Chinese National Rice Research Institute (CNRRI)

General Station of Plant Protection, Ministry of Agriculture, Animal Husbandry, and Fishery, China.

introduced 27,937 rice varieties in 1984. To prevent diseases and insect pests from being imported with the germplasm, the Chinese Government has paid particular attention to rice plant quarantine.

PLANT QUARANTINE ORGANIZATION AND REGULATIONS

The Ministry of Agriculture, Animal Husbandry, and Fishery (MAAHF) leads national plant quarantine efforts. The General Services of Animal and Plant Quarantine is responsible for import and export plant quarantine, and the General Station of Plant Protection of the MAAHF is in charge of domestic plant quarantine. Forty-two Animal and Plant Quarantine Services at seaports, airports, land frontiers, and border river ports, and 18 Plant Quarantine Stations in the capitals of provinces and autonomous regions handle international exchanges. Domestic plant quarantine is undertaken by plant and forest protection divisions of the agricultural and forestry departments of the provinces, autonomous regions, and municipalities (directly under the Central Government), prefectures (cities), and counties (banners) (Liu 1984).

These plant quarantine organizations currently employ about 7,000 personnel, many of whom have had training at universities and professional schools. They are able to identify and investigate plant diseases and insect pests, as well as perform plant quarantine treatments. Most of the quarantine organizations are equipped with the necessary references and instruments.

In addition, the MAAHF has set up the Plant Quarantine Experiment Service, which does research.

The State Council promulgated the Quarantine Regulations for the Import and Export of Animals and Plants in June 1982. The regulations state that quarantine inspection shall be applied to any plant or plant product entering or leaving the frontier of the country, and to any plant or plant product carried or checked by entering passengers and communication personnel, or in transit through China's territory, or entering China by mail (State Council of the People's Republic of China 1982).

In January 1983, the State Council issued the Plant Quarantine Regulations. To prevent any infectious plant disease or pest capable of causing injury or damage to plants from being carried into uncontaminated areas and to check the spread of severe infectious pests in the country, domestic plant quarantine inspection is applied to certain plants and their products.

Following these regulations, the MAAHF promulgated a series of implementing rules and provisions for plant quarantine.

These regulations, provisions, and rules provide the legal framework for China's plant quarantine system.

INTERNATIONAL COOPERATION

The Chinese Government has signed bilateral agreements for plant quarantine and the prevention and treatment of crop pests separately with Canada, the Democratic People's Republic of Korea, Hungary, the Netherlands, Romania, and Yugoslavia.

Chinese plant protection organizations have taken part in activities organized by the Asia-Pacific Region Plant Protection Committee and the Food and Agriculture Organization of the United Nations to promote technical cooperation in plant protection in the region and in other countries of the world (Morschel 1980).

RICE PLANT QUARANTINE

Principles

Following the stipulations of the Quarantine Regulations for the Import and Export of Animals and Plants (revised in January 1986), the following pests are important quarantine objects in China:

- rice water weevil *Lissorhoptrus oryzophilus* Kuschel
- rice stem nematode *Ditylenchus angustus* Butler
- granary weevil *Sitophilus granarius* (L.)
- khapra beetle *Trogoderma granarium* Everts

In addition, depending on the situation in exporting countries, the Chinese quarantine services may specify diseases, insect pests, and other organisms that may do harm to the country's rice production as quarantine requirements when China imports rice seeds.

Procedures

Import license. The regulations for introducing rice seeds and germplasm resources from foreign countries state that approval must be obtained from the General Station of Plant Protection of the MAAHF and affiliated plant quarantine services (State Council of the People's Republic of China 1982). The exchange of rice germplasm is conducted in a coordinated way by the Institute of Crop Germplasm Resources. The CNRRI organizes trial planting nurseries in isolation for introduced germplasm. The plant quarantine services carry out quarantine inspection. When the germplasm is proved to be free from important quarantine objects, dangerous diseases, and pests, it can be distributed and grown in China.

Requirements for countries exporting rice seeds. For any rice seeds imported into China, the exporting country must issue an official phytosanitary certificate proving them free from important quarantine objects and other dangerous diseases and pests (International Seed Testing Association 1976).

Inspection at entry.

- *Checking phytosanitary certificate.* When the imported seeds reach the point of entry, the quarantine services check the phytosanitary certificate issued by the exporting country to see if the seed lots are free from quarantine objects and other dangerous diseases and pests.
- *First inspection.* At the entry port, preliminary inspection is made with the naked eye or with a magnifying glass to look for pests, weed seeds, sclerotia, or evidence of pathogen activity.
- *Second inspection.* Another inspection is carried out in the laboratory. Soft X-ray equipment may be used to inspect for insect pests — eggs, larvae, pupae, or adults — hiding in the interior of seeds. A culture method that promotes the development of seedborne plant pathogens may be used.

Certain techniques may be used to inspect for seedborne parasitic nematodes. Serological and bacteriophage methods may be used to identify seedborne bacteria such as the pathogens causing bacterial blight and stripe.

- *Quarantine treatment.* The diseases, pests, and other living organisms found at the entry point are treated by fumigation with methyl bromide as in Table 1.

Postentry quarantine. Some important plant pathogens, notably viruses, are difficult to detect in the entry quarantine examination. Postentry quarantine must be conducted at a trial planting nursery (State Council of the People's Republic of China 1982). At present there are two methods of postentry quarantine. One is to establish state trial planting nurseries. The cities of Shanghai, Guangzhou, and Dalian have established such quarantine isolation nurseries. The second method is to make an isolation survey for one growing season at the quarantine trial area of the CNRRI in Hangzhou, at the CAAS in the Beijing area, or at the Provincial Academies of Agricultural Sciences. Those rice seeds exhibiting no dangerous diseases or pests can be distributed, grown, or maintained as germplasm resources. The whole process of trial planting must be supervised by the local plant quarantine service.

QUARANTINE RESEARCH

The scientific research organizations involved in quarantine are the Institute of Plant Quarantine under the MAAHF, the Plant Quarantine Department of the Institute of Crop Germplasm Resources under the CAAS, Beijing Agricultural University, Nanjing Agricultural University, and the Provincial Academy of Agricultural Sciences in Guangdong, Fujian Province. The experts engaged in rice disease and pest research also do research on quarantine methods and treatment techniques for rice seeds.

STRENGTHENING RICE PLANT QUARANTINE WORK

The Asia-Pacific region accounts for 91% of the world's rice output. To develop rice production and breed new varieties, we must prevent dangerous diseases and pests from propagating and spreading into new countries while simultaneously expanding the exchange of germplasm resources (Hewitt and Chiarappa 1977). International cooperation in rice quarantine needs to be strengthened. To this end, the following suggestions are made:

Table 1. Methyl bromide treatment for diseases and pests.

Concentration (g/m^3)	Time (h)	Temperature (°C)	Organisms treated
11.8	24	22	Granary weevil
12.0	24	25	Khapra beetle (larva)
18.0	24	17	Khapra beetle (pupa)

- Exchange information on rice plant quarantine, including the occurrence and dispersion of new diseases and pests in rice-producing countries; methods of quarantine, prevention, and control of diseases and pests; computer data storage; and provision of data to the countries concerned.
- Compile and publish a handbook on rice plant quarantine containing the quarantine regulations and laws, quarantine procedures, and treatment methods of countries and regions.
- Hold a symposium on rice seed health at regular intervals, attended by plant quarantine departments of rice-producing countries, to develop technological cooperation in rice seed health.

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Indian plant quarantine systems for rice

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Collaboration with the International Rice Research Institute (IRRI) has greatly benefited the Indian rice improvement program. Many high-yielding varieties from IRRI varieties and breeding lines have been released throughout the country. India in turn has also significantly enriched the IRRI germplasm collection to the benefit of plant breeders both at IRRI and in other countries. Various types of rice material (germplasm, advanced breeding lines, yield and observation nurseries, and pest and disease screening nurseries, etc.) are introduced into India. An effective plant quarantine system is necessary as a safeguard against the possible entry of new pest and disease problems. This paper describes the plant quarantine system in India, and the main features of the Quarantine Act. Quarantine procedures for detecting and intercepting exotic pests and diseases are described. Treatment schedules are discussed. Suggestions are made to facilitate the rapid clearance of rice material with adequate quarantine safeguards.

Mankind has gained substantially from the exchange of plant material all over the world. In the process we have learned to be careful about quarantine needs; it is necessary to have a viable plant quarantine and seed health system in each country to safeguard against the possible entry of new diseases and pests through seed and planting material. We must identify for every crop the risk factors that could lead to dangerous consequences, and we must understand the specific requirements of each importing country while exchanging germplasm.

India is known for the rich genetic diversity of many of its crop plants, including rice. Rice being the foremost staple food crop, rice breeding programs are under way at several institutes in different states, including the Central Rice Research Institute, Cuttack. Much genetic variability has been collected and utilized in the past, and efforts are presently aimed at collecting all available genetic variability in rice from the different regions of the country.

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India has also gained much through its collaboration with the International Rice Research Institute (IRRI), Philippines. IR8, introduced in 1965, is still cultivated in large areas, whereas more recent IRRI material has helped in developing at least 23 improved genotypes to suit various agroclimatic conditions

Table 1. IRRI varieties or breeding lines (other than IR8) used in India for developing high-yielding varieties.

Name/Designation	Cross combination	Year of release	Days to 50% flowering	Grain type[a]
	Andhra Pradesh			
IR20	IR262/TKM6	1971	90	MS
IR36	IR1561/IR1737//CR94-13	1981	80	LS
IRM13525 (IR62)		1986	80	LS
	Bihar			
Sita	IR8/IR12-178-2-3	1972	105	LS
Radha	IR20/IR5-114-3	1984	100-115	MS
	Karnataka			
IR20	IR262/TKM6	1970	105	MS
	Madhya Pradesh			
IR36	IR1561/IR1737//CR94-13	1981	85	LS
	Maharashtra			
Satya	BG79/IR400-28-4-5	1973	100	LB
Surya	BG79/IR400-28-4-5	1973	92	LB
IR36	IR1561/IR1737//CR94-13	1981	85	LS
	Manipur			
Punshi	Phouren/IR661-1-140-3-2	1981	105	LS
	Orissa			
IR36	IR1561/IR1737/CR94-13	1981	85	LS
	Pondicherry			
Bharathidasan	IR3403-267/Ptb. 33//IR36	1984	85-90	LS
	Punjab			
Palman 579	IR579	1972	73	LS
PR106	IR8/Peta 5//Bella Patna	1978	108	LS
	Tamil Nadu			
ASD15	IR26/IR22	1979	90	MS
IR34	IR833/IR1561//IR1737	1979	105	LS
Paiyur-1	IR1721-14/IR1330-3-3-2	1981	100-115	MS
IR50	IR2153-14-1-1-6-6-2/ IR28//IR2070-625-1	1982	85	LS
	Uttar Pradesh			
Prasad	IR579/IR747	1978	85-90	MS
Narendra 2	IR8/Tadukan//TKM6/ TNl///IR8/IR24	1982	85	LS
Govind	IR20/IR24	1982	75-77	LS
Pant Dhan-4	IR262/Remadja	1983	95-100	LS

[a] MS = medium slender, LS = long slender, LB = long bold.

(Table 1). India participates on a large scale in IRRI's International Rice Testing Program (IRTP). In 1985-86, more than 73,000 accessions in 396 seed lots were dispatched to 216 scientists through the National Bureau of Plant Genetic Resources (NBPGR) and the Directorate of Rice Research (DRR), Hyderabad (Table 2). Indian scientists have also contributed 2,059 breeding lines to IRTP. Also, various scientists have contributed 8,000-10,000 germplasm accessions — the Assam rice collection, the Raipur collections, and others — to the IRRI germplasm bank. Many Indian breeding lines like PTB21, PTB33, BJ1, DV85, TKM6, and W1263 have been extensively used by IRRI and national programs as sources of insect and disease resistance. Some of the breeding lines nominated from India for the IRTP nurseries have been released as varieties in other countries (Table 3).

IMPORT REGULATIONS

The import and export of seeds, plants, plant products, and planting material in India are regulated by the rules and regulations framed under the Destructive Insects and Pests Act (DIP Act) of 1914 (Directorate of Plant Protection, Quarantine and Storage, Ministry of Agriculture and Irrigation 1976), subsequently revised several times. Enforcement of the DIP Act is the task of the Plant Protection Adviser to the Government of India, Directorate of Plant Protection, Quarantine and Storage, Faridabad, under the Ministry of Agriculture. The main features of the Act are:

Table 2. IRRI-Indian Council of Agricultural Research collaborative germplasm exchange program.

Year	Location	Sets dispatched (no.)	IRTP nurseries (no.)	IRTP samples handled (no.)	Germplasm of breeding lines (no.)	Total accessions handled (no.)
1981	56	206	20	19,325	5,563	24,888
1982	31	212	24	24,036	3,189	27,225
1983	55	234	23	25,413	8,058	33,471
1984	50	355	23	26,413	8,413	34,826
1985	63	396	28	70,109	3,000	73,109
1986	67	272	29	21,194	2,548	23,742

Table 3. Entries originating from India that have been recommended for release in other countries and regions.

Variety	Countries and regions
Rasi	Nepal, West Africa
Jaya	Mali, Ghana, Ivory Coast, Vietnam
Vijaya	Upper Volta
IET2885	Mali
IET2935 (Durga)	Nepal
RP143-4	Tanzania
IET4094 (DR82)	Pakistan

- The Central Government may prohibit or regulate importation into India of any article or class of articles likely to be injurious to any crop.
- The Central Government may prohibit or regulate the export from a state or the interstate transport of any article or class of articles likely to be injurious to any crop.
- The Central Government may make rules prescribing the nature of documents to accompany any article or class of articles.
- The State Governments may make rules concerning the detention, inspection, disinfestation, or destruction of any article or class of articles likely to be injurious to any released variety.

Seed was not originally included in the DIP Act, but because of the changing situation and to meet current requirements, the Government of India passed the Plants, Fruits, and Seeds (Regulation of Imports into India) Order of 1984 (India Ministry of Agriculture, Department of Agriculture and Cooperation 1985), which came into effect in June 1985. The Order is comprehensive; 17 crops are included, and conditions for their import are stipulated. The main features of the Order are as follows:

- Seed has been brought under the purview of the DIP Act.
- No consignment can be imported into India without a valid import permit issued by the Plant Protection Adviser.
- No consignment can be imported into India without an official phytosanitary certificate issued by the official plant quarantine agency of the exporting country.
- Postentry isolation growing of specified crops at approved locations is stipulated.

PLANT QUARANTINE SYSTEM

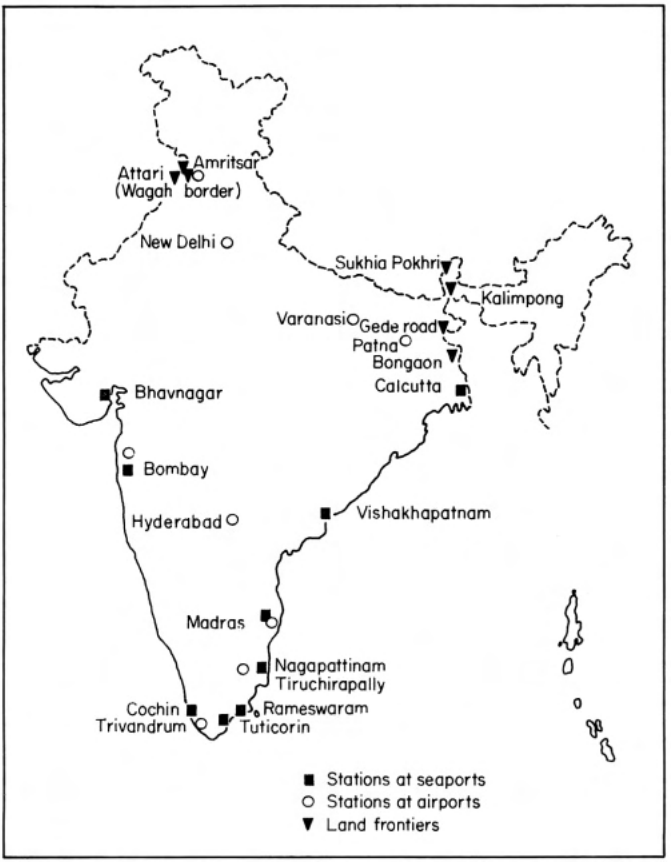
Authority to implement the quarantine rules and regulations framed under the DIP Act rests basically with the Directorate of Plant Protection, Quarantine, and Storage under the Ministry of Agriculture. This Directorate maintains plant quarantine and fumigation stations at 10 international airports, 9 seaports, and 7 land frontiers (Fig. 1).

The Government of India has also approved three other national institutions to act as official quarantine agencies, especially for material for research:

- the NBPGR, New Delhi, for agrihorticultural and silvicultural crops;
- the Forest Research Institute, Dehradun, for forestry plants; and
- the Botanical Survey of India, Calcutta, for other plants.

The Directorate of Plant Protection, Quarantine, and Storage handles bulk imports and exports of seed and planting material for commercial purposes.

The NBPGR has a separate Division of Plant Quarantine with experienced entomologists, nematologists, and plant pathologists, plus well-equipped laboratories, to discharge its plant quarantine responsibilities. A regional plant quarantine station was established in 1986 at Hyderabad, which at present caters to the quarantine requirements of the International Crops Research Institute for the

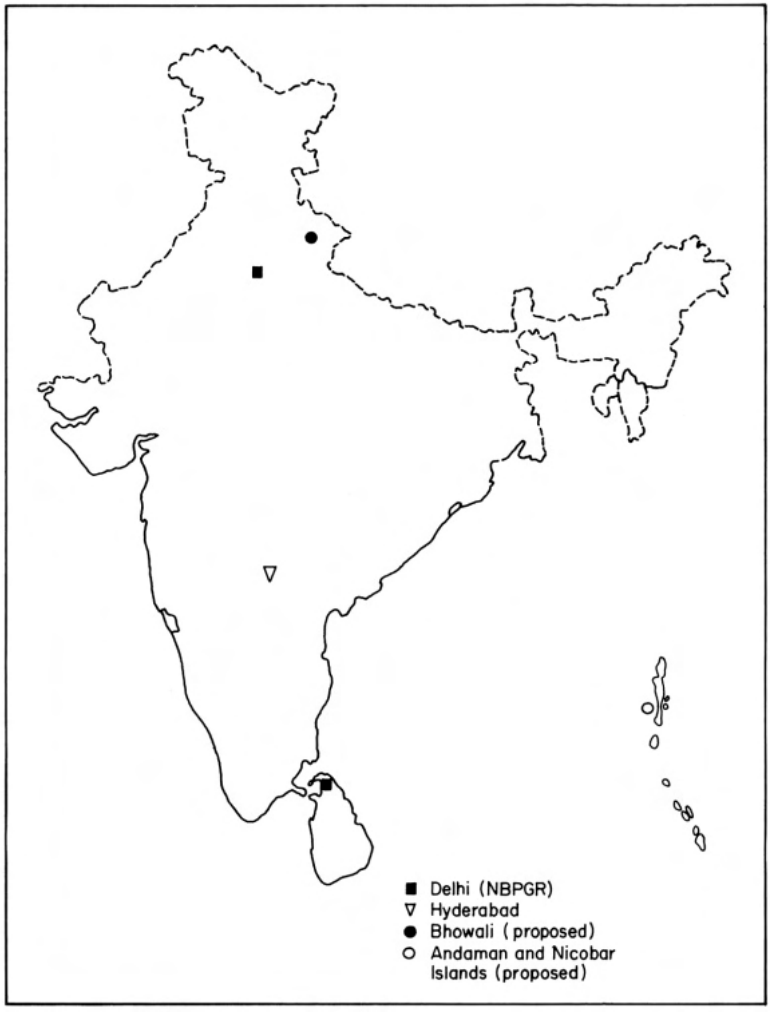


1. Plant quarantine stations in India.

Semi-Arid Tropics and the DRR, Hyderabad. In due course, it will take up quarantine responsibility for the whole of southern India. Until April 1986, postentry plant quarantine work was done at the DRR, Hyderabad, through its Plant Pathology Department. It is also proposed to set up an offshore plant quarantine station at Andamans and a regional quarantine station for temperate crops at Bhowali (Almora). Figure 2 portrays the NBPGR plant quarantine network, and Figure 3 is the flow chart of the agencies involved in the rice testing program.

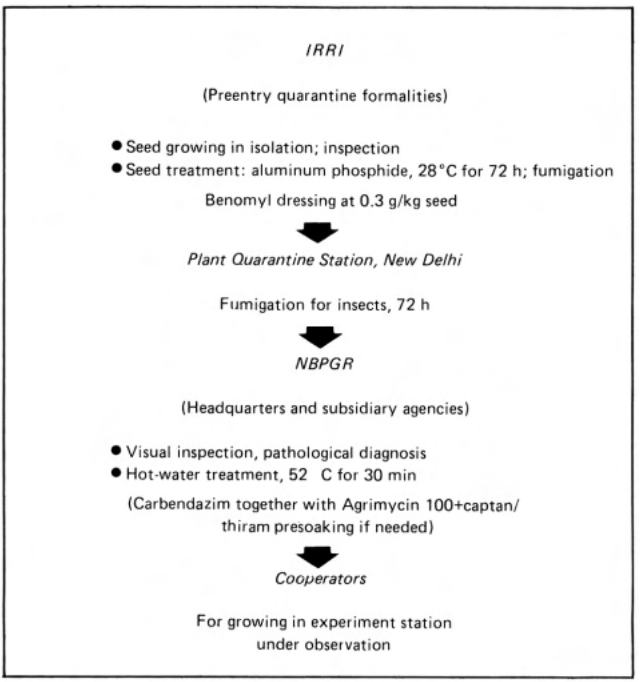
NBPGR PROCEDURES FOR RICE

The NBPGR has produced a brochure, *Guidelines for the exchange of seed/planting materials* (National Bureau of Plant Genetic Resources 1986), which has been circulated widely among Indian scientists. These guidelines are applicable for the exchange of rice seed as well.



2. The NBPGR plant quarantine network.

Consignments of rice for research are imported into India by either air freight or airmail. The Division of Germplasm Exchange is responsible for the release of consignments from the airlines, customs, and quarantine at the New Delhi Airport. Incoming consignments are normally subjected to preliminary inspection and fumigation by the plant quarantine and fumigation station at the airport before they are released to the NBPGR. Material coming by airmail is either sent directly to the NBPGR or routed through point of entry quarantine by the postal authorities. When a consignment is received by the Bureau in the Division of Germplasm Exchange, it is immediately sent unopened to the Division of Plant Quarantine, along with available information on an import quarantine proforma. The indentor



3. The NBPGR (ICAR)-IRRI seed exchange program.

as well as the sender are also informed about the receipt of the consignment and the approximate time required for clearance.

The NBPGR and the DRR actively cooperate with IRRI (as per the Indian Council of Agricultural Research-IRRI collaborative agreement) in IRTP trials in India. Through this program, rice researchers in the country request and receive rice germplasm, advanced breeding lines, and test entries of yield and observational nurseries. The best rice seed material generated elsewhere in the world and likely to be suitable to the different agro-ecosystems in India is thus promptly made available to the country's rice scientists. India is presently getting the most IRTP nurseries from IRRI. Conversely, the varieties and accessions developed in India have been made accessible to rice researchers of other countries. The DRR coordinates the rice research activities of IRRI in India; 216 scientists in the country received the following seed material from IRRI through the NBPGR:

- rice germplasm from the IRRI genebank;
- advanced breeding lines for specific situations;
- test entries of yield nurseries, observational nurseries, and insect, disease, and abiotic stress nurseries; and
- seed material for collaborative research programs on hybrid rice, bacterial blight, rice tungro virus, brown planthopper, cold tolerance, rapid generation advance, and early generation breeding lines for rainfed lowland and hill regions.

In the Plant Quarantine Division, the consignments are opened first in the common inspection laboratory, and all available information is examined and recorded. Individual packets are then studied for insect pests under the microscope as well as through soft X-ray machine. If any insect infestation is detected, the whole consignment is immediately fumigated. The samples are then examined simultaneously for nematodes and seedborne pathogens. Weed seeds, if any, are mechanically removed. For the detection of nematodes, a few grains from each sample are separately soaked for 24 h before they are teased out in water and examined under a stereomicroscope to detect internal infestation. For the detection of plant pathogens, dry seeds are first examined under the stereomicroscope for infected plant debris, false smut (*Ustilaginoidea virens*), bunt (*Tilletia barclayana*), and seed discoloration. Apparently diseased seeds are incubated on moist blotters for 1 wk at 20 ± 1 °C under alternating cycles of 12 h light and 12 h darkness. The incubated seeds are then examined under the stereomicroscope for associated pathogens and symptoms produced on young seedlings. A general hot-water treatment (52 °C for 30 min, air drying at 42 °C for 72-96 h) is also given to all rice seed material before it is dispatched to cooperators.

INTERCEPTIONS IN RICE

Plant quarantine has assumed greater importance in recent years as a result of increased emphasis on the utilization of genetic variability in breeding programs all over the world. A constant vigil is essential to prevent the introduction of new pathogens. As far as rice is concerned, India is at a disadvantage on the quarantine front for the following reasons:

- Rice, having originated in India, evolved along with a gamut of pests and pathogens, many of which are highly virulent and aggressive. Detecting epidemics resulting from chance introductions of new pathogens or pests into the country is very difficult.
- The geographical location of the country favors the transmigration of insects and diseases from the neighboring rice-growing countries of Bangladesh, Burma, Sri Lanka, Pakistan, Nepal, Bhutan, and China.
- Rice is grown under diverse agroecosystems, and interstate movement of pathogens and pests is rapid, which complicates the management of insects and diseases through quarantine.

During the last 10 yr, a number of insect pests, nematodes, and pathogens have been intercepted in imported rice seed (Table 4, 5). Most are already known to occur in India. The larger grain borer, which was not known to occur in India, was recently detected in wheat and maize seed received in the Quarantine Division for export from Almora, Uttar Pradesh (B.R. Verma and B. Lal, pers. comm.). It is not known, however, whether this pest is by now well established in India. White tip, false smut, bunt, and stackburn, which until recently were considered of minor economic importance, are now threatening to become diseases of major significance in many parts of India. Whether this is due to changes in the varietal pattern, to evolution, or to the introduction of more virulent forms is difficult to say.

Table 4. Interceptions of pathogens in rice.

Disease	Causal agent	Hosts	Sources
White tip	*Aphelenchoides besseyi*	*Digitaria smutsii, Guilielma gasipaes, Oryza glaberrima, O. sativa*	Philippines, USA, Brazil, Nigeria, Madagascar, Burma, Indonesia, UK, Australia, Costa Rica
Ufra	*Ditylenchus angustus*	*O. sativa*	Madagascar
Stackburn	*Alternaria padwickii*	*Gossypium* spp.	France
		O. sativa	Philippines, France
Brown spot	*Drechslera oryzae*	*Eleusine* spp.	U.K., Zambia
		O. sativa	Netherlands, Philippines, USA, Zambia
Bunt	*Tilletia barclayana*	*O. sativa*	Philippines
False smut	*Ustilaginoidea virens*	*O. sativa*	Philippines

Table 5. Interceptions of insect pests in rice.

Common name	Pest	Sources
Hymenopterous parasite	*Chaetopsila elegans*[a]	Vietnam
Flat bark beetle	*Laemophloeus* spp.	Brazil, Nigeria
Flat bark beetle	*L. minutus*	Brazil, Indonesia, Philippines
Cigarette beetle	*Lasioderma serricorne*	Philippines
Siamese grain beetle	*Lophocaterus pusillus*	Philippines
Sawtoothed grain beetle	*Oryzaephilus surinamensis*	Philippines
Larger grain borer	*Prostephanus truncatus*[b]	Philippines
Lesser grain borer	*Rhizopertha dominica*	Afghanistan, Burma, Sri Lanka, France, Indonesia, Philippines, Thailand, USA
Rice weevil	*Sitophilus oryzae*	Brazil, Burma, Sri Lanka, Ivory Coast, Philippines, Taiwan (China)
Angoumois grain moth	*Sitotroga cerealella*	Brazil, Sri Lanka, FAO (Italy), Guyana, Hungary, Vietnam, Philippines, Thailand, Taiwan (China), USSR
Red flour beetle	*Tribolium castaneum*	Philippines

[a] Parasite recovered along with *S. oryzae.* [b] Reported in one indigenous consignment of wheat and maize from Almorah, Uttar Pradesh (B.R. Verma and B. Lal, pers. comm.); establishment still not known.

While nematodes and most of the rice diseases are reported to occur in India, many insect pests of rice, some with a wide host range, are so far unknown there (Table 6). Of these, only *Sitophilus granarius* is listed in the DIP Act as a quarantine object, but there is need to guard against the introduction of other pests as well.

SEED TREATMENT OF RICE

As a general policy, all rice seed received for quarantine clearance at the NBPGR is subjected to hot-water treatment. The seed is first soaked in a solution of 250 ppm of streptocycline + 500 ppm of wettable ceresan for 8-10 h before it is put in hot water at 52-54 °C for 30 min. The treated seed is immediately dipped in cold water and then dried at 42 °C for 72-96 h. Random retesting has shown that this treatment is highly

Table 6. Rice pests not yet reported in India.

Common name	Scientific name	Major hosts	Material accompanied	Distribution
American sugarcane borer	*Diatraea saccharalis* (F.)	Sugarcane, rice	Straw, hay	Argentina, Brazil, Central and South America, Florida, Guyana, Surinam, Texas, West Indies
American rice stalk borer	*D. plejadellus* Zinck	Rice	Straw, hay	Georgia, Louisiana, Mexico
Neotropical corn borer	*Zeadiatraea lineolata* (Walk.)	Maize, rice, sorghum	Straw, hay	Bahamas, Colombia, Cuba, Ecuador, Guyana, Guatemala, Nicaragua, Surinam, Trinidad, Venezuela, Mexico, Texas
Yellow headed borer	*Diatraea centrella* (Mosch)	Sugarcane, maize, sorghum, rice	Straw, hay	Guyana, Surinam, Trinidad to Martinique, Venezuela
Tobacco moth	*Ephestia elutella* (Hbn.)	Tobacco, stored grain	Seeds	Temperate regions
Greater grain borer	*Prostephanus truncatus* (Horn)	Wheat, rice	Needs	Africa, Central America, Mexico, Tanzania
Seed corn maggot	*Hylemya cilicrura* (Rond.)	*Allium* spp., vegetables, corn	Soil clods, seeds	Alaska to South America, Bermuda, Britain, North Europe to Japan, South Africa
Granary weevil	*Sitophilus granarius* (L)	Stored grain, rice in field	Seeds	Temperate regions
Smaller strain grain weevil	*S. sasakii* (Takahashi)	Wheat, rice	Seeds	Japan
Maize weevil (large strain)	*S. zeamais* (Motschulsky)	Wheat, rice, maize	Seeds	Warm and tropical parts of the world
Confused flour beetle	*Tribolium confusum* J. du Val.	Flour mills	Seeds	Temperate climates

Table 7. Effect of postentry quarantine treatment on the fungal-nematode pest complex and seed viability.

Item	Postentry treatment[a] fumigation	Hot-water treatment
Insects (no.)[b]	0	0
Nematode white tip[c]	18	0
Pathogen[d]	*Acrocylindrium oryzae* (6)	0
	Fusarium moniliforme (11)	3
	Acrocylindrium nizer (14)	2
	Helminthosporium oryzae (4)	0
Germination (%)	76-92	69-87

[a]100 random samples collected from IRRI germplasm and rapid generation advance material, 1983-84, after plant quarantine station fumigation treatment at new Delhi. [b]Based on glasshouse observational plantings in steam-sterilized soil. [c]Based on blotter technique frequency. [d]Presoaking 8 h in carbendazim 1 g/liter + thiram 2.5 g/liter + streptomycin 1g/liter (0.15% streptomycin sulfate) followed by 52-54 °C hot-water treatment for 30 min, followed by air drying at 40-42 °C for 96 h.

effective in eradicating the seedborne inoculum of rice pathogens (Table 7). However, at present it is difficult to say whether the treatment is effective against bunt, as fresh bunt spores are difficult to germinate. There is need for more research on this aspect.

After quarantine clearance, the rice seed samples are sent back to the Division of Germplasn Exchange, where relevant data received with the seed material — source, varietal designations, special features of the material, name and address of the indentor, etc. — are recorded. Numbers are given to each sample before they are dispatched to the user scientist in the country by airmail or airfreight.

DOMESTIC QUARANTINE

Under the DIP Act, the Directorate of Plant Protection, Quarantine, and Storage is responsible for regulating the interstate movement of plants and plant material to prevent the spread of destructive insects and diseases. For this purpose, notifications are issued by the Central Government and are enforced in collaboration with the State Governments. At present, there are restrictions on the movement of potato from the Darjeeling District of West Bengal to any other part of India because of potato wart disease (*Synchytrium endobioticum*); movement of banana and any plant of genus *Musa* from Assam, Kerala, Orissa, West Bengal, and Tamil Nadu to any other state because of bunchy top disease, and from Maharashtra and Gujarat to any other state because of banana mosaic; and movement of potato from the Nilgiri and Kodai Canal areas to any other place because of golden nematode (*Globodera rostochiensis*).

The rice stem nematode (*Ditylenchus angustus*), which causes ufra, is restricted to some pockets in Assam and West Bengal. The movement of rice seed from these two states to other parts of the country needs the immediate attention of all concerned, since this nematode is known to cause serious losses and is also

seedborne, making internal quarantine efforts all the more relevant. In the case of rice diseases, the specific relevance of internal quarantine will arise, especially when knowledge of biotypes and the race spectra of insects and pathogens becomes more clear through the intensification of seed health research.

SOME SUGGESTIONS

The exchange of large quantities of seed material (70,000-80,000 accessions weighing 5-10 t) across national boundaries is a gigantic task. Scientists often view their seed requirements in isolation and scarcely appreciate the magnitude and problems of quarantine work involved. All concerned organizations and researchers should therefore consider these suggestions:

- The proper guidelines for exchange, circulated by the NBPGR, should be followed when requesting seed material. Because of the new DIP Order, seed for research purposes must be exchanged through proper organizations such as the NBPGR, since introduction directly by individuals is prohibited.
- Seed requests should be kept to a bare minimum. Often, seed requests are sent without much consideration. Some researchers even requisition seed material for the wrong environment (e.g., hill nurseries and drought nurseries requisitioned for irrigated areas). Such requests should be examined critically. IRRI could play a major role in this regard.
- Repeat requests for the same material should be avoided unless absolutely necessary.
- Proper feedback concerning the performance and utilization of exotic germplasm and breeding material is necessary for effective exchange among collaborating countries and institutions. Also, proper acknowledgment of concerned agencies assisting in the process is desirable.
- The material to be exchanged should have high germinability and be free from plant debris, soil, and weed seeds. Treatment with pesticides and fungicides should be avoided, because it hampers quarantine examination.
- IRRI and the NBPGR should develop effective collaboration on seed health research relating to detection techniques, salvaging methods, and quarantine examination before the dispatch of seed material.
- Exchange of information on seed health and quarantine among all concerned will help generate awareness. Information on the occurrence of pests and diseases in the seed crop meant for exchange will be of considerable benefit.
- There is a need to initiate research relating to internal quarantine while conducting multilocational trials in a country that differs considerably in agroclimatic conditions.
- Advance planning and dispatch of international trials and nurseries with sufficient notice to concerned quarantine organizations regarding the quantity and magnitude of anticipated exchanges will help in the timely processing of material. Problems are encountered when seed arrives just before the sowing season without allowing 4-6 wk for quarantine clearance and transportation to the importing country.

- A manual on seed health and quarantine aspects of rice should be published and circulated to all concerned.

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The plant quarantine system for rice in Nigeria

M. O. ALUKO

Massive rice importation by Nigeria and the West African Rice Development Association for research and distribution has been accompanied by the high risk of introducing dangerous foreign pests, diseases, and noxious weeds. The paper highlights the implications of such risks to the region and describes the legal provisions, regulations, and procedures of the Nigerian Plant Quarantine System that guard against the risks. Enforcement of the regulations concerning seed treatments, certifications, and additional declarations is related to the virulence, mode of transmission, and global distribution of bunt, bacterial blight, hoja blanca, rice dwarf virus, kernel smut, ufra, white tip nematode, and some virulent strains of rice blast and brown leaf spot, as well as the postentry quarantine processing of imported seeds to intercept them under quarantine laboratory and glasshouse conditions. Almost 30,000 rice varieties were imported for research purposes and processed from 1975 to 1982 without a single foreign pest or disease slipping through to set back the pace or negate the advances of the rice development program — a testimony to the contribution made by the Nigerian Plant Quarantine Service to rice development in West Africa.

Nigeria and West Africa as a whole are naturally endowed with a tremendous but not fully tapped potential for rice production. One of the main tasks of the various national research institutes and the West Africa Rice Development Association (WARDA) is to tap this potential by rice breeding and research to suit the requirements of the various ecological zones within the region that can support rice production. The various research programs depend highly on the availability of a large pool of improved rice germplasm, which is acquired through the introduction of rice material from all over the world — a process fraught with the risk of introducing dangerous pests, diseases, and noxious weeds. The Nigerian Plant Quarantine Service has the task of protecting the region.

In addition to the efforts of the Nigerian Government to develop a postentry Plant Quarantine Station at Ibadan, WARDA set up a Rice Quarantine Project in 1975 and incorporated it into its annual program of activities. To date, the

Region Plant Quarantine Station and Training Centre, Moor Plantation, Ibadan, Nigeria.

Association has financed the construction and equipping of eight glasshouse compartments at the Plant Quarantine Station at Ibadan for processing its imported rice material. There is thus only minimal delay, if any, in processing WARDA material passing through the postentry Quarantine Station.

This paper reviews the risks posed to West Africa by the introduction of improved rice germplasm from other parts of the world and elaborates on the system of quarantine in Nigeria and the role it has so far played in eliminating the risks during introduction and subsequent multiplication and distribution.

RISK POTENTIAL

The risk potential of any exotic pest or disease can best be assessed either in relation to the damage being caused by similar pathogens that have been introduced into the country or by assessing the losses it has caused in other parts of the world.

Although it is desirable to prevent or retard the introduction of foreign plant pests and diseases into uninfested countries or regions, the true importance of the Nigerian Quarantine System cannot be fully recognized because the service has been so efficient that no such pests and diseases have found their way into Nigeria. Perhaps a brief review of some destructive plant enemies that have been introduced and have become established in countries formerly free from them may serve to emphasize the risks inherent in their introduction and spread.

The spectacular damage done by maize rust caused by *Puccinia polysora* in Africa and the East typifies what a relatively unimportant pest can do in a new environment. This rust apparently never caused much loss in its native habitat in tropical America, but when it was found in Sierra Leone in 1949, the losses it had caused necessitated an expensive research and breeding program through the establishment of the West African Maize Research Unit (WAMRU), which has not yet succeeded in eradicating the disease. From Sierra Leone, the disease spread rapidly across Central Africa and after several years reached Kenya and Rhodesia; it finally crossed the Indian Ocean and appeared in Southeast Asia.

Coffee leaf rust is another classical example of the danger of introducing a disease into countries where it was previously unknown. The fungus appeared originally to have been confined to Ethiopia and Uganda. In 1869, it made its appearance in Ceylon, which at that time was the chief producer of coffee in the world. Within 10 yr, coffee production was cut in half by the disease, and in another 10 yr, the plantations were on their last legs. The coffee growers were ruined and many had to sell their estates, causing a major financial crisis on the island. Eventually, nearly all the coffee was pulled out, and tea took its place. The center of coffee production moved from the Old World to the New, to which the rust had not spread. With coffee no longer available within the British Empire, the British people changed from coffee drinkers to tea drinkers — all because of the introduction of a plant disease to a country in which it was not native.

More recent examples can be found in Nigeria in the discovery of cassava bacterial wilt caused by *Xanthomonas manihotis* and of the noxious weed *Chromolaena odorata* (= *Eupatorium odoratum*). In the Eastern Central States of Nigeria, cassava bacterial wilt was reported to have caused a loss of US$3.75 million

in 1972 and was on the brink of causing a nationwide famine, while the problem of *C. odorata* necessitated the National *Eupatorium* Eradication Program, which expended thousands of dollars without satisfactory result. For the past 5 yr, research on cassava by the International Institute of Tropical Agriculture (IITA) and the Nigerian National Root Crops Research Institute has concentrated on finding a solution to the problem of cassava bacterial blight, which has set back the pace of progress in cassava research and development for the tropics by several decades. This is in addition to the millions of dollars being spent annually by both international organizations and the Nigerian Government in combating this disease, which might have been prevented through quarantine from entering the region.

It is thus essential for Nigeria and West Africa to operate an effective plant quarantine system. It is still possible to prevent or at least retard the introduction of some of the world's most destructive rice pests and diseases at negligible cost in relation to the potential losses and the much larger costs of eradication programs.

RICE QUARANTINE REGULATIONS

To formulate the necessary plant quarantine regulations and processing procedures for rice, the most dangerous foreign pests and diseases not yet known to occur in West Africa were first determined (Table 1). These organisms constitute the real threat to the region and the chief concern of the plant quarantine services. Aluko (1976) described these organisms and the damage they cause.

The most serious threats are undoubtedly the virus and viruslike diseases of unknown etiology, most of which are fortunately not known to be seedborne. The importation of all vegetative material of rice other than seed is prohibited because of the threat of these diseases. Most insect pests and nematodes can be eliminated by plant treatment, while seed can be inspected for fungal and bacterial diseases in laboratories and glasshouses.

The regulations intended to prevent introduction of the diseases (Table 2) range from complete prohibition (for most vegetative material) to conditional entry and are usually specified on the import permit. Of course. the conditions for entry for each consignment vary according to the rice pests and diseases occurring in the country of origin, their virulence and mode of transmission, and the plant part that is required.

PLANT QUARANTINE PROCESSING OF IMPORTED RICE MATERIAL

Many expensive and sophisticated procedures are used in quarantine to detect and intercept foreign pests, diseases, and noxious weeds in imported rice material. These range from laboratory seed health testing (Aluko 1983; Kado and Hesket 1970; Kulshrestha et al 1976; Neergaard 1969, 1973, 1977; Neergaard and Saad 1962; Phatak 1974) to grow-on tests within closed quarantine glasshouses. Methods for eliminating infection and infestation range from plant treatments (vacuum fumigation, thermopeutic and chemopeutic treatments, etc.) to complete destruction of any given consignment. In general, the methods used at any given time depend on the type of disease suspected.

Table 1. World distribution of important rice diseases not yet recorded in West Africa (Commonwealth Mycological Institute 1976-86).

Disease organism	Distribution
Xanthomonas campestris pv. *oryzae* (bacterial blight)	Asia: India, China, Indonesia, Japan, Malaysia, Korea, Taiwan, Philippines, Thailand North America: USA
Rice dwarf virus	Asia: India, Japan, Philippines
Hoja blanca virus	Asia: Japan North America: Mexico, USA Central America: British Honduras, Costa Rica, Cuba, Dominican Republic, Guatemala, Panama, Salvador South America: Colombia, Surinam, Venezuela
Neovossia horrida (bunt disease)	Asia: Burma, China, India, Indonesia, Japan, Philippines, Vietnam
Tilletia barclayana (rice kernel smut)	Australasia and Oceania: Australia, Fiji Africa: Sierra Leone North America: USA, Mexico Asia: Burma, Cambodia, China, India, Indonesia, Japan, Korea, Malaysia, Pakistan, Philippines, Taiwan, Thailand, Vietnam Europe: Greece South America: Brazil, Guyana, Surinam, Venezuela Central America: Cuba, Nicaragua, Panama, Trinidad North America: USA, Mexico
Sclerospora oryzae	Africa: Eritrea, Ethiopia, South Africa Europe: Bulgaria, Italy, Austria, Poland, Yugoslavia Asia: Japan, Manchuria, India, Pakistan Australasia and Oceania: Australia, New Zealand North America: USA, Canada, Mexico
Xanthomonas campestris pv. *oryzicola*	Asia: Cambodia, China, India, Indonesia, Malaysia, Thailand, Philippines
Ditylenchus angustus (ufra)	Asia: Burma, India, Malaysia, Pakistan, Philippines
Virulent biotypes of *Pyricularia oryzae* (rice blast)	Europe: Italy Asia: India, Japan, Pakistan North America: USA

For the purpose of setting up quarantine methods for processing rice in Nigeria, the important rice diseases are classified into three categories as shown in Table 3. The classification itself is based on 1) the local situation in West Africa in terms of the presence or absence of the pathogens, and 2) the local epidemiological conditions pertaining to these pathogens. Furthermore, consideration is given to local and international distribution of the pathogenic races (pathotypes) — those variations that cannot be distinguished in appearance but vary greatly in ability to attack different varieties of the same crop. Each race must therefore be considered a separate pathogen from the plant quarantine point of view.

Category A contains rice pathogens that justify strict quarantine measures. Such pathogens are not present in any nation in West Africa and would be

Table 2. Nigerian regulations for rice importation.

Plant parts	Countries to which restrictions apply	Entry conditions	Reasons and requirements
All parts, except seed for propagation and milled or polished rice	All countries	Prohibited	Exclusion of dangerous pests and virus pathogens of rice
Seed for propagation (rough rice)	All countries except Chad, Benin, Ghana, Guinea, Liberia, Mali, Niger, Burkina Faso	Postentry quarantine	Exclusion of black ring *(Ephelis oryzae),* smut *(Tilletia barclayana),* downy mildew *(Sclerospora oryzae),* bacterial blight *(Xanthomonas campestris* pv. *oryzae),* and ufra *(Ditylenchus angustus)*
Seed for propagation	Chad, Benin, Ghana, Guinea, Liberia, Mali, Niger, Burkina Faso	Permit	Phytosanitary certificate, plant treatment
Milled, polished, or parboiled seed for consumption	All countries	Unrestricted	None

Table 3. Plant quarantine classification of rice pests and diseases in Nigeria.

Category A	Category B	Category C
Xanthomonas campestris pv. *oryzae* (bacterial blight)	*Aphelenchoides besseyi* (white tip)	*Trichoconis padwickii* (seedling blight, etc.)
Hoja blanca virus	*Pyricularia oryzae* (rice blast, neck rot)	*Trematosphaerella oryzae* (white disease)
Tungro virus	*Drechslera oryzae* (seedling blight, leaf spot, etc)	*Cercospora oryzae* (narrow brown leaf spot)
Yellow dwarf virus	*Entyloma oryzae*	*Fusarium graminearum* (head blight, node rot, etc.)
Grassy stunt virus	*Tilletia barclayana* (kernel smut)	*Sclerotium oryzae* (stem rot)
Ditylenchus angustus (ufra)		*Ustilaginoideavirens* (false smut or green smut)
Neovossia horrida (bunt)		*Fusarium moniliforme* (foot rot)
Sclerospora oryzae (downy mildew)		*Rhizoctonia solani* (sheath rot, sheath spot)
Xanthomonas translucens (bacterial leaf streak)		*Colletotrichum* sp.
Ephelis oryzae (black ring disease)		*Phoma* sp.
		Anguina sp.

dangerous to the rice crop because of their harmful effects and their potential to spread.

Category B denotes quarantine objects that are of restricted local distribution in Nigeria or in some other West African nation and against which quarantine provisions can be adequately covered by field inspection or standard laboratory methods of seed health inspection and treatment. A representative sample of the seed consignment can be health tested to determine the need for an effective seed treatment.

Category C denotes internationally widespread seedborne rice disease organisms that are of importance to the planting value of the seed. In such cases, seed lots can still be health tested, and tolerance levels above zero may be accepted depending on the certification standards required.

Bacterial diseases

Bacterial blight caused by *Xanthomonas campestris* pv. *oryzae* (Uyeda and Ishiyama) Dowson is the most dangerous bacterial disease of rice. It causes considerable damage to the foliage of the rice plant, but its importance to rice production in tropical countries such as India, Thailand, the Philippines, and Indonesia was recognized only recently (Ou 1965).

Bacterial pathogens of rice are not at present easily diagnosed with certainty by laboratory seed health testing methods in quarantine, and hence all seed lots found with bacterial contamination are planted out in controlled environment glasshouses, watched throughout a growth cycle, and tested for the presence of the diseases.

Fungal diseases

The majority of the important fungal diseases of rice already occur in West Africa, but even among them, a few like rice blast (*Pyricularia oryzae*) and brown leaf spot (*Helminthosporium oryzae)* still need to be guarded against because they are known to exist in many physiological races. In the USA, 10 different virulent races of *P. oryzae* are known to occur (Atkins 1962, Laterell et al 1960), and more than 500 races are known in other parts of the world, whereas only a few mild races have been discovered in West Africa. From the plant quarantine point of view, all the races not yet recorded within the region are regarded as distinct pathogens against whose importation strict quarantine measures are taken.

Kernel smut of rice caused by *Tilletia barclayana* is not common in West Africa. The cereal smuts in general, of which many occur worldwide, are of great quarantine concern, whether they are present or not, because each exists as a hundred or more different races. Another fungal disease not yet recorded in West Africa is bunt caused by *Neovossia horrida,* recognized by the presence of blackened masses of spores on the surface of affected grain.

In quarantine, these fungal pathogens as well as many others are usually detected by laboratory seed health testing methods. Inter-African Phytosanitary Council-coordinated legislation does not deal with them specifically, but prescribes organomercurial seed treatment. Such treatment is far from being 100% effective, although it substantially reduces the risk of importing new physiological races. Infected seed lots are not admitted without full consideration of possible risks. In

consequence, the Plant Quarantine Service has determined acceptable levels of infection as shown in Table 4.

Diseases caused by nematodes

The importation of two seed-transmitted nematode-caused diseases of rice is strictly avoided by quarantine. These are white tip caused by *Aphelenchoides besseyi* and ufra disease caused by *Ditylenchus angustus.* In quarantine, both are usually detected by laboratory seed health testing methods and effectively controlled by hot-water treatment at temperatures between 55 and 60 °C for 15 min.

Virus diseases

West Africa has remained free from almost all the rice virus diseases (Adair and Ingram 1957). Detailed descriptions for their diagnosis and a full account of their alternate hosts have been given by Aluko (1976).

In general, there is very little evidence that rice virus diseases are seedborne, but the possibility of their transmission by alternate host plants poses a serious risk from the quarantine point of view. The importation of such host plants (Table 5) is therefore restricted, while that of rice vegetative material other than seed is strictly prohibited.

RESULTS AND CONCLUSION

The results of postentry quarantine processing of rice seed in Nigeria from 1975 to 1982 are shown in Tables 6 and 7. For the 8-yr period, a total of 29,888 rice varieties were processed: 26,929 varieties processed directly after importation and 2,959 varieties processed by WARDA for redistribution within West Africa. Eleven dangerous pests and diseases were intercepted. some of them many times over, on seed lots imported at different times and from different countries. Notable among the pests and diseases of quarantine importance that were constantly intercepted are

Table 4. Acceptable levels of seedborne infection of rice in Nigeria.[a]

Zero (0%) tolerance	Above-zero tolerance	
	Pathogen	Tolerable level of infection (%)
Xanthomonas campestris pv. *oryzae*	*Pyricularia oryzae*	2
Tilletia barclayana	*Drechslera (Helminthosporium) oryzae*	10
	Cercospora oryzae	2
Ephelis oryzae	*Sclerotium oryzae*	2
Sclerospora oryzae	*Fusarium moniliforme*	10
Ditylenchus angustus	*Colletotrichum* sp.	2
Aphelencoides besseyi	*Phoma* sp.	2

[a]Figures from personal data based on experimental results of seed health testing followed by growing-on tests in the greenhouse.

Table 5. Alternate hosts for virus diseases of rice.

Virus disease	Insect vectors	Alternate hosts
Tungro	*Nephotettix impicticeps* (Ishihara)	*Elevsine indica* (goose grass) *Echinochloa colonum* (jungle rice) *E. crus-galli* (barnyard grass)
Grassy stunt	*Nilaparvata lugens*	–
Orange leaf	*Inazuma dorsalis* (Motsch)	–
Yellow dwarf	*Nephotettix impicticeps* (Ishihara) and *Nephotettix cincticeps*	*Alopecurus aequalis* (shortawn foxtail) *Glyceria acutiflora* (manna grass) *Oryzae cubensis*

Table 6. Results of quarantine processing of imported rice seed in Nigeria, January 1975 to December 1982.

Year	Entries and varieties processed (no.)	Pests and diseases intercepted
1975	3,713	*Drechslera oryzae, Fusarium moniliforme, Tilletia barclayana, Xanthomonas campestris* pv. *oryzae*
1976	2,649	*D. oryzae, F. moniliforme, T. barclayana, Aphelenchoides besseyi, Phoma glumarum, X. campestris* pv. *oryzae*
1977	1,454	*Cercospora oryzae, D. oryzae, F. moniliforme, Pyricularia oryzae, A. besseyi, X. campestris* pv. *oryzae*
1978	5,385	*D. oryzaq F. moniliforme, Pyriculuria oryzae, T. barclayana, A. besseyi, X. campestris* pv. *oryzae*
1979	4,536	*Colletotrichum dermatium, D. oryzae, F. moniliforme, Pyricularia oryzae, T. barclayana, X. campestris* pv. *oryzae*
1980	3,760	*D. oryzae, F. moniliforme, X. campestris* pv. *oryzae*
1981	2,475	*D. oryzae, F. moniliforme, X. campestris* pv. *oryzae*
1982	2,957	*D. oryzae, F. moniliforme, X. campestris* pv. *oryzae*
Total	26,929	

Table 7. Results of quarantine processing of rice seed for redistribution by WARDA, 1975-81.

Year	Varieties processed (no.)	Pests and diseases intercepted
1976	7	*Drechslera oryzae, Fusarium moniliforme, F. graminearum, Trichoconis padwickii, Aphelenchoides besseyi, Phoma glumarum*
1977	34	*D. oryzae, F. moniliforme, T. padwickii, A. besseyi*
1980	16	*D, oryzae, F. moniliforme, T. padwickii*
1981	2902	*D. oryzae, F. moniliforme, T. padwickii*
Total	2959	

bacterial blight (*X. campestris* pv. *oryzae*), the nematodes *A. besseyi* and *D. angustus,* and other diseases of economic importance like *Phoma glumarum, Colletotrichum dematium, Drechslera oryzae,* and *Pyricularia oryzae.* If not for the interception, treatment, or destruction of infected material, some of these dangerous pests and diseases would have by now become established in the region, which would divert the attention of the research institutes from development programs to finding ways and means of eradicating them at considerable cost, which the West African countries can ill afford. The fact that not a single exotic foreign pest or disease has yet become established in Nigeria constitutes testimony to the effectiveness of its plant quarantine system.

Joint efforts of plant quarantine systems and adherence to plant quarantine requirements are the best ways of achieving effective protection at the introduction stage, which, when blended with crop improvement and control activities within rice-growing countries, will continue to confer on rice development efforts an internationally respected sanitary warrant expected of any progressive agricultural economy.

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Rice pathogens of quarantine importance

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The international movement of rice germplasm has increased with the increase in rice improvement activities. Seedborne pathogens of rice not only cause deterioration in seed health but also spread diseases. Plant quarantine provides the means to control the dissemination of plant pathogens. Plant quarantine should be based on sound biological principles and well-established methods. The diseases caused by more than 100 rice pathogens — bacteria, fungi, nematodes, viruses, and mycoplasmalike organisms — range from very destructive to those producing minimal damage, and many are distributed worldwide. It is important to survey disease occurrences on a country, regional, and continental basis, not only to ensure good disease management programs but also to verify if there are any new introductions through seed. The roles of seedborne pathogens in seed health, disease management, and epidemics need critical assessment. Detection methods, especially for bacterial pathogens, are not well developed.

The success of modern rice improvement and production is partly attributable to extensive international germplasm exchange and utilization. The volume of the exchange will surely increase as the attention of varietal improvement is shifted from favorable to less favorable environments. Rice is propagated by seed, and many factors, both biotic and abiotic, contribute to seed health and seed purity, principally the effect of pathogens. Like any plant organ, rice seed is attacked by many pathogens. The infected seed not only deteriorates in health but also spreads the pathogen it carries. A seed may transmit a pathogen with which it is infected or infested.

Many measures are applied to control seed infection, including fungicides, hot-water treatments, sorting, field crop inspection, and routine seed health testing to improve or to certify seed health status. The efficiency of the measures and the role of seed pathology in treatment were reviewed by McGee (1981). The movement of seed from one locality to another so that the organisms it carries, especially those that can cause devastating effects on crop production and those that are absent from

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the destination, is the major concern of plant quarantine. Plant quarantine provides the means to control the dissemination of plant pathogens and to assure that only healthy, quality seeds are transported. Certain premises are fundamental to plant quarantine. One of them is that the measures should be based on sound biological principles (Mathys and Baker 1980). If not practiced properly, plant quarantine regulations could hinder the exchange of germplasm and limit the progress of crop improvement and production.

In this paper we review the state of our knowledge of rice seed pathology and identify areas where research is needed to implement sound plant quarantine measures for rice seed exchange and transport.

DISTRIBUTION AND DAMAGE

Rice is the host for 12 bacterial, 58 fungal, and 17 viral and mycoplasmalike pathogens (Ou 1985), and more than 30 nematode species. They cause disease on all parts of the plant, including the seed. The diseases they cause range from very destructive to those inflicting minimal damage. The infection may be systemic or local. Distribution of many of the pathogens is worldwide, especially those causing foliar diseases and stem, root, or leaf sheath problems, such as *Pyricularia oryzae, Helminthosporium oryzae, Gerlachia oryzae, Rhizoctonia solani,* and *Sclerotium oryzae.* There are others, however, with regional distribution. Most of the rice viral pathogens have a narrow geographical distribution. Rice tungro, ragged stunt, and grassy stunt, perhaps the most important rice virus diseases in tropical Asia, are not found outside Asia. The bacterial diseases of rice, especially bacterial blight and bacterial leaf streak, were known to occur only in Asia until the 1970s, when they were first reported in other continents (Ou 1985).

Plant pathogens are crafty enemies. In the past 20 yr in Asia, disease spectra and intensities have changed whenever agriculture has started moving toward higher productivity. With the change of rice cultivars from traditional to modern, and the change in cropping intensity from low to high, some diseases that were formerly less important have emerged, others have vanished, and new ones have appeared. It is important to keep a record of disease occurrences on country, regional, and continental bases, be they of major or minor importance. Proper disease surveys and monitoring are helpful not only to ensure good disease management programs but also to verify if there are any new introductions through seed importation.

PATHOGEN GROUPS

For many of the following rice pathogens that are of plant quarantine concern, seedborne status is uncertain and the current method of detection is inadequate.

Viruses

Ou (1985) listed 17 viral and mycoplasmalike agents causing damage in rice (Table 1). All of them except rice necrosis mosaic virus (RNMV) are transmitted by insect vectors. None of the insectborne viruses or mycoplasmalike organisms are

Table 1. Virus and mycoplasmalike diseases of rice (Ou 1985).

Disease	Mode of transmission
Dwarf	*Nephotettix cincticeps, N. nigropictus,* and *Recilia (Inazuma) dorsalis*
Stripe	*Laodelphax (Delphacodes) striatellus, Unkanodes sapporonus,* and *Ribautodelphax albifascia*
Yellow dwarf	*Nephotettix virescens, N. cincticeps,* and *N. nigropictus*
Black-streak dwarf	*Laodelphax (Delphacodes) striatellus, Unkanodes sapporonus,* and *Ribautodelphax albifascia*
Hoja blanca	*Sogatodes (Sogata) oryzicola* and *S. cubanus*
Transitory yellowing	*Nephotettix nigropictus, N. cincticeps,* and *N. virescens*
Tungro, penyakit merah, yellow-orange leaf mentel	*Nephotettix virescens, N. nigropictus, N.* spp., and *Recilia (Inazuma) dorsalis*
Waika	*Nephotettix cincticeps, N. virescens, N. nigropictus,* and *N. malayanus*
Bunchy stunt	*Nephotettix cincticeps* and *N. virescens*
Gall dwarf	*Nephotettix nigropictus*
Grassy stunt	*Nilaparvata lugens*
Ragged stunt	*Nilaparvata lugens*
Wilted stunt	*Nilaparvata lugens*
Orange leaf	*Recilia (Inazuma) dorsalis*
Yellow mottle	*Sesselia pusilla,* other beetles, and mechanical transmission
Giallume	*Rhopalosiphum padi*
Chlorotic streak	*Brevennia rehi (Heterococcus rehi, Ripersia, oryzae)*
Mosaic	Mechanical transmission
Necrosis mosaic	Soil transmission
Wrinkled stunt and witches' broom	Seed transmission
Crinkle	Soil transmission

known to be transmitted through rice seed. Wrinkled stunt and witches' broom were reported by Ou (1985) to be seed-transmitted.

RNMV is soilborne and probably transmitted by a soil fungus, *Polymyxa graminis* (Inouye and Fujii 1977). Fujikawa et al (1971, 1972) reported that 2.6-5.3% of seed from RNMV-transmitted rice plants carried the virus; but there was no seed transmission in about 16,000 rice seedlings (Inouye and Fujii 1977). Seed transmission of RNMV has not been confirmed. A virus disease similar to RNMV has been reported in India (Ghosh 1980), but its seed transmission is so far not known. Although transmission through seed is unlikely, RNMV can spread through movements of seed lots containing residual soil and root fragments.

Bacteria

The major bacterial diseases of rice are listed in Table 2. Seed transmission of all 12 bacterial pathogens appears to be possible. The status of *Xanthomonas campestris* pv. *oryzae* (Xco), the bacterial blight pathogen, remains uncertain. When the disease was reported in other continents, it was assumed to result from importation of seed from Asia, yet conclusive evidence is lacking. Singh and Rao (1975) used a paper

Table 2. Major bacterial disease of rice (Ou 1985).

Organism	Disease
Xanthomonas campestris pv. *oryzae (X. oryzae)*	Bacterial blight
Xanthomonas campestris pv. *oryzicola (X. translucens* f. sp. *oryzicola)*	Bacterial leaf streak
Pseudomonas syringae pv. *panici (P. panici)*	Bacterial stripe
Pseudomonas syringae pv. *syringae (P. oryzicola)*	Bacterial sheath rot
Erwinia carotovora ssp. *carotovora*	
Pseudomonas fuscovaginae	
Erwinia chrysanthemi	Bacterial foot rot
Various bacteria	Black rot and other bacterial disease of rice grain

towel technique to detect 30% seed transmission of Xco from seed harvested from diseased plants. Xco was directly isolated from artificially infected seed with an antibiotic-resistant mutant (Hsieh et al 1974). Ou (1985) showed that Xco declined rapidly from artificially infected seed stored at high temperature. The information merely suggests that Xco is potentially transmitted by seed. Recently we applied a method modified from Fang et al (1982) to isolate Xco phage from seed. The results indicated that the seed may carry Xco when rice plants with a disease severity score of 7 in the field are stored for 2 wk at room temperature. Seed from plants with a disease score of 3 or less showed no indication of harboring Xco (N. Unnamalai, Centre for Advanced Studies in Botany, University of Madras, pers. comm.). All this suggests that rice seed may transmit Xco if the seed was obtained from a severely diseased field. However, rice seed also carries a large number of yellow colony-forming bacteria (International Rice Research Institute 1986) that may interfere with the direct isolation and perhaps with the survival of Xco in or on seed. There is no single reliable and efficient method for routine seed testing for pathogenic bacteria (Schaad 1982).

Other bacterial pathogens except the pseudomonads, especially pathogenic fluorescent pseudomonads of rice, may present similar dilemmas (Goto et al 1988).

Fungi

There are 56 fungal pathogens causing diseases affecting the leaves, leaf sheaths, stems, roots, and grains of rice (Table 3). Of these pathogens, 33 species cause distinct diseases. The rest, which may not cause any symptoms, occur on plant parts and seed. The majority of these pathogens are reported to be seedborne (Richardson 1979,1981) (Table 4). Seedborne pathogens causing diseases of rice stems and leaves include *Pyricularia oryzae* (rice blast), *Drechslera oryzae* (brown spot), *Cercospora janseana* (narrow brown leafspot), *Alternaria padwickii* (stackburn), *G. oryzae* (leaf scald), *Magnaporthe salvinii* (stem rot), *Fusarium moniliforme* (bakanae), and *Sarocladium oryzae* (sheath rot).

Another group of pathogens causing grain diseases includes *Ustilaginoidea virens* (false smut), *Tilletia barclayana* (kernel smut), *Curvularia* spp. (black kernel),

Table 3. Fungal pathogens and diseases they cause in rice (Ou 1985).

Pathogen	Disease
Wide distribution	
Pyricularia oryzae Cav.	Rice blast
Cochliobolus miyabeanus (Ito & Kuribay.) Drechsl. Dastur *(Drechslera oryzae)* Subramanian & Jain	Brown spot
Sphaerulina oryzina Hara *(Cercospora janseana)* (Racib.) O. Const.	Narrow brown leaf spot
Alternaria padwickii Ganguly	Stackburn
Monographella albescens (Thumen) (Parkinson, Sivanesan & Booth *(Gerlachia oryzae)* (Hashioka & Yokogi) W. Gams	Leaf scald
Magnaporthe salvinii (Catt.) Krause & Webster *(Nakataea sigmoidea)* (Cav.) Hara *(Helminthosporium sigmoideum* var. *irregulare* Cralley & Tullis)	Stem rot
Gibberella fujikuroi (Sawada) Wollenw. *(Fusarium moniliforme)* Sheld.	Bakanae and foot rot
Entyloma oryzae H & P. Sydow	Leaf smut
Thanatephorus cucumeris (Frank) Donk *(Rhizoctonia solani)* Kuhn	Sheath blight
Sarocladium oryzae (Sacc.) Gams & Hawksw. *(Sarocladium attenuatum)*	Sheath rot
Ustilaginoidea virens (Cke) Tak.	False smut
Tilletia barclayana (Bref.) Sacc. & Syd.	Kernel smut
Curvularia spp.	Black kernel
Nigrospora spp.	Minute leaf and spot
Phoma sorghina (Sacc.) Boerema, Dorenb. & v. Kest.	Glume blight
Gibberella zeae (Schw.) Petch. *(Fusarium graminearum)* Schwabe	Scab
Sclerotium rolfsii Sacc.	Seedling blight
Mycovellosiella oryzae (Deighton & Shaw) Deighton	White leaf streak
Less distributed	
Drechslera gigantea (Heald & Wolf) Ito	Eye spot
Phomopsis oryzae-sativae Catt.	Collar rot
Sclerophthora (Sclerospora) macrospora (Sacc.) Thirum. Shaw & Naras	Downy mildew
Balansia oryzae-sativae Hashioka	Udbatta disease
Septoria spp.	Speckled bloth
Epicoccum purpurascens Ehrenberg & Schlecht.	Redblotch of grains
Myrothecium verrucaria (Alb. & Schw.) Ditm. & Fr.	Myrothecium blotch
Pyrenochaeta oryzae Shirai & Miyake	Sheath blotch
Gaeumannomyces graminis var. *graminis* (Sacc.) Arx & Olivier	Crown sheath rot
Cylindrocladium scopairum Morgan	Sheath net-blotch
Rhizoctonia oryzae Ryker & Gooch	Sheath spot
R. oryzae-sativae (Saw) Mordue	Other diseases of leaf sheath
Sclerotium oryzicola Nakata & Kawamura	Other diseases of leaf sheath
S. fumigatum Nakata & Hara	Other diseases of leaf sheath
S. hydrophilum Sacc.	Other diseases of leaf sheath
Dictyuchus spp.	Seedling damping off

Continued on next page

Table 3 continued

Pathogen	Disease
Pythium spp.	Seedling damping off
Achlya spp.	Seedling damping off
Phytophthora spp.	Seedling damping off
Puccinia graminis f. sp. *oryzae* Fragoso	Rust
Uromyces coronatus Yosh.	Rust
Mycosphaerella spp.	Other diseases on foliage and glumes
Sphaerulina spp.	Other diseases on foliage and glumes
Trematosphaerella spp.	Other diseases on foliage and glumes
Metasphaeria spp.	Other diseases on foliage and glumes
Melanomma	Other diseases on foliage and glumes
Leptosphaeria spp.	Other diseases on foliage and glumes
Sphaeropsis spp.	Other diseases on foliage and glumes
Coniothyrium spp.	Other diseases on foliage and glumes
Diplodia spp.	Other diseases on foliage and glumes
Phaesoptoria spp.	Other diseases on foliage and glumes
Oospora spp.	Other diseases on foliage and glumes
Cladosporium spp.	Other diseases on foliage and glumes
Helminthosporium spp.	Other diseases on foliage and glumes
Helicoceras spp.	Other diseases on foliage and glumes
Monascus purpureus Went	Grain discoloration
Wolkia decolorans (Van der Wolk) Ramsbottom	Grain discoloration
Penicillium puberulum Bain.	Grain discoloration

Nigrospora spp. (minute leaf and grain spot), *Phoma sorghina* (glume blight), and *Fusarium graminearum* (scab).

Rice seedlings are also attacked by a few fungi in genera *Dictyuchus, Pythium, Achlya,* and *Phytophthora* that cause seedling damping off. *Sclerotium rolfsii* causes seedling blight.

Routine seed health testing for seedborne fungi in the Seed Health Unit of the International Rice Research Institute detected 20 species from 4,744 seed lots in 1984-86 tested by the standard blotter technique (Table 5). Seedborne fungi with high incidence included grain-infecting groups like *Trichoconiella padwickii, Curvularia* spp., *Phoma* spp., *N. oryzae, Tilletia barclayana,* and *Phyllosticta* glumarum. Of the major rice pathogens, *Sarocladium oryzae* was detected in the majority of the seed lots tested, followed by *G. oryzae, D. oryzae, F. moniliforme, Cercospora oryzae, Nakataea sigmoidea,* and *Pyricularia oryzae.*

Table 4. Fungal species reported seedborne (Richardson 1979, 1981).

Alternaria longissima Deighton & MacGarvie
A. padwickii (Ganguly) M. B. Ellis
Ascochyta oryzae Catt.
Balansia oryzae (Syd.) Narasimham & Thirumalachar
Brachysporium spp.
Cercospora oryzae Miyake
Cochliobolus miyabeanus (Ito & Kuribay.) Drechsl. & Dastur
Curvularia spp.
Diplodia oryzae Miyake
Drechslera australiense (Bugn.) Subramanian, Jain & M. B. Ellis
D. halodes (Drechsl.) Subramanian & Jain
D. hawaiienses (Bugn.) Subramanian & Jain & M. B. Ellis
D. longirostrata (Subramanian) Ram Nath, Neergaard & Mathur
D. neergardii Danquah
Epicoccum spp.
Fusarium moniliforme Sheld.
F. graminearum Schwabe
Fusarium spp.
Helicoceras spp.
Hendersonia spp.
Khuskia oryzae Hudson
Magnaporthe salvinii (Catt.) Krause & Webster
Melanomma glumarum Miyake
Monascus purpureus Went
Mycosphaerella danubialis Savulescu
M. shiraiana (Miyake) Tomilin
Myrothecium verrucaria Ditm. & Fr.
Oospora oryzetorum Sacc.
Ophiobulos oryzinus Sacc.
Penicillium puberulum Bain.
Phaeotrichoconis crotoloriae (Salam & Rao) Subramanian
Phoma spp.
Phyllosticta glumarum Ell. & Tr.
Pyricularia oryzae Cav.
Rhynchospurium oryzae Hashioka & Yokogi
Sarocladium oryzae (Sawada) W. Gams D. Hawksw.
Sclerotium rolfsii Sacc.
Tilletia barclayana (Bref.) Sacc. & Syd.
Trematosphaerella oryzae (Miyake) Padw.
Ustilaginoidea virens (Cooke) Tak.
Wolkia decolorans (Van der Wolk) Ramsbotton

In seedborne pathogens from 372 incoming seed lots in 1986 (Table 6), *Curvularia* spp. was the most frequently detected of the grain-infecting fungi, followed by *Trichoconiella padwickii, Phoma* spp., *Nigrospora oryzae, T. barclayana, Epicoccum purpurascens, Leptosphaeria* spp., and *Phyllosticta glumarum.* Detection of some major rice pathogens was considerably less. *D. oryzae* was found in almost half of the seed lots, followed by *Sarocladium oryzae, F. moniliforme, G. oryzae, Pyricularia oryzae, Cercospora oryzae,* and *Nakataea sigmoidea.*

Detection methods for seedborne diseases of rice have been studied at the Seed Pathology Institute (Mathur and Neergaard 1970, Neergaard 1979, Neergaard et al 1970). Dry inspection can be used for detecting and identifying seedlike structures

Table 5. Incidence of seedborne fungi detected in 4,744 seed lots tested by the blotter technique, Seed Health Unit, IRRI 1984, 1985, and 1986.

Pathogen	Affected seedlots (%)	Range of inspection (%)
Drechslera oryzae	24.4	1-52
Fusarium moniliforme	21.8	1-26
Gerlachia oryzae	28.7	1-37
Sarocladium oryzae	55.6	1-52
Cercospora oryzae	3.9	1-8
Pyricularia oryzae	0.5	1
Nakataea sigmoidea	1.3	1-8
Trichoconiella padwickii	96.9	1-91
Curvularia spp.	87.8	1-70
Phoma spp.	39.8	1-54
Nigrospora oryzae	38.3	1-29
Pyrenochaeta oryzae	0.5	1-2
Leptosphaeria spp.	1.1	1-2
Phyllosticta glumarum	4.5	1-17
Drechslera sorokiniana	0.8	1-2
D. maydis	0.2	1
D. rostrata	0.4	1-3
D. halodes	0.4	1-2
Epicoccum purpurascens	0.1	1-6
Tilletia barclayana[a]	8.3	1-40

[a]Counted in blotter tests although present as concomitant contamination.

Table 6. Incidence of seedborne pathogens in 372 incoming seed lots without treatment, Seed Health Unit, IRRI, 1986.

Pathogen	Affected seed lots (%)	Detected range (%)	Mean value (%)
Dreschslera oryzae	47.8	1-47	5.27
Fusarium moniliforme	19.9	1-59	5.07
Gerlachia oryzae	19.9	1-20	2.59
Sarocladium oryzae	25.8	1-19	2.40
Cercospora oryzae	1.34	1-1	1.00
Pyricularia oryzae	4.80	1-9	2.06
Nakataea sigmoidea	0.27	1-1	1.00
Trichoconiella padwickii	69.3	1-92	18.6
Curvularia spp.	82.8	1-42	8.23
Phoma spp.	40.0	1-25	3.08
Nigrospora oryzae	18.0	1-58	3.07
Tilletia barclayana	17.7	1-96	20.1
Leptosphaeria spp.	1.07	1-1	1.00
Phyllosticta glumarum	0.81	1-1	1.00
Epicoccum purpurascens	8.87	1-68	22.1
Bacteria on blotter	76.6	1.26	3.99
Aphelenchoides besseyi	16.7	1-136[a]	10.7

[a]Actual count based on 200 seeds/seed lot.

like sclerotia of *Rhizoctonia* and *Sclerotium* spp. (Schoen 1983). Dry inspection and washing tests are used for different diseases, but each has its limitations. For example, the washing test reveals only spores of seedborne fungi gathered from the rice seed surface and not mycelial infection. The majority of seedborne fungi are detected by the blotter technique, and some by agar-plating techniques. Detecting some fungal species improves with the deep-freezing method (Kim et al 1984).

Nematodes

Many genera of plant parasitic nematodes are known to be associated with the rice plant and its cultivation (Table 7), but only a few are presently of proven or potential economic importance (Table 8), and only one, *Aphelenchoides besseyi,* is definitely known to be seedborne.

The recorded nematode pests of rice (Table 8) have diverse parasitic habits and often different geographical distribution in the rice-growing areas of the world (Table 9). They are characterized by morphological structures that enable feeding on plant tissues. The symptoms of parasitism differ, but all nematodes cause mechanical damage or malfunctions of the physiological processes involved in plant development, resulting in poor growth and yield loss.

Species of some nematode genera cause damage on many different rice types (upland, irrigated, lowland, and deepwater), while others are restricted to one particular rice and environment (Table 10).

The nematodes that cause or may cause yield loss in rice can be conveniently divided into groups by parasitic habit and position on the rice plant: the foliar parasites, feeding on stems, leaves, and panicles; and the root parasites, confined to below-ground activity on the root systems.

Many rice nematode pests are widely dispersed throughout the rice-growing regions of the world (Table 9). Although some of them are indigenous in certain areas, many have been spread by man's recent activities and are still crossing quarantine barriers by various means. Only one nematode species is definitely spread in seed; another can be spread in dead foliage and possibly seed; but the only means of dispersal for all other nematode pests is roots or soil.

Table 7. Plant nematode genera associated with rice, worldwide.

Aglenchus	*Hoplolaimus*	*Rotylenchulus*
Aphelenchoides	*Lelenchus*	*Rotylenchus*
Aphelenchus	*Longidorella*	*Scutellonema*
Basiria	*Longidorus*	*Telotylenchus*
Caloosia	*Malenchus*	*Triversus*
Criconemella	*Meloidogyne*	*Trichodorus*
Ditylenchus	*Paralongidorus*	*Trichotylenchus*
Dolichodorus	*Paraphelenchus*	*Tylenchorhynchus*
Filenchus	*Paratrichodorus*	*Tylenchus*
Helicotylenchus	*Paratrophurus*	*Uliginotylenchus*
Hemicriconemoides	*Paratylenchus*	*Xiphinema*
Hemicycliophora	*Peltamigratus*	*Xiphinemella*
Heterodera	*Pratylenchus*	
Hirschmanniella	*Psilenchus*	

Table 8. Plant nematode genera and species known or suspected to cause yield loss in rice.

Foliar parasites	
Aphelenchoides besseyi	White tip disease nematode
Ditylenchus angustus	Ufra disease nematode
Root parasites	
Caloosia heterocephala	
Criconemella onoensis	Ring nematode
Criconemella spp.	Ring nematode
Helicotylenchus spp.	Spiral nematode
Heterodera elachista	Cyst nematode
H. oryzae	Cyst nematode
H. oryzicola	Cyst nematode
H. sacchari	Cyst nematode
Hirschmanniella caudacrena	Rice root nematode
H. imamuri	Rice root nematode
H. mucronata	Rice root nematode
H. oryzae	Rice root nematode
H. spinicaudata	Rice root nematode
Hoplolaimus indicus	Lance nematode
Hoplolairnus spp.	Lance nematode
Meloidogyne graminicola	Root-knot nematode
M. incognita	Root-knot nematode
M. javanica	Root-knot nematode
M. oryzae	Root-knot nematode
Paralongidorus australis	Needle nematode
Pratylenchus brachyurus	Lesion nematode
P. indicus	Lesion nematode
P. sefaensis	Lesion nematode
P. zeae	Lesion nematode
Rotylenchulus spp.	Reniform nematodes
Tylenchorhynchus annulatus	Stunt nematode
Tylenchorhynchus spp.	Stunt nematode

A. besseyi is a seedborne nematode; seed originating from infected plants is the primary means of disease transmission. Nematodes survive in a state of anabiosis in dried seed, mainly on the inner surface of hulls, but also on the kernels. They can remain viable in rice seed for 23 mo (Fortuner and Orton-Williams 1975, Todd and Atkins 1958).

A. besseyi is the most readily transmitted nematode of all the plant parasites occurring in rice. Generally it is found in low numbers in rice seed and causes no observable damage to the seed. Detection of *A. besseyi* entails the soaking of seed in water for 12-24 h and examination of the suspension for reactivated nematodes.

The most effective control of *A. besseyi* in seed material is hot water. Large seed batches are presoaked in cold water for 24 h, then immersed in hot water at 51-53 °C for 15 min; smaller batches can be treated at 55-61 °C for 10-15 min without presoaking (Todd and Atkins 1959).

Ditylenchus angustus, the only other foliar nematode on rice, can be transmitted in dried rice foliage, but there are no substantiated reports of seed transmission. The nematode can survive in a dried state enclosed in the leaf sheath, particularly at the base of the panicle. In the natural state, *D. angustus* can survive for 4-5 mo in dry foliage, although after this time few nematodes remain alive and

Table 9. World distribution of plant nematodes on rice.

	Aphelenchoides besseyi	
Bangladesh	Egypt	Mali
Benin	El Salvador	Nigeria
Brazil	Fiji	Pakistan
Bulgaria	Gabon	Philippines
Burma	Ghana	Senegal
Cameroon	India	Sierra Leone
Central African Republic	Iran	Taiwan, China
Chad	Italy	Tanzania
China	Ivory Coast	Togo
Colombia	Japan	USA
Comoro Islands	Kenya	USSR
Congo	Korea	Vietnam
Cuba	Madagascar	Zimbabwe
	Ditylenchus angustus	
Bangladesh	Madagascar	Thailand
Burma	Malaysia	Vietnam
India		
	Hirschmanniella spp.	
Bangladesh	Japan	Philippines
Cameroon	Korea	Senegal
Cuba	Madagascar	Sierra Leone
El Salvador	Malaysia	Sri Lanka
Gambia	Mauritania	Taiwan, China
Ghana	Mexico	Thailand
Hong Kong	Nigeria	USA
India	Pakistan	Venezuela
Indonesia	Panama	Vietnam
Ivory Coast		
	Pratylenchus spp.	
P. brachyurus:	Bolivia	Madagascar
	Brazil	Nigeria
	Central African Republic	Senegal
	Congo	Vietnam
	Ivory Coast	
P. indicus:	India	Pakistan
P. zeae:	Australia	Philippines
	Brazil	Senegal
	Cameroun	Thailand
	Colombia	USA
	Cuba	Venezuela
	Egypt	Vietnam
	Ivory Coast	Zimbabwe
	Malaysia	
Other species:	Bangladesh	Pakistan
	Bolivia	Philippines
	Egypt	Senegal
	Gambia	Sierra Leone
	Guinea	Taiwan, China
	Japan	Thailand
	Korea	Vietnam
	Liberia	
	Hoplolaimus spp.	
H. indicus:	India	Pakistan
Other species:	Bangladesh	Pakistan
	Egypt	Philippines

Continued on next page

Table 9 continued

	Gambia	Senegal
	India	Taiwan, China
	Mexico	USA
	Nigeria	Vietnam
	Meloidogyne spp.	
M. graminicola:	Bangladesh	Laos
	Burma	Thailand
	China	USA
	India	Vietnam
M. incognita:	Colombia	Ivory Coast
	Cuba	Japan
	Egypt	Nigeria
	Guinea	South Africa
M. oryzae:	Surinam	
Other species:	Bolivia	Pakistan
	Brazil	Panama
	Colombia	Senegal
	Costa Rica	South Africa
	Egypt	Taiwan, China
	Ghana	Thailand
	Nigeria	
	Heterodera spp.	
H. elachista:	Japan	
H. oryzae:	Bangladesh	Senegal
	Ivory Coast	
H. oryzicola:	India	
H. sacchari:	Gambia	Nigeria
	Ivory Coast	Senegal
Heterodera spp :	Egypt	USA
	Criconemella spp.	
Bangladesh	Guinea	Senegal
Bolivia	Ivory Coast	Sierra Leone
Central African Republic	Japan	Surinam
Congo	Liberia	Taiwan, China
Costa Rica	Malaysia	Thailand
Egypt	Pakistan	USA
El Salvador	Philippines	Vietnam
	Tylenchorhynchus spp.	
T. annulatus:	Australia	Pakistan
	Bangladesh	Philippines
	Costa Rica	Sierra Leone
	Cuba	Surinam
	Gambia	Taiwan, China
	India	Thailand
	Iran	USA
	Malaysia	Vietnam
Other species:	Australia	Mexico
	Bulgaria	Nigeria
	Cameroon	Pakistan
	Egypt	Philippines
	Gambia	Senegal
	Guinea	Surinam
	India	Thailand
	Ivory Coast	Vietnam
	Mauritania	

Table 10. Main nematode pests of rice and means of spread.

Nematode	Rice affected	Means of spread
Aphelenchoides besseyi	Upland, irrigated lowland, and deepwater	Seed, stem, panicles, and soil
Ditylenchus angustus	Deep water	Stem, panicles, and soil
Heterodera spp.	Upland and irrigated	Soil and roots
Hirschmanniella spp.	Irrigated, lowland, and deepwater	Soil and roots
Hoplolaimus spp.	Upland and irrigated	Soil and roots
Meloidogyne spp.	Upland, irrigated, lowland, and deepwater	Soil and roots
Pratylenchus spp.	Upland	Soil and roots
Criconemella spp.	Upland, irrigated, and lowland	Soil
Paralongidorus spp.	Upland and irrigated	Soil
Tylenchorhynchus spp.	Upland, irrigated, lowland, and deepwater	Soil

active (Cox and Rahman 1979, Dang-ngoc 1981). Movement of *D. angustus* between countries in dry foliage is therefore a feasible but rare means of transmission.

D. angustus can be found inside filled and unfilled grains of freshly harvested rice, but the nematodes are apparently killed when the seed is sun-dried (Nguyen-thi and Giang 1982, Tin Sein 1977). The possibility of *D. angustus* being transmitted in seed is slim but cannot be completely ruled out.

Because rice is propagated from seed, soil and roots are unlikely constituents of rice samples sent around the world. It should follow that nematode pests of rice roots are infrequently spread between countries. However, these nematodes may also be spread by infested field soil, which may be deliberately or accidentally shipped with plant material. In addition, many rice nematodes have crop and weed hosts other than rice, and when planting material from alternate hosts includes roots, nematodes can be transmitted into rice-growing areas.

The rice nematode genera that can be transmitted in both roots and soil are *Helicotylenchus, Heterodera, Hirschmanniella, Hoplolaimus, Meloidogyne, Pratylenchus,* and *Rotylenchulus;* those genera found only in the soil are *Criconemella, Paralongidorus, Tylenchorhynchus,* and other ectoparasites.

There are reports that the two foliar nematodes, *A. besseyi* and *D. angustus,* can also be found in soils (Nguyen-thi 1982, Terry 1972). Soil is a minor component of transmission for both nematodes, but infested soil planted to rice has been shown to produce ufra disease (Nguyen-thi 1982).

THE ROLE OF SEED PATHOLOGY

In a recent review, McGee (1981) pointed out four phases of a pathogen in relation to its life cycle: survival, transmission, infection, and disease development. On this basis

McGee categorized microorganisms into four groups:

- those for which seed is the main source of inoculum; when seed infection is controlled, the disease is controlled;
- those for which the seedborne phase is of minor significance as a source of inoculum;
- those that have never been shown to cause disease; on the contrary, their presence may have a beneficial effect; and
- those that can infect seed both in the field and in storage.

Based on these criteria, many pathogenic microorganisms isolated from seed such as those shown in Table 1 may be of minor importance even though they are abundant. The first two groups deserve our attention in routine seed testing. Testing methods for them should be reliable and efficient. Recently we have isolated many bacteria from rice seed. Some show inhibitory effects on a broad spectrum of fungal pathogens and may also inhibit bacterial pathogens. Their use in future seed treatments is worth pursuing.

Detecting fungal pathogens on rice seed is difficult in some cases, and no single method is best for all organisms. Pathogens differ in their relative saprophytic abilities. Certain methods favor the more necrotrophic pathogens over those that develop more vigorously on living tissue. *Pyricularia oryzae,* for example, is easier to detect by the blotter method than by the agar plating technique, where it is often overgrown by other fungi. However, detecting important fangal pathogens on rice seed is only one aspect of seed pathology.

A more critical issue for rice pathologists is determining the relative importance of fungi detected on seed. How do these seedborne pathogens affect disease development in the rice crop? Under what environmental and cultural circumstances do seedborne inocula contribute to epidemic development? In rice blast, infected seed can be the primary inoculum when seed is densely sown in seedling boxes, as is practiced in Japan (Honda and Nemoto 1985). It is unlikely, however, that seed infection is equally important in tropical lowland rice, where conditions generally do not favor blast development and seed is often sown in wet beds. Much remains to be done to assess the impact of seed health on disease in the field in the world's diverse rice-growing environments. As pointed out by McGee (1981), without "epidemiological studies . . . to relate laboratory seed health tests to the risk of subsequent field disease, these tests are of little practical value."

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Nonseedborne rice pests of quarantine importance

O. MOCHIDA

The most important nonseedborne pests of rice from the quarantine viewpoint are freshwater snails — *Pomacea canaliculata* (Lamarck) and related species (Gastropoda, Basommatophora, Pilidae) — which originated in South America and have been introduced into Japan, the Philippines, and Taiwan, China; a parthenogenic strain of the rice water weevil *Lissorhoptrus oryzophilus* Kuschel (Insecta, Coleoptera, Curculionidae), which might have come from California, USA, into Japan; and black bugs *Scotinophara* spp., especially *S. coarctata* (Fabricius) (Insecta, Heteroptera, Pentatomidae), which is indigenous to Southeast Asia but has recently become serious in the Philippines (Palawan), Malaysia, Brunei, Indonesia, and Thailand.

Of the more than 900 invertebrate species recorded as pests of rice plants and rice grain throughout the world (Grist and Lever 1969), the majority are insects. Because around 90% of the world's rice is produced in Asia, most of these pests are commonly found there. Stem borers (*Chilo, Scirpophaga,* and *Sesamia*), planthoppers (*Laodelphax, Nilaparvata,* and *Sogatella*), leafhoppers (*Nephotettix, Recilia,* and *Thaia*), armyworms (*Mythimna* and *Spodoptera*), gall midge (*Orseolia*), leafeaters (*Cnaphalocrosis, Parapoynx, Dicladispa,* etc.), bugs (*Leptocorisa, Nezara,* and *Cletus*) and mealybugs (*Ripersia*) are indigenous to Asia and are all important pests. However, most of them, except *Scotinophara* spp., are of questionable importance from the plant quarantine viewpoint.

The most important nonseedborne pests from the quarantine viewpoint are freshwater snails *Pomacea* spp., a parthenogenic strain of the rice water weevil *Lissorhoptrus oryzophilus* Kuschel, and the black bug *Scotinophara coarctata* (Fabricius).

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FRESHWATER SNAILS

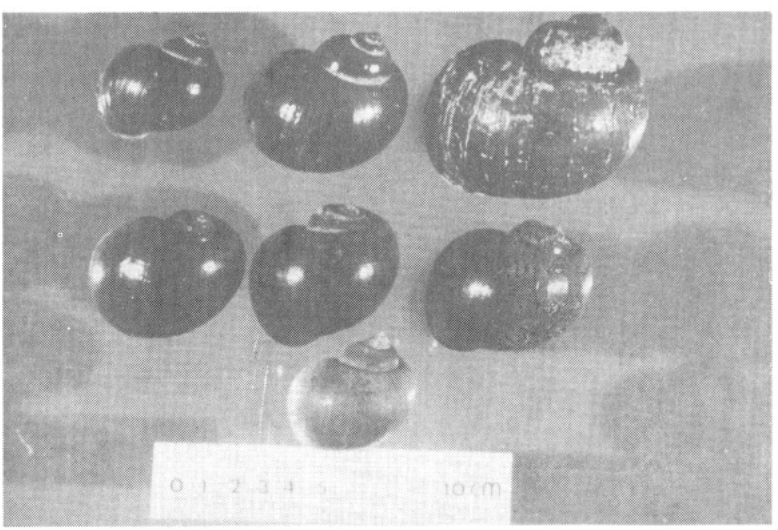
Taxonomy

Phylum	Mollusca
Class	Gastropoda
Order	Basommatophora
Family	Pilidae (Synonym: Ampullaridae)
Scientific name	*Pomacea canaliculata* (Lamarck)
	Synonyms: *Ampullaria canaliculata*
	Ampullarius canaliculata

History

Golden snails — golden apple snails, apple snails, and the jumbo snails *Pomacea* canaliculata (Lamarck) and related species (Fig. 1) — are indigenous to South America and were introduced into Taiwan, China, from Argentina in 1980, and into Kyushu, Japan, in 1981. The snails are cultured in ponds and sold fresh, canned, or bottled as human food, but their commercial value has recently dropped. Escaping from culture ponds into open fields, they attack aquatic plants including young rice seedlings, taro(*Colocasia esculenta*), swamp cabbage (*Ipomoea aquatica*), lotus (*Nelumbo nucifera*), mat rush (*Juncus decipiens*), water chestnut (*Trapa bicornis*), and water rice (*Zizania latifolia*). Large expenditures are required to control them in Taiwan and Japan.

There are at least three sources of *Pomacea* spp. in the Philippines. *P. canaliculata* was introduced from Taiwan into the Rafael Atay de Hatchery, Lemery, Batangas, Luzon, in 1982; and *P. gigas* (Spix) was imported by the Bio-Research Institute, Metro Manila, from Florida, USA, in 1983 (R. Esguerra,



1. *Pomacea* snails in the Philippines.

Table 1. Occurrence of *Pomacea* snails, area treated with molluscides, estimated loss, and fingerlings released for controlling the snails in Taiwan, China (MAF, Taiwan, 1985, 1986).

Item	Year				
	1982	1983	1984	1985	1986
Occurrence (ha)					
Ricefields	13,000	40,574	72,780	147,311	151,444
Others	4,000	11,071	16,500	19,382	19,980
Area treated with molluscicides (ha)					
Ricefields	–	32,000	15,000	35,560	90,000
Others	–	14,000	5,000	12,135	13,350
Estimated loss only in ricefields (US$ million)	2.7	8.3	14.9	30.1	30.9
Fingerlings released (no.)					
Black carp *Mylopharyngodon piceus*	–	–	85,000	–	592,000
Common carp *Cyprinus carpio*	–	–	500,000	–	650,000

pers. comm.). I visited the Asturias Farm in Asturias, Cebu, in 1985 and 1986 and learned that *Pomacea* snails had been introduced directly from Argentina in 1984. *P. cuprina* (Reeve) is also found in the Philippines (R. Esguerra, pers. comm.).

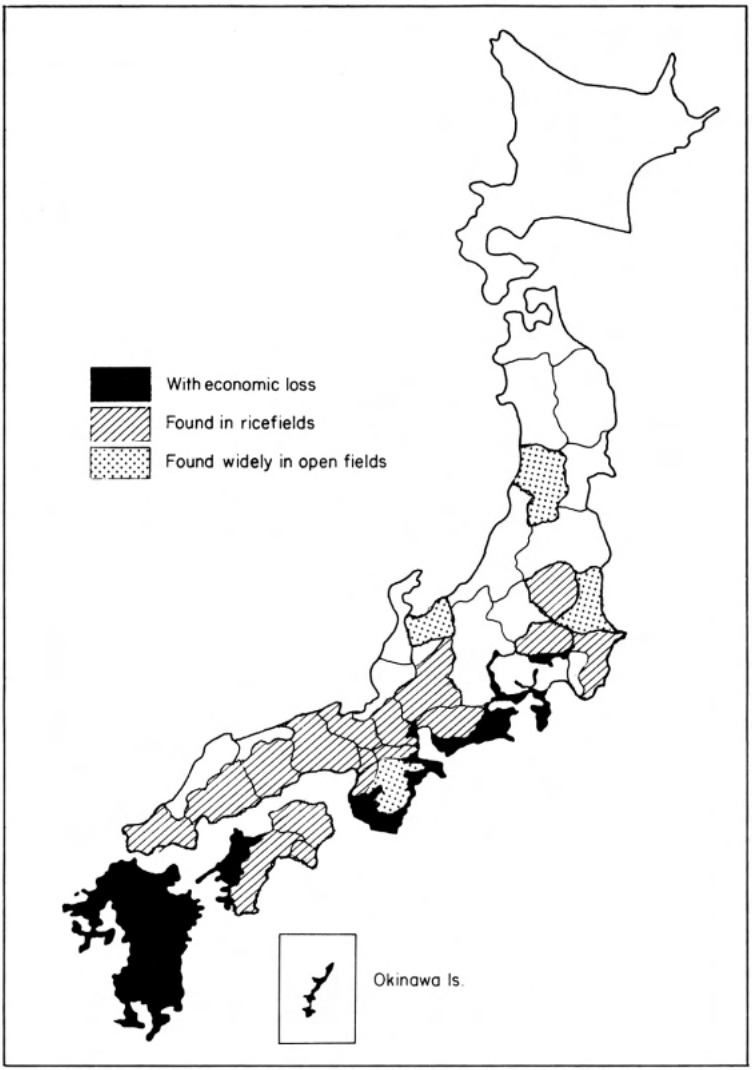
P. canaliculata was confirmed as an intermediate host of *Angiostrongylus cantonensis*, causing the human disease eosinophilic meningoencephalitis, in Taiwan in 1985 (Chen 1985) and in Ryukyu in 1986 (Nishimura and Sato 1986).

Pest situation

In Taiwan, *Pomacea* snails infested 17,000 ha in 1982 and 171,425 ha in 1986. In 1986, the area treated with molluscicides was 103,350 ha, and the estimated loss in ricefields alone was US$30.9 million. Over half a million fingerlings of black carp *Mylopharyngodon piceus* and even more of common carp *Cyprinus carpio* were released to control the snails (Table 1). In Japan, snails were confirmed to have occurred in 34 of 47 prefectures by the end of 1986 (Fig. 2); in 1986, 174 ha of ricefields were attacked and had to be replanted, and the central government spent US$64,285 on control. In the Philippines, the rice crop in Luzon, especially in Kalingai-Apayao Province, has been attacked, and the snails destroy azolla (IRRI 1987); 2-wk-old rice seedlings were damaged more than 4-wk-old ones, and rice more than 6 wk old was hardly damaged.

Biology

Eggs hatch in about 2 wk in Taiwan (MAF, Taiwan 1986) and 3 wk (range 9-37 d) in Japan (Miyahara 1987), depending on the water temperature. Hatchability is 7-90%, depending on location and season. The snails grow to about 3 cm in height within 2 mo, when they are mature and ready for oviposition. Males and females copulate in the water, and females oviposit an average of 321 eggs/egg mass on plants, concrete walls, etc. above the water level at night. Oviposition was observed in all months except January and February in Okinawa; it started in May in Fukuoka (Kyushu), Japan. A female produces an average of 4,375 eggs (range 2,410-8,680) /yr.



2. The occurence of *Pomacea* snails in Japan by the end of 1986 (Morita 1987).

The snails are estimated to survive for 2-3 yr in Japan and 3-5 yr in Taiwan. Mortality is high at water temperatures higher than 35 °C. The snails can survive for 15-20 d at 0 °C, 2 d at -3 °C, but only 6 h at -6 °C. In Okinawa, snails were confirmed to survive 234 d without water.

After the ricefield is drained and harvested, some snails enter the canals, but most remain in the soil in the lower portions of the ricefield. The tops of the shells can just be seen above the soil surface during winter. Snails less than 1.3 cm in height cannot damage rice seedlings; those more than 1.5 cm can eat seedlings in the water. At water depths less than 1 cm, seedlings are hardly damaged; seedlings are damaged

more at lower depths. Feeding activity is highest at around 30 °C water temperature. The relationship between snail size (X, in cm) and the fresh weight of rice seedlings consumed (Y, in g/d per individual) is $Y = 0.0100X^3 + 0.026$ ($r^2 = 0.988$**) (MAF, Taiwan 1986; Miyahara 1987; Miyahara et al 1986a,b; Ōya et al 1986).

Control

In Taiwan, the following are recommended (MAF, Taiwan 1985; 1986):

- Pick up and crush egg masses and snails.
- Burn rice straw after harvest in the fields where snails occur to kill those near the soil surface.
- Place 5-mm mesh metal screens at the irrigation water inlets.
- Apply molluscicides:
  - — in ricefields:
    - — triphenyl-tin acetate 45% WP at 0.6 kg/ha at water temperatures higher than 20 °C, and at 1.2 kg/ha at lower temperatures; do not drain water for 3 d, and leave at 1–to 3-cm depth for 7 d.
    - — metaldehyde 80% WP at 1.2 kg/ha at water temperatures higher than 20 °C.
  - — in waterways, streams, and ponds:
    - — prohibit triphenyl-tin acetate in and around rivers, streams, and fishponds.
    - — metaldehyde 80% WP at 2.4 kg/ha.
- Release fingerlings of black carp *Mylopharyngodon piceus* and common carp *Cyprinus carpio.*
- Place 2 kinds of metal screens (6-10 and 16-32 mm mesh) at each water inlet and outlet of the pond.

In Japan, triphenyl-tin acetate, clonitralide, and other chemicals with high fish toxicity are strictly prohibited from use in ricefields. At least 32 chemicals were tested in 1986 (MAFF, Japan 1987). Metaldehyde 6% G was effective when broadcast at 40-50 kg/ha (=2.4-3.0 kg ai/ha) or baited at 10 kg/ha (=0.6 kg ai/ ha) by mixing at 2:2:1 by weight with Irish potato and wheat flour. Cartap 4% G is applied to seedling boxes (60 × 30 × 3 cm) at 60-100 g/box or to ricefields at 40 kg/ha at 30 d before harvest, but it cannot kill the snails; it merely acts as a repellent. Bensultap 4% G and disulfoton 3% + tiocyclam 2% G are effective as repellents, like cartap, when applied at 40 kg/ha just after mechanical transplanting. Calcium cyanamide can kill snails when applied at 200-400 kg/ha at 3 d after the first plowing, but 200 kg/ha is recommended in practice in Miyazaki Prefecture because 400 kg/ha provides too much N. A metal screen (5 mm mesh) should be placed over water inlets to prevent snail invasion. Picking snails by hand during land preparation and 5-7 d after mechanical transplanting, and destroying the pink egg masses are also recommended. Rototilling during January and February produced mortality 27% higher than that in unplowed fields in Miyazaki Prefecture (MAFF, Japan 1987).

In the Philippines, triphenyl-tin acetate 60% WP and clonitralide 70% WP were confirmed to be very effective on the snails but extremely toxic to Nile tilapia *Sarotherodon niloticus.* Metaldehyde 6% G is effective but less toxic to fish (IRRI 1987).

RICE WATER WEEVIL

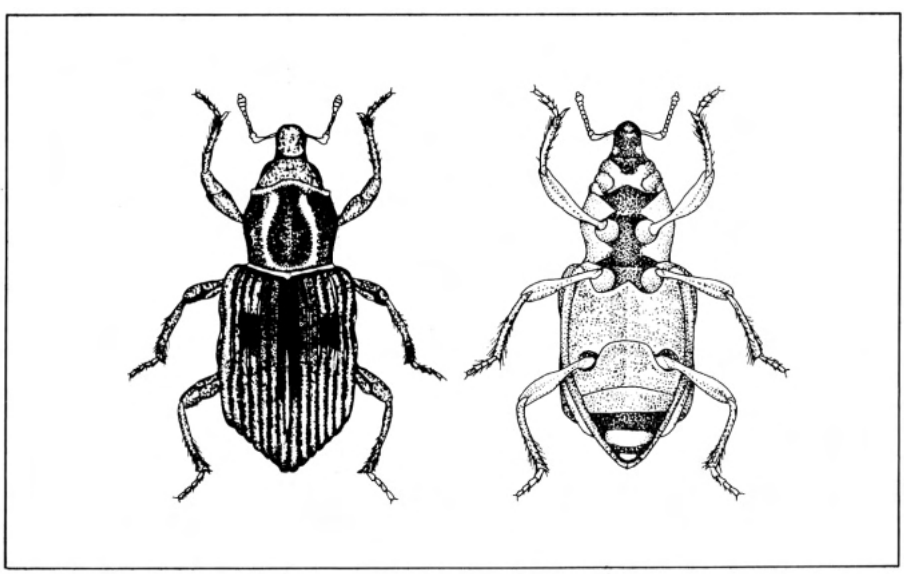
Taxonomy

Phylum	Arthropoda
Class	Insecta
Order	Coleoptera
Family	Curculionidae
Scientific name	*Lissorhoptrus oryzophilus* Kuschel

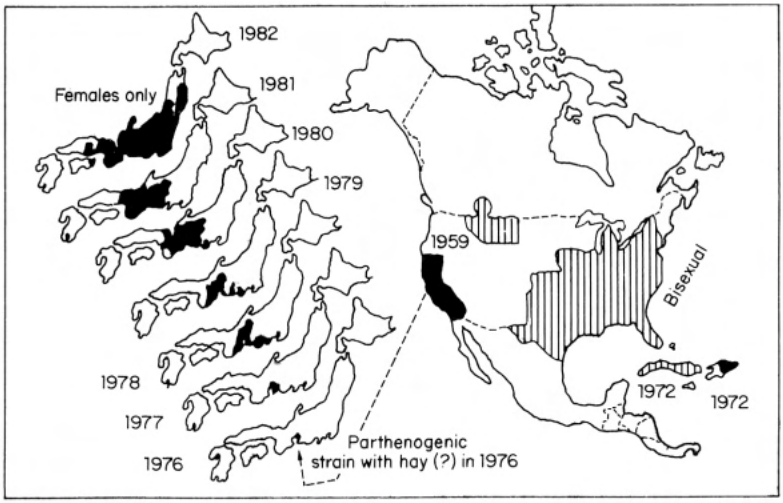
History

The rice water weevil originated in the Mississippi River basin in the USA but spread to the New England states, Canada, and Florida many years ago (Blatchley and Leng 1916, Riley 1881). It was discovered to have reached California in 1959, but only parthenogenic females (Fig. 3) were found (Lange and Grigarick 1959). Weevils were observed in Cuba and the Dominican Republic in 1972 (Fig. 4); the Dominican Republic strain consisted of females only (Sommeijer 1972).

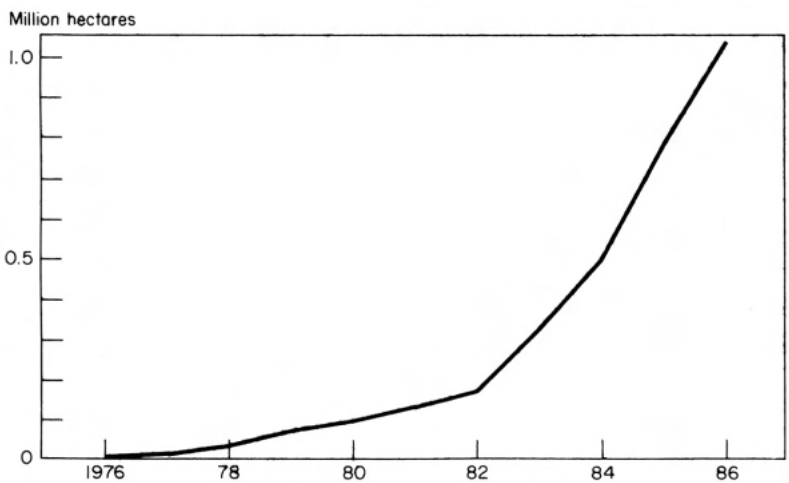
In Japan, females (only) were found on rice plants in Tokoname City, Aiti Prefecture, Central Japan, in May 1976 (Tsuzuki and Isogawa 1976). They are believed to have been introduced with hay from California (Nagoya Plant Protection Station 1978). By the end of the year the insect was confirmed on more than 730 ha of ricefields. Since 1976 it has rapidly expanded in distribution (Fig. 5). It was found on Okinawa in 1985 and on Hokkaido in 1986; it now occurs on all four main Japanese islands.



3. Parthenogenic female of the rice water weevil *Lissorhoptrus oryzophilus* Kuschel (drawings by Y. lsogawa from Tsuzuki et al 1984).



1. Spread of the rice water weevil (Tsuzuki and Mochida 1983).



5. Occurrence of the rice water weevil in Japan since 1976.

Pest situation

The rice water weevil is one of the most destructive and persistent pests of rice in Japan (Tsuzuki and Mochida 1983). Because polyphagous females reproduce parthenogenically, adapt to various habitats from cold (Hokkaido) to hot (Okinawa) areas, move easily by water or air across seas and rivers, and can survive without fresh food for long periods, there is a very high probability that the parthenogenic strain will spread throughout the rice-growing areas of Asia, especially from military bases in Okinawa to those in the Philippines.

Biology

Females overwinter in plant residue on dikes, bushes, and levees, and in orange and Japanese persimmon orchards, bamboo groves, etc.; they can survive at −5 °C for 3 mo and under 1 m of snow for 3 mo. Overwintered females start to feed on gramineous plants in Central Japan from late April through early May. Rice seedlings are usually transplanted in May in Aiti Prefecture. The insects fly into ricefields from late April through June and remain on the plants, where they feed on the leaves, mainly at night. Two weeks after initial feeding on rice or gramineous plants, females deposit eggs separately in the epidermis of leaf sheaths, mostly just below the water level or in the roots. A female deposits 50-100 eggs in her lifespan and an average of 2.4 eggs/d. The egg stage is about 6-9 d. Larvae feed at first within the basal part of the leaf sheaths and then move to the roots. Rice plants with root systems heavily infested by many larvae grow poorly. Larvae may move more than 30 cm through the soil. Thus, few larvae are usually found on heavily damaged roots. The larval stage is 30-40 d. The pupal stage is 7-10 d. Larvae and cocoons are found most frequently 3-9 cm below the soil surface. Females in the first generation appear on the rice crop in Central Japan from June through August and move to overwintering sites (Tsuzuki and Mochida 1983). Damage to rice plants caused by first-generation adult females is not very serious, whereas that caused by larvae in the first generation is usually very serious (Iwamoto et al 1986).

Okada (1980) reviewed 14 species of Gramineae, 4 of Cyperaceae, and 1 of Onagraceae that are regarded as hosts and 3 of Gramineae that are food plants for adults in the USA. In Japan, 86 species are reported as food plants for adult females and 22 as food plants for larvae (Iwamoto et al 1986). Eggs, larvae, and pupal cocoons have been confirmed on the following 22 species (Okada 1980):

Alismataceae	*Sagittaria pygmaeae*
Commelinaceae	*Commelina communis*
	Murdannia keisak
Cyperaceae	*Carex thungergii*
	Eleocharis congesta japonica
	E. kuroguwai
	Scirpus juncoides hotarui
Gramineae	*Arthraxon hispidus*
	Beckmannia syzigachne
	Echinochloa crus-galli
	Glyceria actiflora japonica
	Hermarthria sibirica
	Isachne globosa
	Leersia japonica
	L. oryzoides sayanuka
	Oryza sativa
	Paspalum distichum
	P. thunbergii
	Setaria viridis minor
	Zizania latifolia

Juncaceae	*Fimbristylis tristachya subbispicata*
	Juncus leschenaultii

No important natural enemy was found in Japan (Tsuzuki and Mochida 1983).

Control

The following practices are expected to lessen damage:

- transplanting rice seedlings after the peak appearance of adult females in the overwintered generation,
- using larger (10-15 cm long) rather than smaller rice seedlings, and
- direct sowing on well-drained ricefields.

Aldrin was popularly used in the USA for several years, but insecticide-resistant populations appeared in Louisiana in 1964. Since then, bufencarb or a mixture of m-(ethylpropyl)phenylmethylcarbamate and m-(1-methylbutyl)phenyl-methylcarbamate and carbofuran granules has been used in the USA.

Insecticides used in Japan are given in Table 2.

Table 2. Insecticides registered for controlling the rice water weevil in Japan (Iwamoto et al 1986, Tsuzuki et al 1984).

Trade name	Common name	Formulation	Rate
	Seedbox treatment (g/box[a])		
Tato	bendiocarb	5% G	60-100
Advantage	carbosulfan	5% G	50- 70
Padan	cartap	4% G	80-100
Padanbeam	cartap + tricyclozole	4 + 4% G	60- 80
Disystonsucide	ethylthiometon + propoxur	3 + 2% G	100
Ekamart	ethylthiometon + thiocyclane	3 + 2% G	100
Kayaphos	propaphos	5% G	100
Kayaphos-Fuji-one	propaphos + isoprothiolane	6 + 12% G	70- 85
	Effective against adults (kg or liter/ha)		
Sumibassa	fenitrothion + BPMC	2 + 2% D	30- 40
Baycid	fenthion	2% D	30- 45
Baybassa	fenthion + BPMC	2 + 2% D	30- 45
Tsumabaycid	fenthion + MTMC	2 + 2% D	40
Baycidsuncide	fenthion + propoxur	2 + 0.5% D	30- 45
Karphos	isoxathion	2% D	30- 40
Ofunak-M	pyridaphenthion + MTMC	2 + 2% D	40
Sumibassa L75	fenitrothion + BPMC	45 + 30% EC	2 liters
Karphos	isoxathion	20% EC	5 liters
	Effective against larvae (kg/ha)		
Padanbassa	cartap + BPMC	2 + 2% G	40
Ethimeton	ethylthiometon + diazinon	3 + 3% G	40- 50
Baycid	fenthion	5% G	30- 40
Bassacid	fenthion + BPMC	2 + 2% G	40
BaycidMIPC	fenthion + MIPC	3 + 4% G	30- 40
Baycidsuncide	fenthion + propoxur	4 + 3% G	30- 40
Suncide	propoxur	5% G	30- 40

[a] The size of the box is standard – 60 × 30 × 3 cm; it includes about 5 liters soil.

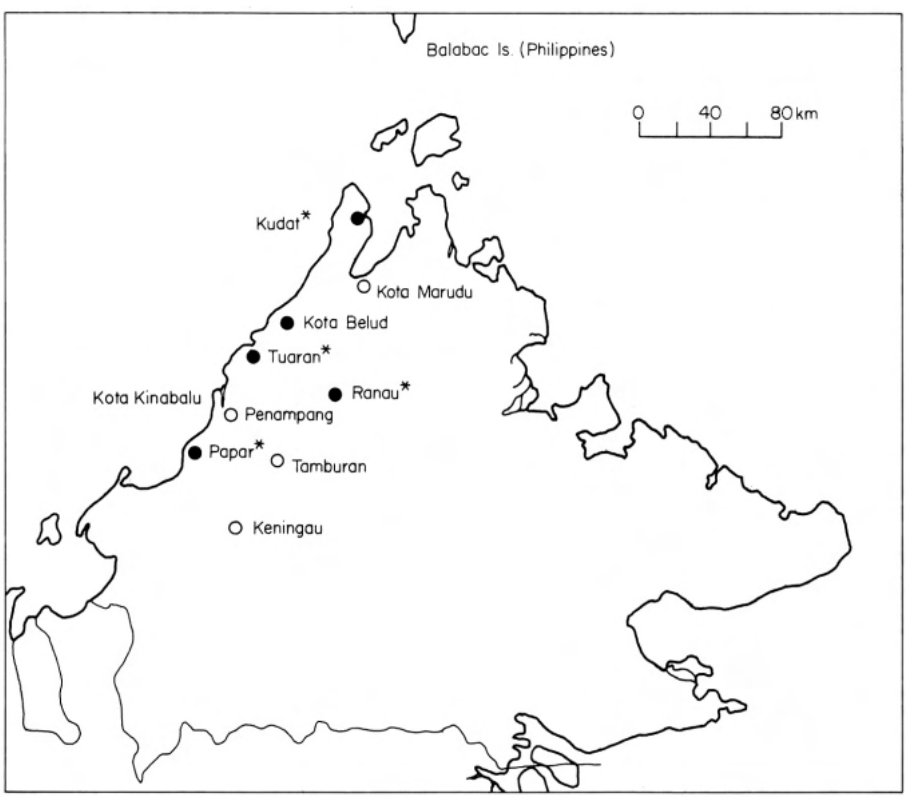
BLACK BUGS

Taxonomy

Phylum	Arthropoda
Class	Insecta
Order	Heteroptera
Family	Pentatomidae
Scientific name	*Scotinophara coarctata* (Fabricius) and related species

History

Forty-one species belonging to the genus *Scotinophara* are known — 26 from Asia, 2 from Europe, 11 from Africa, and 2 from Australia. Four of them attack rice plants in Asia. *S. coarctata* was described in India but is important on rice in Malaysia, Indonesia (Java and Sumatra), Brunei, Thailand, and the Philippines (Palawan). Heavy infestation has been reported on Palawan since September 1979. *S. latiuscula*



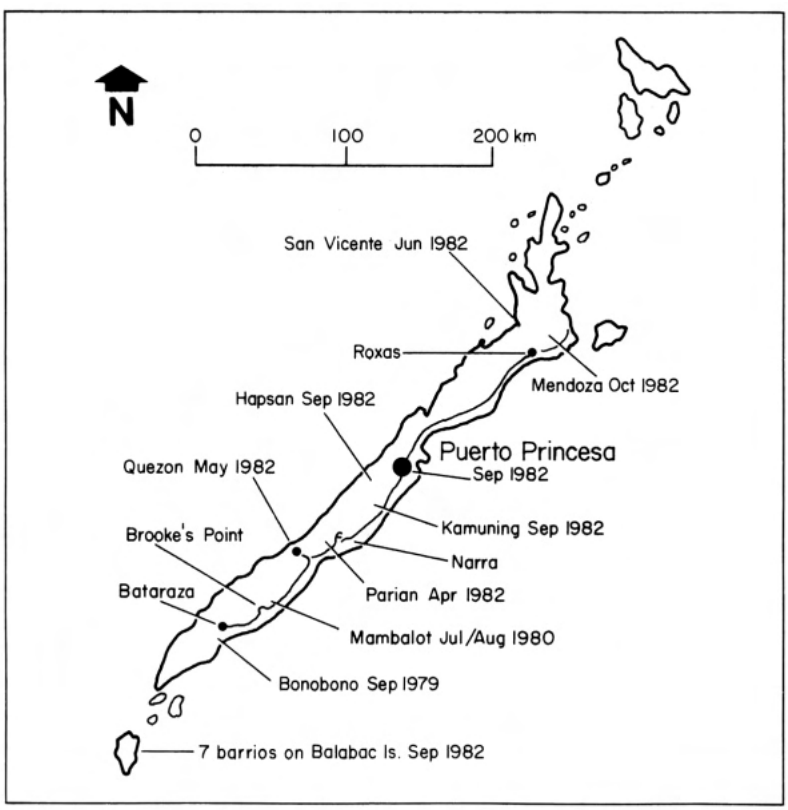
6. Lowland rice-growing areas (⊖ survey sites, ●= not surveyed) and sites (*) where *Scotinophora coarctata* was collected in Sabah (Mochida et al 1983).

Breddin was reported in rice in Luzon, Philippines. *S. lurida* (Burmeister) is widely distributed in India, Sri Lanka, Thailand, Vietnam, Kampuchea, Japan (from Isigaki to Honshu), and Taiwan, China. It was one of the most serious insect pests on rice in 4 prefectures along the Japan Sea more than 20 yr ago but is no longer important in Japan (Miyamoto et al 1983). In Sarawak, Rothschild (1967) reported two other species as minor pests on rice — *S. cinerea* (= *S. latiuscula*) and *S. serrata* (Vollenhoven).

Pest situation

In Indonesia, serious damage to rice crops by *S. coarctata* has frequently been reported in several parts of Sumatra; along the Barito, Kapuas, and Kahojanu Rivers in Kalimantan; and in West Java.

In East Malaysia, a heavy infestation of *Scotinophara* spp. on lowland rice was reported in Kota Marudu in 1979 (C. T. Pang, pers. comm.). *S. coarctata* was confirmed to be distributed widely in Sabah (Fig. 6). In West Malaysia, *S. coarctata* was recorded as a pest on rice a half century ago (Corbett and Yusope 1924) and confirmed by the author as an important rice pest in Tanjong Karan, Serdang, in



7. Spread of *Scotinophora coarctata* on Palawan Island, Philippines, since 1979.

1979. The area of occurrence has been increasing recently (Ministry of Agriculture, Malaysia, unpubl. data).

In Brunei, *S. coarctata* was confirmed by the author as an important rice pest in Wasan.

In the Philippines, S. coarctata has infested lowland and upland rice since 1979 only in Palawan (Mochida et al 1986) (Fig. 7).

Biology

During her lifespan, a female deposits several hundred eggs in masses of 40-50. The egg stage is about 5 d. Females protect their eggs from spiders and egg parasites. The nymphal stage is 35-42 d. The adult stage may extend to 7 mo (Grist and Lever 1969). Adults enter the water when approached. Grist and Lever (1969) described three plants as alternate hosts: *Scirpus grossus, Scleria sumatrensis,* and *Hymenachne pseudointerrupta. Scotinophara coarctata* nymphs grow to adults on taro and maize under experimental conditions.

Control

Monocrotophos, carbosulfan, endosulfan, fenthion, triazophos (0.5 kg ai/ha), carbofuran 3 G (0.5 kg ai/ha), deltamethrin (0.0125 kg ai/ha), and permethrin (0.05 kg ai/ ha) are effective (Mochida et al 1986).

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Progress in seed health research on seedborne and contaminant bacteria, viruses, and nematodes

M. GOTO, R. S. ZEIGLER, and V. T. JOHN

Seed transmission has been confirmed for *Xanthomonas campestris* pv. *oryzicola, Pseudomonas fuscovaginae, P. avenae, P. glumae,* and *Pseudomonas* sp. out of I2 pathogenic bacteria causing rice diseases or isolated from rice grains. Seed transmission of *X. campestris* pv. *oryzae* is still controversial despite intensive studies. Other bacteria have been reported as not transmitted by seed. *Erwinia herbicola* was reported to attack only grains, turning the palea brown; its transmission by seed must be investigated. Some of these bacteria were known before as weakly virulent or saprophytic. The development of these bacterial diseases in severe forms in Japan seems to be favored by the change in the cropping system caused by the use of mechanical rice transplanters. Methods for inspecting the infected or infested seed are discussed. Rice virus diseases have been considered not transmittable by seed, but recently two viruslike diseases, wrinkled stunt and witches' broom, were reported to be seedborne in growth chamber experiments. This must be confirmed in the field. Of 12 nematodes pathogenic to rice, only *Aphelenchoides besseyi* is known to be seed-transmitted. Although the damage it causes has diminished in Japan, emphasis bas recently been placed on its importance in Latin America. Prospects for research as well as quarantine policy on seedborne bacteria, viruses, and nematodes are discussed.

The international transfer of seed always entails the risk of global distribution of plant pathogens. Quarantine procedures and policies have been developed to prevent such occurrences. Generally speaking, however, rice seed health has not been given due attention with regard to bacterial, viral, and nematode diseases. The dissemination of *Xanthomonas campestris* pv. *oryzae* (Ishiyama) Dye (hereafter called Xco) through seed has been controversial for a long time; seedborne *X. campestris* pv. *oryzicola* has not been established so far in temperate regions despite the extensive transfer of seed as genetic material; and the damage caused by the seedborne nematode *Aphelenchoides besseyi* has not been significant in the past few decades. However, recent outbreaks of bacterial diseases on panicles and

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seedlings in Japan and elsewhere have provoked serious attention to the importance of seed health in rice.

This review presents recent information on rice diseases caused by bacteria, viruses, and nematodes that seem to be associated with seed in any manner.

BACTERIAL DISEASES

Innovations in cropping systems or crop management sometimes bring unforeseen plant health problems. The change from lowland nurseries to nursery boxes for use with a widely adopted mechanized rice transplanter in Japan may have resulted in increased seedling damage caused by bacteria, and in the subsequent spread of diseases in the field. Some such diseases are caused by bacteria previously thought to be only weakly virulent.

Seed transmission of bacterial diseases

Table 1 lists the bacteria that cause diseases in rice. In addition, the pathogen *Erwinia carotovora* ssp. *carotovora* (Jones) Bergey, Harrison, Breed, Hammer, and Hontoon has been isolated from rice grains. Most of these bacteria can be isolated from grains of infected rice plants, but others may also be present in seed from symptomless plants.

Evidence of seed transmission has been obtained for *X. campestris* pv. *oryzicola, Pseudomonas avenue, P. glumae, P. fuscovaginae,* and *P. syringae* pv. *syringae.* Although Xco persists in infected rice grains, seed transmission under natural conditions remains to be proven, despite some articles reporting positive results. *P. glumae* is a pathogen that attacks primarily grains, but other bacteria causing diseases of leaves or leaf sheaths may infect rice grains at panicle emergence. Several bacterial species other than those mentioned have been isolated from seed or brown rice and have been identified mainly from the viewpoint of food hygiene (Ou 1972); these saprophytic bacteria are not considered here.

Table 1. Bacterial diseases of rice.

Disease	Bacterium
Bacterial blight	*Xanthomonas campestris* pv. *oryzae* (Ishiyama) Dye
Bacterial leaf streak	*Xanthomonas campestris* pv. *oryzicola* (Fang, Ren, Chen, Chu, and Wu) Dye
Bacterial brown stripe	*Pseudomonas avenae* Manns
Sheath brown rot	*Pseudomonas fuscovaginae* Tanii, Miyajima and Akita
Bacterial grain rot	*Pseudomonas glumae* Kurita and Tabei
Seedling blight	*Pseudomonas* sp. (to be named *Pseudomonas plantarii* Azegami, Nishiyama, Watanabe, Kadota, Ouchi, and Fukazawa)
Bacterial halo blight	*Pseudomonas syringae* pv. *oryzae* Kuwata
Bacterial sheath rot	*Pseudomonas syringae* pv. *syringae* van Hall *(=Pseudomonas oryzicola* Klement)
Bacterial foot rot	*Erwinia chrysanthemi* pv. *zeae* (Sabet) Victoria, Arbeleda, and Muñoz
Bacterial palea browning	*Erwinia herbicola* (Lohnis) Dye
Brown stripe	*Erwinia* sp. of "*amylovora* group"

No information is available about seed transmission of *E. chrysanthemi* pv. *zeae.* Seed transmission of *P. syringae* pv. *oryzae* was reported to be negligible in greenhouse trials both with rice seed from fields where bacterial halo blight occurred and with those artificially inoculated (Kuwata 1985, Oikawa et al, 1986). *E. carotovora* ssp. *carotovora* was isolated from seed in the Ukraine and was reported to be pathogenic on rice seedlings before tillering (Koroleva et al 1984). However, the results must be reviewed because of the absence of detailed information on the taxonomic and pathogenic traits of the strain. Information is also too limited to verify seed transmission of bacterial brown stripe of upland rice in Brazil, which was reported to be caused by *Erwinia* sp. of the *"amylovora* group" and thought to be seedborne (Faira and Prabhu 1984).

Pathogenic bacteria detected in rice seed

Xanthomonas campestris pv. *oryzae.* Pathogenicity of this bacterium, which causes bacterial blight, is expressed by two phases of infection: elongated white lesions on the leaves (leaf blight), and systemic infection that wilts the entire plant (kresek).

Persistence of Xco in rice hulls for several months after harvest has beer. demonstrated. In contrast to bacterial diseases caused by pseudomonads, seedborne infection by Xco of rice plants either in nurseries or in fields has not been proved, despite intensive studies in Japan (Mizukami and Wakimoto 1969, Murty and Devadath 1984, Sato et al 1979, Tagami et al 1963). Available information implies that the pathogens in seed hulls emerge into the water during imbibition prior to germination, but die before the first leaf develops, resulting in failure to infect seedlings. The ecological or physiological features of the quick decline of Xco in water remain to be determined, although bacteriophages may be involved (Kauffman and Reddy 1975). Some data suggest the epiphytic survival of Xco originating from infected seed. Seedlings raised from unsterilized seed showed no visible symptoms, but bacterial exudation tests suggested the presence of Xco on the seedlings. In contrast, bacterial exudation tests were negative for seedlings raised from sterilized seed. Seeds taken from ostensibly disease-free plants were also positive in bacterial exudation tests (Isaka 1973). The capacity of the bacterium to multiply on the rice phyllosphere should, however, be confirmed by more direct methods.

There are claims that seedlings are infected through seed (Koroleva et al 1985, Reddy 1983, Singh et al 1983, Srivastava and Rao 1964), but most of the experiments were conducted with relatively few seeds, and the conclusions contradict those obtained with larger numbers of seeds. Such discrepancies may arise from seed inspection methods as well as from the definition of pathogenicity. Isolation of Xco from rice grains in storage is often made difficult by the presence of rapidly growing saprophytic bacteria such as *E. herbicola.* No useful selective medium has been developed. Fastidious nutritive traits of Xco may be responsible for the failure to develop selective media. Therefore, in addition to the application of drug-resistant mutants (Hsieh et al 1974), several indirect methods have been widely used to detect the pathogen in nature, at the inevitable sacrifice of precision. When these indirect methods, discussed below, are applied to seed transmission of Xco, care must be taken to avoid misinterpretation of the results.

- *Bacterial streaming.* In infected rice seed in storage, Xco is often replaced by saprophytic bacteria. The saprophytes may persist longer than the pathogen, and the bacteria that stream out of rice hulls may be only contaminants. Unless Xco is confirmed by isolation, streaming should be considered as merely suggestive.
- *Bacterial exudation method.* This method tries to detect the presence of Xco streaming out of the leaves at the inoculation site. Unless typical lesions of bacterial blight develop on the inoculated leaves, the bacterium should be purified to conclude that the streaming bacteria are Xco.
- *Phage technique.* A positive phage reaction is usually reliable to show the presence of Xco. When the phage technique is applied in situ, however, negative reactions may result from host specificity of phages, and from bacterial populations below the phage multiplication threshold (Goto 1969, Goto and Okabe 1965).
- *Identity of bacteria.* The identity of suspected pathogens isolated on agar plates should be proved by either the pathogenicity test, phage sensitivity test, Hugh and Leifson test (Hugh and Leifson 1953), or serological test to eliminate possible confusion with *E. herbicola,* which is most frequently isolated from rice hulls and forms yellow colonies on agar plates.
- *Pathogenicity.* Pathogenicity is the most reliable method of confirming the identity of the bacteria isolated from infected seed or diseased seedlings, presumably through infected seed. However, the positive results in seed transmission of Xco are not always reliable despite positive pathogenicity tests, mainly because of inadequate inoculation methods. Inoculation tests for this purpose must be made on expanded leaves of mature seedlings. Positive results must be interpreted only as the development of elongated typical lesions of bacterial blight from which Xco can be isolated on agar plates. Symmetrical brown or white spots of various sizes with definite borders are often induced around pricks when the inoculum is prepared by macerating rice hulls. This type of reaction is not determinative unless Xco is re-isolated on agar plates. Pricking of seedlings at the base has been used to detect infection through seed (Durgapal et a1 1980). Even if some damage has occurred on seedlings and bacterial streaming is observed, it is not conclusive unless the pathogenic bacterium is isolated and its virulence confirmed (Pandey 1984).

In summary, infected rice seed can definitely carry Xco until the following crop season, depending on the infection rate in the field as well as storage conditions. However, seeds seem to be a weak point in the life cycle of the pathogen, because seedling infection rarely takes place, and disease incidence through infected seed is much lower than that originating from other sources such as straw, stubble, volunteers, ratoons, wild rice, or susceptible weeds (Mizukami and Wakimoto 1969).

Xanthomonas campestris pv. *oryzicola.* Bacterial leaf streak caused by *Xanthomonas campestris* pv. *oryzicola* (Fang et al) Dye produces water-soaked, translucent streaks confined between veins. The lesions enlarge lengthwise and sometimes laterally over the veins. Later, the diseased leaves turn orange to brown

and die. A copious bacterial exudate appears on the surface of the lesions as small yellow beads.

Seed transmission of this bacterium was clearly demonstrated by Shekhawat and Srivastava (1972). Infected seed constitutes a potential source of epidemics, especially in single-cropped areas, since there is no evidence of any other plant acting as host. Seed infection in panicles occurs from bacterial exudates on the flag leaf. These bacteria survive under the glumes in mature seeds. During germination, the coleoptile, leaf sheath, and first leaf are infected through the stomata. Seed transmission was confirmed in both outdoor plots and the laboratory, where individual seeds were examined in test tubes. Seven percent of the individual seeds that germinated in test tubes developed water-soaked minute flecks on the first and second leaves. The lesions enlarged to 2 mm long in a few days and turned brown. The identity of the bacterium was confirmed by isolation and pathogenicity tests.

Pseudomonas fuscovaginae. Bacterial sheath brown rot caused by *Pseudomonas fuscovaginae* Tanii, Miyajima, and Akita has been reported in Asia, Latin America, and Africa (Autrique and Maraite 1983, Miyajima et al 1985, Tanii et al 1976, Zeigler and Alvarez 1986). Dark-brown to grayish-brown blotches with no definite margins develop on the flag leaf sheath. Young panicles in such diseased sheaths are infected. Dark-brown blotches also develop on the lower leaf sheaths at the water level of transplanted seedlings.

Miyajima (1983) found that the pathogen could be isolated from infected seeds with rusty blotches on their hulls and from rusty brown rice, but not from seeds with only brown flecks on their hulls. In seeds, after storage for about 6 mo, bacteria were detected at a concentration of 0.4-8 × 10^4cells per grain, 1-2% of these bacteria being *P. fuscovaginae* when it is present. The pathogen survived in dry grains until the next fall at the longest. These infected seeds sown in sterilized soils caused the disease when rice plants at booting were kept under wet conditions. Zeigler and Alvarez (1986) were able to isolate the pathogen from symptomless seeds at a low frequency.

Serious rot damage caused by *P. fuscovaginae* was reported in northern Japan on seedlings just after transplanting, but it is not known if it was seedborne (Miyajima 1977, 1983). Planting of infected seed develop few symptoms when booting and later stages occur during dry periods (Zeigler, unpubl. data).

Pseudomonas avenae. Bacterial brown stripe caused by *Pseudomonas avenae* Manns was known as a disease of millet *(Panicum miliaceum)* and Italian millet *(Setaria italica)* before it was found on rice seedlings (Elliott 1923, Ikata and Yamauchi 1931, Okabe 1934). The symptoms on rice seedlings are brown stripes on leaves and leaf sheaths, bending of leaf sheaths, and elongation of mesocotyls (Goto and Ohata 1956, 1961). Seed germination is also inhibited. The disease was first seen in lowland and upland nurseries and in greenhouse pots. Presently, losses are related to seedling damage occurring in nursery boxes adapted to mechanized transplanters. The first observation of the disease in nursery boxes was made in 1976 in Niigata Prefecture, Japan (Tominaga et al 1983). Early in the 1980s, as many as 10,000-30,000 boxes were affected. The disease is aggravated in nursery boxes when the seed is water-soaked to obtain uniform germination. Secondary infection of the bacterium in nursery boxes is not as severe as that of *Pseudomonas glumae.* The infected seedlings are scattered in the boxes rather than forming patches. Seed

transmission has been confirmed by germination of artificially inoculated seeds in test tubes. Bending symptoms appeared on seedlings after incubation for 3 d (Sato et al 1983).

P. avenae is carried in symptomless seeds that become the primary source of infection in nursery boxes. These carrier seeds can be obtained from panicles inoculated a few days before or after flowering. The highest rate was observed when flowering panicles were inoculated (Kadota and Ouchi 1985).

Pseudomonas glumae. In addition to *Pseudomonas glumae* Kurita and Tabei, which causes bacterial grain rot, several bacteria have been isolated from diseased grains showing similar symptoms. They were *P. syringae* pv. *aptata,* a strain of *P. fluorescens,* and an unidentified bacterium. These bacteria attack rice grains under lower temperatures than does *P. glumae* (Goto and Ohata 1958, Goto et al 1983).

Bacterial grain rot was found in the Kyushu district of Japan in the early 1950s. The symptoms were first described by Goto and Ohata (1956, 1958). A subsequent taxonomic study revealed the pathogen to be a new species, which was named *P. glumae* (Kurita and Tabei 1967). The grains on the panicles turn greenish white at first, become pale pink to yellowish brown, and then dry up. In diseased grains, brown to dark-brown lesions are observed on the basal part of the hulls. The lesions gradually enlarge upward; as soon as they appear at the base of the grains, the hulls turn faded green and begin to wither. The affected grains are either sterile or carry brown rice with dark-brown discoloration at the base. In severe cases, more than half of the grains on a panicle are attacked. The symptoms vary considerably, depending on the temperature and the amount of N applied before panicle emergence (Kan 1985). The typical symptoms mentioned above develop under higher temperatures of around 30°C or minimum temperatures between 21 and 26°C, whereas only dark-brown discoloration of the palea occurs at lower temperatures of 16-20°C (Goto 1980, Yokoyama and Nakayama 1986). Small light-brown to dark-brown spots or stripes appear on the ligules, collars, and upper edges of the leaf sheaths. Coincidence of the development of these two symptoms (on grains and leaf sheaths) ranged between 65 and 90%, depending on the cultivar. A selective medium for *P. glumae* has been developed (Tsushima et al 1986). Highly specific antisera have been effective for the rapid and accurate identification of *P. glumae* isolated from infected panicles, seeds, and seedlings (Isogawa et al 1986).

P. glumae originating from infected seed or lightly infected seedlings may grow in the phyllosphere without producing symptoms throughout the rice-growing stages at a relatively low density. As the panicles emerge, however, the pathogen population in the grains rapidly increases (Goto 1982, 1983). The highest infection of the grains occurs when the flowering panicles are infected a few days after emergence.

After 1956, bacterial grain rot was a minor disease in Japan, with limited areas affected and low crop losses, but in the early 1970s its severity increased, coinciding with wider use of the rice transplanter. In 1976 it was found that the bacterium causes an entirely different syndrome — seedling rot in nursery boxes — which seems to be seedborne. Seedling rot in nursery boxes may occur on seedlings derived from

infected seed, on those infected during presowing water soaking, or on those infected secondarily (Uyematsu et al 1976).

Seedling rot has scarcely been observed in lowland nurseries, even if infected grains were present in seed. In artificial inoculation tests, infection occurred most severely on seeds that were soaked in water to make the embryo partly emerge. Seedlings raised from infected seeds or those infected during water soaking are usually killed by rotting. When infection takes place 10-12 d after sowing, the disease becomes less severe and induces either brown discoloration of the leaf sheaths or death of the folded youngest leaf (Endo 1985).

Pseudomonas plantarii. Seedling blight has been found in Chiba and Niigata Prefectures, Japan (Azegami et al 1985, 1987b; Kadota and Ouchi 1985). The disease also occurs in nursery boxes. Marked growth inhibition of the root system is observed in infected seedlings, which turn yellowish white and easily lodge. They eventually wither and die, but never rot. This bacterium is characterized by the production of tropolone, which is toxic to root formation and subsequent growth of rice. It was identified as a new bacterium based on pathological, physiological, and biochemical properties, and will be named *P. plantarii.* Although this disease seems to be seedborne, the life cycle of the pathogen and its behavior on rice plants have not yet been clarified.

Pseudomonas syringae pv. *syringae.* Klement (1955) first described this pathogen from southern Europe. The symptoms of bacterial sheath rot are identical to those caused by *P. fuscovaginae.* Seed transmission has been proved. Young et al (1978) decided that this pathogen was equivalent to *Pseudomonas syringae* pv. *syringae* van Hall (=*Pseudomonas oryzicola* Klement). It may be distinguished from *P. fuscovaginae* by arginine dihydrolase and oxidase reactions, which are negative for pv. *syringae* and positive for *P. fuscovaginae.*

Erwinia herbicola. The well-known saprophytic epiphyte *Erwinia herbicola* (Lohnis) Dye can easily be isolated from the surface of healthy plants as well as wounded or diseased plant tissues. The bacteria have peritrichous flagella and grow quickly on nutrient agar plates, forming separate yellow colonies within 24 h. Because of these traits, the organism was often misidentified as a plant pathogen in the early days of plant bacteriology. For example, *Bacillus oryzae* Hori et Bokura (Bokura 1911), incorrectly identified as the bacterial leaf blight pathogen, is now presumed to be *E. herbicola.* Rice plants, like other plant species, carry a high population of *E. herbicola* as an epiphyte. Although it is nothing but a saprophyte in most cases, it sometimes causes brown discoloration of the palea on panicles. This disease was named bacterial palea browning (Azegami et al 1983, Yoshida et al 1982). It was first reported by Yoshida and Yasugi (1980), who confirmed pathogenicity of the bacterium by spray inoculation. The disease is characterized by brown to dark-brown discoloration of the palea a few days after panicle emergence. Discoloration sometimes reaches 30% of the grains on a panicle. Both high temperature and humidity at flowering seem to be essential for disease development. A crop loss assessment revealed that infected grains reached about 10% of total seeds in the most severe case; about 15-20% of these infected seeds were sterile, the remainder yielding low-quality rusty brown rice.

E. herbicola consists of strains that are extremely heterogeneous in physiological and biochemical traits. It is uncertain whether the pathogenic strain of bacterial palea browning is distinct from the saprophytic ones. The pathogen of bacterial palea browning is likely to be a facultative parasite, because inoculation tests imply that the virulence of these strains is very low (Azegami et al 1983). The bacterium does not induce disease on rice plant tissues other than the grain. Because of the remarkable epiphytic nature of *E. herbicola,* it is unlikely that infected seed is important as an inoculum source in fields.

Distribution and importance of seedborne *Pseudomonas* spp.

Most of the research on *Pseudomonas* spp. that attack rice grains has been conducted in Japan. Until very recently, the distribution of these pathogens was thought to be limited to Japan and other temperate areas. However, several recent reports indicate that some of them are more widespread. Shakya et al (1985) reported *P. avenae* to be present in rice seed from 28 countries. Zeigler and Alvarez (1986) reported *P. fuscovaginae* to cause sheath rot and grain discoloration in rice in Latin America. A survey of discolored rice seed received by the International Center for Tropical Agriculture (CIAT) from various countries (Table 2) showed that pathogenic fluorescent *Pseudomonas* spp. are widespread in Latin America (Zeigler, unpubl. data). In this first survey, heterogeneity was found among pathogens. For example, Chilean isolates are most similar to *P. syringae* pv. *syringae,* while isolates from the other countries may be considered to be *P. fuscovaginae.* Thus, the global distribution of these pathogens is probably very complex.

The economic importance of these pathogens is unknown at present. Miyajima (1983) measured yield losses, on a hill basis, and found hulled weight reduced up to 58% when infection was severe. However, no data have been published on yield losses at production levels. Zeigler and Alvarez (1986) suggested that *P. fuscovaginae* and related species may play an important role in the "dirty panicle" (glume discoloration, *manchado de grano*) disease that seems to be increasing in worldwide importance. That the samples presented in Table 2 were from rice described only as suffering from "dirty panicle" disease by those who sent the samples to CIAT supports this idea.

Isolating *Pseudomonas* spp. from rice

The most simple method of isolating and purifying fluorescent *Pseudomonas* spp. from rice is to plate tissue on King's B medium and purify those isolates producing pigments that fluoresce under longwave, near-UV light. The efficiency of isolation of *P. fuscovaginae* can be increased by adding penicillin (750,000 units/liter), ampicillin (750,000 units/ liter), and cycloheximide (750 mg/liter) to the medium. Impure isolates can be purified by injecting into the leaf sheaths of 15- to 25-d-old seedlings and reisolating from the margins of necrotic lesions on King's B medium.

The virulence of *P. fuscovaginae* (Zeigler, unpubl. data) and *P. glumae* (Kamiunten et al 1985) is unstable and can be lost during repeated transfer. Therefore, serial transfers to separate fluorescent strains from common contaminants such as *E. herbicola* can yield nonpathogenic variants of the organisms.

Table 2. Origin of samples of discolored rice grain from which pathogenic isolates of fluorescent *Pseudomonas* spp. were obtained by CIAT. All isolates reacted positively with *P. fuscovaginae* antiserum.

Country	Variety[a]	Symptoms[b]		Arg	Ox
		ShR	GD		
Argentina	BL, IRGA409, Bluebonnet 50	+	+	+	+
Bolivia	BL	+	+	+	+
Brazil	BI, IRGA409, IRGA410, CICA8, CICA9, IAC164, Bluebelle	+	+	+	+
Burundi	?	...	+	+	+
Chile	BL, Ovacion, Oro Quella	+	+	−	−
Colombia	BL, CICA4, CICA8, Metica 1, Oryzica 1	+	+	+	+
Costa Rica	CR201	...	+	+	+
Dominican Republic	BL	+	+	+	+
Ecuador	BL, INIAP7, INIAP10	...	+	+	+
El Salvador	CENTA A-2	+	+	+	+
Guatemala	BL, IRGA501	+	+	+	+
Jamaica	Inglés, CICA8	+	+	+	+
Nicaragua	BL, CICA8	+	+	+	+
Panama	BL, CR1113	+	+	+	+
Peru	?	+	+	+	+
Philippines	BL, IR58, JKAU	+	+	+	+
Surinam	Camponi, Eloni	+	+	+	+
Uruguay	?	+	+	+	+

[a]BL = breeding line, ? = unknown. [b]ShR = sheath rot or discoloration, ... = sheath samples not received, GD = grain discoloration, Arg = arginine dihydrolase test, Ox = oxidase test.

This can be avoided by the following method: 1) plate tissue on King's B medium; 2) after 24-48 h, transfer fluorescent colonies (with contaminants) to nutrient broth; 3) incubate at 24 °C for 24 h; 4) inject nutrient broth directly into test seedling; 5) reisolate pathogen from necrotic margins at least 3 cm from the point of inoculation.

This method may be enhanced by testing the nutrient broth culture with a reasonably specific antiserum (Zeigler, unpubl. data). A strong positive agglutination reaction indicates that the pathogen is present and that the broth culture should be used to inoculate test plants. A negative reaction indicates that the pathogen is present in such low concentration that inoculation will be unlikely to yield positive results. However, this method is useful only when looking for a specific pathogen; it should not be used if unsure which, if any, of the several *Pseudomonas* spp. capable of causing grain and sheath disorders of rice is involved.

Phages have been used to detect low levels of *P. fuscovaginae* in seed samples and on leaves and sheaths (Miyajima 1983). Although this method is useful for epidemiological studies, it does not aid in isolations. Likewise, the serological method for enhancing recovery success is of use only if one is reasonably certain of the identity of the pathogen.

Selective media are probably the most useful means of isolating these pathogens. This is particularly important for the nonfluorescent pseudomonads such as *P. glumae* and *P. avenae.* For *P. glumae* and *P. avenae,* selective media have

been developed (Kadota and Ouchi 1987, Tsushima et al 1986), and some work has been conducted at CIAT. However, the most promising antibiotics in initial attempts (tetracycline, refomycin, and pyocillin) were found to have differential activity within pathogenic groups tentatively classified as the same species.

Control of seed transmission of bacterial diseases

Intensive studies have been made in Japan for controlling seedling rot caused by *P. glumae* in nursery boxes. The recommended cultural control methods include I) eliminating the infected seeds by saltwater selection with a specific gravity of 1.18, 2) keeping the bed surface even and level to avoid localized standing water, 3) avoiding overwatering, and 4) temperature management between 15 and 30 °C (Goto 1982).

Effective compounds for chemical control of *P. glumae* include kasugamycin, thiram, benomyl, copper hydroxy nonylbenzenesulfonate, ammonium ethylenebis (dithiocarbamate), methasulfocarb, and NaOCl. The most effective control has been obtained by soaking seed in kasugamycin solution for 24-48 h, or by mixing kasugamycin dust with bed soil before sowing. In applying NaOCl, care should be taken to avoid phytotoxicity to seedlings (Endo 1985, Isogawa 1986, Omori and Watanabe 1986). Chemical control of bacterial grain rot on panicles in the field seems to be more difficult than that of seedling rot in nursery boxes. When the disease occurs in a severe form, the chemicals mentioned above become less effective; a new compound (Code No. S-0208) seems effective. The effectiveness of chemical spray is expected only when it is applied at or a few days after panicle emergence (Isogawa 1986, Yasunaga et al 1985).

P. fuscovaginae may be eradicated from seed samples by dry heat treatment at 65 °C, for 6 d (Zeigler and Alvarez 1986). This harsh treatment does not significantly reduce the germination of recently harvested indica rice, which remains high for several months. This treatment is useful for experimental seed lots, and CIAT heat-treats all seed sent to cooperators. The pathogen is also susceptible to kasugamycin. Zeigler (unpubl. data) found that a 20 ppm concentration of this antibiotic significantly reduces colony growth in vitro, and 40 ppm completely inhibits growth. The usefulness of this product as a seed treatment is being investigated; however, preliminary results indicate that 0.2 g ai/kg seed can substantially reduce pathogen frequency.

Seed treatment with kasugamycin effectively controls damage to seedlings caused by bacterial brown stripe in nursery boxes (Yaoita 1985, Yaoita and Fujimaki 1984). Applying kasugamycin at high dosage also effectively controls bacterial palea browning on panicles. Streptomycin plus oxytetracycline mixtures have been used to control bacterial sheath brown rot in fields (Miyajima 1983). The application of Fe compounds effectively suppresses the development of bacterial blight *(P. plantarii)* because the pathogen does not produce the toxin tropolone in the presence of Fe (Azegami et al 1987a).

Methods of seed health testing

Growth temperature. In seed health testing, enrichment procedures are often needed for the subsequent detection of causal bacteria. However, the procedures also

stimulate the growth of contaminants unless selective media are available. Growth of many pseudomonads, including several rice pathogens, is more active at lower temperatures than that of *E. herbicola,* the most common saprophytic bacterium in rice seed. Therefore, samples to be enriched for pseudomonads may be maintained at around 20 °C even if their optimum growth temperature is 28-30 °C. At this temperature, growth of *E. herbicola* is significantly retarded, delaying the accumulation of harmful metabolites that depress the growth of pseudomonads. Thus, the relative population level of pseudomonads to that of *E. herbicola* may be significantly raised (Goto et al 1970, Young et al 1977).

Direct examination. Because the discoloration of rice grains resulting from various causes is similar, it is difficult to specify the discoloration caused by a certain bacterium by direct examination, even with a microscope. Saltwater selection may be applicable for sampling seed to be examined by detailed methods such as agar plating, the phage method, or the serological method, because the infected rice grains that become sterile or ripen poorly have reduced specific gravity.

Selective media. The most common method for seed health testing is agar plating, in which seeds are put on the appropriate agar medium in petri dishes to determine infection with pathogenic bacteria. This is useful when the seeds carry simple microflora consisting of the pathogenic bacterium as a major component and a small number of contaminants. However, rice seeds often harbor a large number of rapidly growing saprophytic bacteria, making the agar plating method very difficult unless selective media are available. Although an efficient selective medium for Xco is not yet available, one has already been developed for *P. glumae* (Tsushima et al 1986). The development of selective media for other pseudomonads should be encouraged more than those for Xco because pathogenic pseudomonads are not as nutritionally fastidious as Xco.

Seedling symptom test. Seedling rot caused by *P. glumae, P. avenae,* and *Pseudomonas* sp. (=*P. plantarii*) is found primarily in heavily seeded nursery boxes in Japan, implying that the seedling symptom test may be applicable for these bacteria. Environmental factors such as temperature and humidity have been reported to be important for the development of these diseases in nursery boxes. Therefore, before the seedling symptom test is planned in vitro, the conditions for germinating rice seeds, the number of rice seeds to be used, and characteristic seedling symptoms for each disease should be carefully determined.

Inoculation test. For preparation of inocula, seed samples to be tested may be soaked in water, or husks broken into small pieces in water, so that the pathogenic bacteria exude from the tissues. The water is subjected to centrifugation after being filtered through cheesecloth, and the sediment is resuspended in a small volume of water. The suspension is inoculated on rice seedlings by pricking leaf blades with needles or by injecting into leaf sheaths with a syringe. Enrichment in the appropriate medium before inoculation may be effective. The rice leaf sheath is susceptible to bacterial invasion. When only small, restricted brown spots are produced around injection sites, the bacteria should be isolated on agar plates and their pathogenicity reconfirmed with dilute inoculum (around 10^4-10^5 cells/ml). When pathogenicity is confirmed, the bacteria should be identified by examining several properties described in brief identification schemes such as the levan,

oxidase, potato rot, arginine dihydrolase, tobacco hypersensitivity reaction (LOPAT) test (Lelliott et al 1966).

Phage test. Seed samples are macerated in an appropriate medium (e.g., nutrient broth) and maintained for a certain period of time (e.g., 24 h) to allow the causal bacterium to grow. The phage is added to the preparation, and aliquots of the mixture are plated on agar together with the indicator bacterium for counting the initial number of phage particles. After incubation of the mixture for several hours at the proper temperature (e.g., 20 or 28 °C), the phage particles are counted again. A significant increase indicates the presence of the host bacterium in the original samples. The phage may be directly added to the macerated seed at the initial step. In the phage technique, the specificity for bacterial strains, latent period, and burst size of the phage should be checked previously. Bacterial thresholds for phage adsorption are also important in analyzing the results (Goto 1969, Goto et al 1970).

Serological method. The serological method would be the most reliable and practical for seed health testing in combination with agar plating, as it has already proved to be effective with *P. glumae* (Isogawa et al 1986). Successful application of the technique is dependent largely on the immunological homogeneity of the bacteria under consideration. When the bacteria are too heterogeneous to share common antigens, the technique is difficult. Therefore, the immunological make-up of the bacterium under consideration should be examined first with a number of isolates of different geographical origin. The slide glass agglutination test or the immunofluorescent test may be most efficient for practical seed health testing. The monoclonal antibody technique should also be tested, as its potential usefulness is apparent (Alverez et al 1985).

DNA probing. When the species- or pathovar-specific DNA fragments for any phenotypic properties including pathogenicity are identified and cloned, these fragments may be used as the probe for screening pathogenic bacteria grown on isolation plates by the colony hybridization technique (Hanahan and Meselson 1980). Although the practical use of this technique is still being investigated, it may prove useful in seed health testing.

VIRUS DISEASES

More than 22 diseases affecting rice are reported to be caused by viruses or mycoplasmalike organisms (MLOs). All rice virus diseases are systemic and extremely damaging, especially in susceptible varieties at early growth stages. The symptoms vary from foliar discoloration and abnormalities to stunting, necrosis, incomplete flowering, and sterility. Yield reduction can be extremely high, often leading to complete loss.

Many virus diseases of rice are restricted to specific areas, mostly because of the specificity of their vectors. Japanese rice dwarf, Asian tungro, and African rice yellow mottle are examples of such specificity. The only disease with wide distribution is yellow dwarf caused by a MLO. One of the potential dangers of rice virus diseases is the introduction of yellow mottle outside Africa because of the susceptibility of Asian lowland rice to this disease.

Transmission of rice virus diseases

Most rice virus diseases are transmitted by arthropod vectors, chiefly leafhoppers and planthoppers (Table 3).

Only two viruslike diseases of rice are reported to be seedborne: wrinkled stunt and witches' broom. Both were observed in 1976-78 in Surinam, and affected seeds, when tested in growth chambers at the University of Wisconsin, confirmed the seedborne nature of the diseases. A very high percentage of seed transmission of wrinkled stunt and witches' broom has been reported (Ou 1985). However, each of the diseases has been found only in one line in Surinam. Rice necrosis mosaic virus was once reported as seedborne, but the seedborne nature of the virus has not been confirmed. No other virus disease is known to be transmitted by seed. Several thousand seeds have been tested for seed transmission of tungro virus without positive results.

A mechanically transmissible virus, rice yellow mottle, has been detected in all parts of the plant including the floral parts by agar-gel diffusion and by enzyme-linked immunosorbent assay (Thottappilly and John, unpubl. data) (Table 4). The fact that the fertilized ovary, developing into the seed, does not contain the virus is interesting; more than 5,000 seeds from infected plants failed to produce infected seedlings (International Institute of Tropical Agriculture 1986).

Why there is embryonic occlusion of rice viruses or inactivation in the embryo is not known. However, it is well known that such mechanisms do prevent viruses from being seedborne. The situation is comparable to nonovarial transmission of virus diseases in some insect vectors and to transmission through the eggs for successive generations in others.

Control measures

It is important to devise strategies for controlling seed transmission of wrinkled stunt and witches' broom to prevent outbreaks in other rice-growing countries. In wrinkled stunt, treating seed in hot water for 10-20 min at 52-55 °C does not control

Table 3. Vectors of rice virus diseases.

Vector	Diseases
Nephotettix spp.	Dwarf, tungro, waika, bunchy stunt, gall dwarf, transitory yellowing, yellow dwarf
Laodelphax striatellus	Stripe, black-streaked dwarf
Recilia dorsalis	Dwarf, orange leaf
Sogatodes spp.	Hoja blanca
Nilaparvata lugens	Grassy stunt, ragged stunt, wilted stunt
Rhopalosiphum padi	Giallume
Brevennia rehi	Chlorotic streak
Chaetocnema spp.	Yellow mottle
Seed	Wrinkled stunt, witches' broom
Soil	Necrosis mosaic
Mechanical	Yellow mottle, mosaic
Unknown	Crinkle

Table 4. Distribution of rice yellow mottle antigen in a flowering rice plant (Thottappilly and John, unpubl. data).

Part tested	Presence of virus[a]
Roots	+++
Crowns	+++++
Sheaths	+++
Older leaves	++++
Young leaves	++++
Florets	+++
Stamens	++
Pistils	++
Young fertilized florets	–
Seeds (milk storage)	–
Seeds (hard dough stage)	–
Seeds (harvested)	–

[a] – = not present, ++ = present, +++++ = most abundant.

the disease (Ou 1985). Thermal inactivation of this virus or of witches' broom is unknown. Similarly, soaking seed from witches' broom-affected plants in tetracycline hydrochloride solution at 5-200 ppm does not control the disease.

Experiments at IITA have shown that rice seed can withstand dry-heat treatment for 6-8 d at 75 °C without affecting germination. It is possible that such heat treatment might inactivate the viruses causing these two diseases. The seed transmission potential of other less well-known virus diseases should also be investigated.

NEMATODES

Nematodes attacking rice plants belong to the 12 genera listed in Table 5 (Hollis 1984). Their economic importance depends on the cropping system and geographical area. Of the 12, only the white tip nematode, *A. besseyi*, has been reported to be seedborne. The symptoms of *A. besseyi* infestation are pale-yellow to white necrotic lesions with twisted apices at the upper tips of leaves. Although this nematode invades several other cereals including *Setaria, Panicum,* and *Cyperus,* the damage is most intensive on rice (Ichinohe 1972). Small numbers of *A. besseyi* inside the leaf sheaths rapidly proliferate on young panicles at booting and proceed inside the palea. They coil up in the seeds and retain viability in grains stored dry for at least 3 yr. The white tip nematode has been a minor pest in Japan and the subject of a limited number of scientific papers published since 1970. However, it may become a troublesome pest under new environments or new cropping systems, as in Latin America, where it has been reported in Cuba, Mexico, El Salvador, and Brazil (Feakin 1970, Ou 1985, Sharma and Loof 1978). There is concern, particularly in Brazil, that local populations may achieve pathogenic variability through foreign introductions.

The most intensive studies on the distribution of *A. besseyi* in Latin America have been undertaken in Brazil (Ribeiro 1971, Sharma and Loof 1978). In São Paulo, more than half the 1972 samples collected were contaminated (Silveira et al

Table 5. Parasitic nematodes on rice (Hollis 1984).

Hirschmanniella spp.	Rice-root nematodes
Criconemella spp.	Ring nematodes
Meloidogyne spp.	Root-knot nematodes
Tylenchorhynchus spp.	Rice stylet nematodes
Ditylenchus angustus	Stem nematode
Aphelenchoides besseyi	White tip nematode
Heterodera spp.	Cyst nematodes
Pratylenchus spp.	Lesion nematodes
Helicotylenchus spp.	Spiral nematodes
Hoplolaimus spp.	Lance nematodes
Hemicycliophora spp.	Sheath nematodes
Rotylenchulus spp.	Reniform nematodes

1977). In Piaut, 8 of 28 samples were found to contain the nematode (Sharma and Loof 1978). There is some indication in Brazil that irrigated rice is more severely affected than upland rice (Silveira et a1 1977), which could be problematic in the future, because Brazilian rice culture is shifting to irrigation in the *varzeas* areas.

Losses to seed producers may occur in several ways. First, planting heavily infested seed may result in poor stand establishment. Second, direct yield losses caused by reduced panicle size and by sterility may reduce the productivity of seed lots. However, the most important effect is on seed quality in terms of germinability and certification. Since seedborne nematodes are the most important source of inoculum for the next season's crop, certifying agencies may condemn a seed lot unless it is properly treated.

The best means of avoiding problems with *A. besseyi* in seed production programs is not to plant infected seed. If the variety is known to be susceptible, basic or registered seed should be harvested only from plots in which there are no symptomatic plants. In resistant varieties, asymptomatic plants may harbor the pest in their seed (Taylor 1969). All seed production should therefore be undertaken in fields that have no history of the pest. When this is impossible, small lots of breeder seed may be treated with hot water at 52-53 °C for 15 min (Cralley 1952), which is commercially impractical. Treatment with nematicides can be effective (Feakin 1970) and may be warranted.

In the international exchange of rice germplasm, it is particularly important that the seed be free of *A. besseyi.* The seed is of such value that it should be protected against unnecessary loss. More importantly, all measures should be taken to avoid introducing the pest into uninfested areas. Because most introductions of rice germplasm are made via experiment stations, it is particularly important that this seed be nematode-free. Should these sites become infested, there exists the danger that they will serve as efficient avenues for the distribution of the pest to production areas as promising lines are advanced and evaluated. The International Rice Research Institute therefore treats outgoing seed with hot water, but CIAT does not, since the pest has not been found on its farm.

Brazil is very strict regarding rice seed introductions. All lines are checked for the presence of *A. besseyi.* The National Genetic Resources Center insists that seed to be evaluated for nematode contamination be chemical-free, since some seed treatments make it difficult to identify contaminated samples.

IMPLICATIONS FOR RICE GERMPLASM EXCHANGE

One of the dangers inherent in the modern approach of increasing agricultural production through the introduction of improved germplasm is that seedborne pathogens and pests may be spread to new areas. As appears to be the case with seedborne *Pseudomonas* spp., this may occur before the importance of the pathogen or pest — or the significance of its seedborne nature — is fully appreciated. Such oversight may be further complicated by the organisms being initially considered weak pathogens. The situation may also arise where a weak or unimportant pathogen in one environment or cropping system may take on far greater significance in a different agroecosystem. This risk may be high in rice, where the range of environments extends from deep water to upland and the cropping systems range from intensive small farmer transplanting to large-scale mechanized production.

Although some movement of pathogens may be part of the price of free exchange of germplasm among agricultural institutions, this should be kept to the absolute minimum. Institutions charged with coordinating and conducting the exchange of germplasm should make sure that their material destined for international exchange is grown under conditions unfavorable to disease and pest development. Furthermore, they should institute and improve prophylactic eradication measures against the pests and diseases when available. Institutions receiving rice germplasm should consider which pathogens and pests are already present in their area when establishing tolerance levels. Furthermore, the amount of seed that moves within the international marketplace is far in excess of that involved in institutional exchange. This seed is normally outside any phytosanitary control and may be a much more important means of pathogen and pest movement than germplasm exchange.

RESEARCH NEEDS

Bacterial pathogens of rice seed, particularly *Pseudomonas* spp., are either more important than previously believed or are increasing in importance. The taxonomic relationships among the different species must be determined to establish whether all the diseases discussed in this paper are in fact distinct. Research is needed to determine the economic importance of these pathogens. While most are seedborne and seed-transmitted, little is known of the importance of seed transmission in the ecology and epidemiology of the various diseases. For example, *P. fuscovaginae* has been reported to have a wide host range (Miyajima 1983, Zeigler et al 1986); however, it is not known how important the other hosts may be in the epidemiology of bacterial sheath brown rot, compared to seed transmission or soil and crop residue survival of the pathogen. Environmental conditions are extremely important in disease development, but these are only sketchily known. Detailed ecological and epidemiological studies should be undertaken in the different areas where the pathogens are present. Finally, varietal resistance should be explored as a means of reducing loss or risk of loss due to the most important pathogens.

Although wrinkled stunt and witches' broom were reported to be seedborne in growth chamber experiments, seed transmission of these diseases must be confirmed in the field. Also, the seed-transmission potential of the less studied rice viruses should be carefully reviewed in both laboratory and field.

The following subjects should be carefully checked before a conclusion is drawn on seed transmission of the white tip nematode and its effect on rice production in a given region: 1) identification and confirmation of pathogenicity of the nematodes found in rice seed, 2) yield-loss assessment with infected seed, 3) varietal resistance, and 4) practical methods of eradication. This information is particularly important in the tropics, where nematode damage has been less studied. Research on the nematode by plant pathologists should be encouraged.

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Fungal diseases of rice seed

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The fungi causing blast, brown spot, bakanae, udbatta, and stackburn are internally seedborne and result in diseased seedlings. In addition, *Curvularia* spp., *Alternaria* spp., *Sarocladium attenuatum*, and *Bipolaris sorokiniana* cause grain discoloration and reduce commercial value. The fungi producing spore masses on infected spikelets, such as false smut and kernel smut, disturb seed processing. Other fungi invade only the hulls, causing discoloration and reduced seed quality. Anatomical results of infection, location of the fungi in the seed, and epidemiology of the pathogens are explained. Measures to obtain healthy seed include site selection, fertilizer regulation, careful harvesting, gravity separation, chemical control before and after harvesting, and cold-and-hot- or hot-water treatment.

Fungal diseases of seed are classified into four categories:

1. The fungi invade both hulls and kernels, causing diseased seedlings.
2. The fungi invade both hulls and kernels, causing discolored and low-quality kernels. Pathogens belonging to Category 1 can also reduce quality.
3. The fungi produce spore masses on infected spikelets, causing problems in seed processing.
4. The fungi invade only hulls, causing discoloration and reducing the quality of commercial seed.

Fungi in Categories 1 and 2 are seed-infecting pathogens; those in Categories 3 and 4 are seed-contaminating.

CATEGORY 1

Blast *Pyricularia oryzae* Cav.

Seed infection. The blast fungus invades the spikelets, penetrating the epidermis of the hulls. Primary infection occurs frequently in empty glumes, pedicels, and the distal ends of hulls. Hyphae penetrate the outer surface of hulls, reaching the

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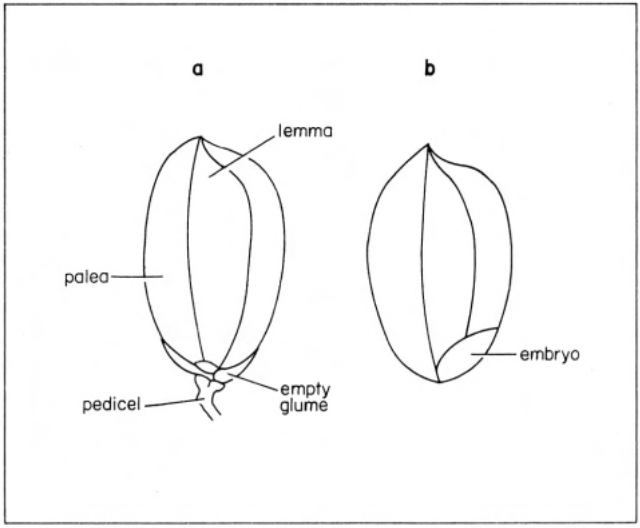
hypodermal tissue within 24 h. They reach parenchymatous tissue and inner epidermis in the next 24 h and vigorously spread to all tissues in the following 24 h. Mycelia are prevalent in the inner epidermis of the lemma at the thickened part next to the periphery of the lemma where it meets the palea. Growth is more profuse in the lemma than in the palea, and more profuse in the distal half than in the proximal half of the hull (Hirano and Goto 1963). Small hairs arise from the outer epidermis. Large hairs, the trichomes, are in contact with the hypodermal tissue at its base. Hyphae grow within the hair cells, and conidiophores protrude from the surface of the hairs (Hirano and Goto 1963, Kato et al 1970) (Fig. 1, 2).

Location of the fungus in seed. In samples collected from diseased panicles in the field, the pathogen is located abundantly in the lemma, palea, and empty glumes, in that order (Hirano and Goto 1963). After seed processing, the pathogen abounds in the empty glumes and pedicels because of the removal of severely attacked spikelets (Suzuki 1985, Yamaguchi et al 1979).

In kernels, infection is most frequently encountered in the hilum and placenta (Suzuki 1985, Yamaguchi et al 1979). In seed with 25% infected pericarp, the fungus was also found in the endosperm of 4%, but no mycelia were detected in the embryos (Chung and Lee 1983) (Fig. 3).

Disease incidence in seedlings. In submerged nurseries, blast is not a problem. Under upland conditions, especially in box nurseries for mechanical transplanting, an outbreak of the disease can be serious. The pathogen attacks seedlings during germination. Two processes of infection have been reported:

- The fungus grows from the hilum through the pericarp to the extruded tip of the scutellum or epiblast, to the coleoptile, and then to the primary leaf. Mycelia from the infected pericarp grow to the radicle and the extended tip of the coleorhiza (Chung and Lee 1983, Suzuki 1976).



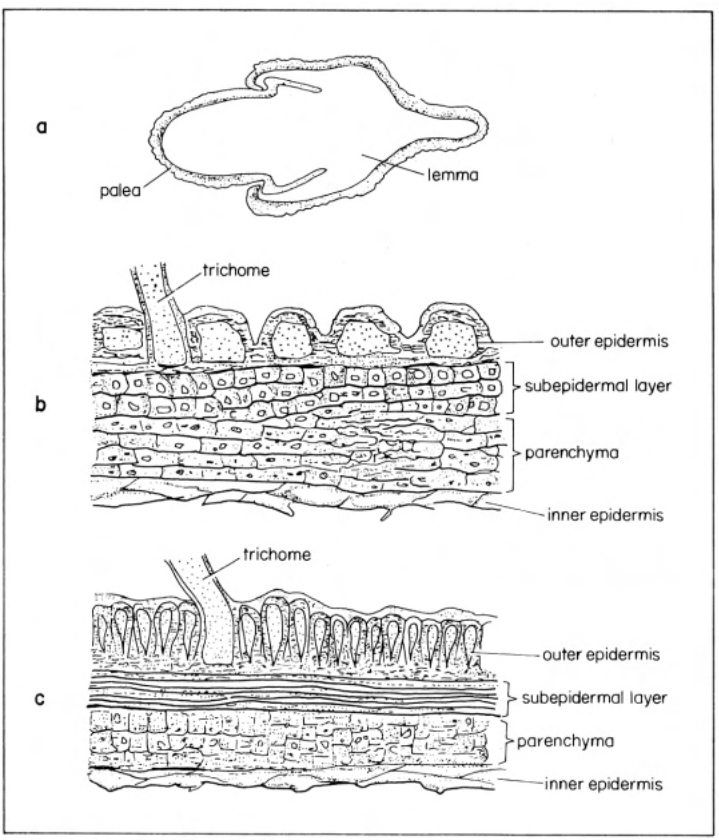
1. The spikelet (a) and kernel (b) of rice.

- Conidia produced on hulls or empty glumes reach the host tissues, such as the coleoptile, by contact or movement of water or air, followed by infection of the host tissue from outside. In this case, a covering of soil can protect the seedling against infection (Suzuki and Fujita 1977).

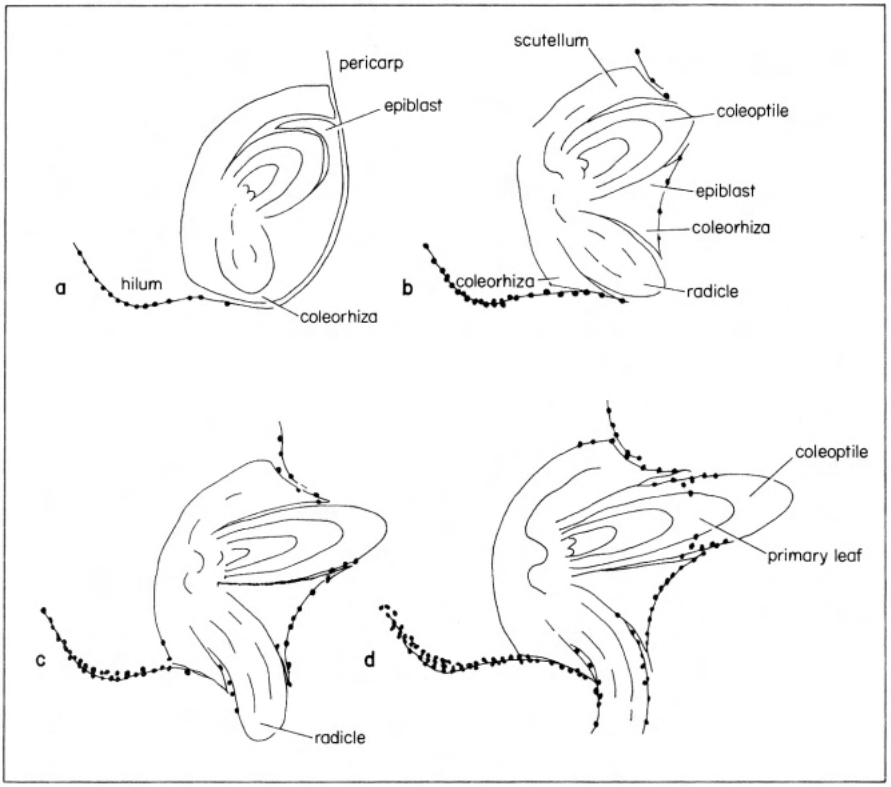
Epidemiology. Spikelet infection can occur anytime during grain maturation. Lesions may be identified by inoculation test until about 20 d after heading. The incubation period is from 5 to 12 d at 20-30 °C. On varieties with leaf resistance, spikelets are susceptible (Kato and Sasaki 1974).

Brown spot *Drechslera oryzae* Subram. et Jain

Seed infection. The most destructive injury to hulls follows hyphal invasion of parenchymatous tissue through the inner epidermis of the hulls at flowering. The germ tube passes through the space between the lemma and palea to reach the inner epidermis. The outer epidermis of the hull is protected from the fungus by a silicated layer, which increases with maturity. Invasion occurs through the basal part of the trichomes and the joints of the outer epidermal cells (Watanabe et a1 1976).



2. Cross section of spikelet (a), cross section of lemma (b), and longitudinal section of lemma (c) (Watanabe et al 1976).



3. Transmission of *Pyricularia oryzae* from the infected seed to the plumule and radicle of germinating rice (Chung and Lee 1983). Dots show infection. a. Sporulation of *P. oryzae* on the hilum and adjacent part of the pericarp after 1 d of incubation. b. The fungus has developed on the ventral part of the pericarp and the edges of the scutellum, epiblast, and coleorhiza after 2 d. c. Development of the fungus on the coleoptile of the emerging plumule and radicle after 3-4 d. d. Further development of the fungus between the coleoptile and the primary leaf.

Location of the fungus in seed. Diseased hulls are more numerous in empty glumes and pedicels than in the lemma and palea. In grains, the hilum and placenta are more severely infected than other areas (Suzuki 1985).

Disease incidence in seedlings. In upland and box nurseries, lesions appear on the coleoptiles, sheaths, and lower leaves, resulting in blight.

Epidemiology. The severity of the disease is influenced by the nutrient conditions of the host plants. A shortage of nutrients such as Fe, Mn, Mg, K, Si, Ca, and N is associated with an outbreak of the disease (Baba 1958, Kaur et al 1984). Root rot caused by high temperature at booting and heading affects the absorption of nutrients and causes serious damage (Ohata et al 1972).

Bakanae *Fusarium moniliforme* Sheld.

Seed infection. Flower infection has been demonstrated, and diseased seed has been proven to be the most important inoculum source compared with other sources such

as weeds (Seto 1935). When inoculated at flowering, mycelia develop on stigmas and anthers, and produce microconidia 2 d after inoculation (DAI) (Sasaki 1975,1987). Mycelia exist within the cells of anthers and the outer epidermis of hulls, and produce microconidia on the surface of hulls at 7 DAI.

Hypodermal and parenchymatous tissues eventually become filled with hyphae. Sporodochia appear at the junction of the lemma and palea, and macroconidia and microconidia are produced at 12-14 DAI. Hyphae reach the pericarp of grains at 14 DAI and then fill the cavities between hulls and kernels. Such seed does not germinate in upland nurseries. The density of mycelia is higher in the palea than in the lemma.

Location of the fungus in seed. In diseased seed, the fungus is found in the empty glume and pedicel (Suzuki 1985). The fungus was isolated from a higher percentage of empty glumes and the proximal parts of hulls than from the distal parts of hulls. Seeds from inoculated spikelets were grouped into 5 classes by specific gravity: <1.01, 1.01-1.06, 1.07-1.14, 1.15-1.20, and >1.20. The infection percentage of embryos was 35.7, 34.8, 21.2, 19.8, and 12.5%, respectively. In seed lots from naturally infected spikelets, the infection percentage of embryos was 20.9, 18.1, 10.5, 6.5, and 0.7%, respectively (Matsumoto 1971).

Disease incidence in seedlings. Typical symptoms are elongation of the sheath and leaf blade, stunting, and wilting. When naturally infected seed is sown, the sheath of the third leaf and both the sheath and leaf blade above the third leaf elongate. When artificially inoculated seed is used, the sheath of the first leaf and the sheath and blade of the second leaf elongate, wilt, and wither. Seedlings from apparently healthy seed obtained from panicles on which diseased spikelets are borne elongate at 8-10 times the number of elongated seedlings from seed originating on apparently healthy panicles (Sasaki 1987). Different isolates cause different symptoms (Yamanaka and Honkura 1978). In some cultivars, mycelial growth is limited to the mesocotyl. Anatomical observation within the organ might distinguish susceptible cultivars (Y. H. Lee, pers. comm.).

Epidemiology. When elongated seedlings are transplanted in a submerged field, withering starts 10 d later, and the number of withered hills increases with time. When apparently healthy seedlings are selected for transplanting from a nursery where 30% of the seedlings elongate, 5-10% of the hills start to elongate 2 wk later. These hills bear conidia on the sheaths, stems, and nodes, which become an inoculum source for panicle infection. Dispersion of conidia and ascospores occurs at night (Sasaki 1987, Yu and Sun 1976). During soaking of seed for pregermination, conidia from infected seed detach and infect healthy seed. A dry seed can absorb a conidial suspension within 5 min through a pore where the pedicel is attached (Ishii 1977, 1979). Bakanae is the only disease checked for seed certification and surveyed in the field for seed production of purebred lines in Japan. The disease loss (y, in %) can be expressed by the equation $y = -0.525x$, where x is the percentage of diseased hills (Umehara 1986).

Stackburn *Alternaria padwickii* (Ganguly) M. B. Ellis

Mycelia grow within the epidermis of the hull, endosperm, and embryo. Large spots with pinkish halos appear on the hulls. No visible symptoms are noticed on leaves by

using the seedling method in a test tube (L. P. Kauraw, pers. comm.). On the other hand, reduced germination, browning of coleoptiles, and seedling death have been reported (Kauraw, pers. comm.; Ou 1985). In the temperate regions, this fungus causes discolored grain when heading occurs during high temperatures.

Udbatta *Ephelis oryzae* Sydow

The pathogen is internally seedborne. Infection initiates at panicle emergence. Untreated diseased seed produced more infected panicles than that treated with hot water (Mohanty 1965, Tai and Siang 1948).

CATEGORY 2

Brown or black smudge of polished grains influences quality and lessens commercial value by discoloring the hulls. In 1978, discoloration of kernels caused heavy losses in the Hokuriku area of Japan. It was thought that the high temperature caused by the foehn after a tvphoon affected the damage by the pathogens during heading. The causative organisms were *Curvularia* spp., *Allernaria* spp., *Sarocladium attenuatum* Gams et Hawksworth (Nasu et al 1982). *Bipolaris sorokiniana* (Sacc.) Shoemaker, *Epicoccum purpurascens* Ehr. ex Schlecht. (Kodama 1982), and *Erwinia herbicola* (Loehnis) Dye (Yoshida et al 1982).

***Curvularia lunata* (Wakker) Boedijn, *C. intermedia* Boedijn, and *C. clavata* Jain**

These fungi cause discoloration of the aleurone and starch layer. Hulls also become brown (Taketani and Yagi 1982, Tullis 1936, Umehara et al 1979). There is a close relationship between the discoloration of glumes and empty glumes, and the discoloration of kernels. When an empty glume dies, severe smudge of the kernels is observed (Taketani and Yagi 1982). Infection is most severe 0-10 d after heading. It is possible to isolate the pathogen from the kernel, palea, and lemma, but not from the empty glume or panicle branch (Yagi and Taketani 1982). Black smudge of polished rice increases when inoculated plants are stored at 27-33 °C (Umehara and Nakagawa 1980b). During storage of unhusked rice at 27-40 °C, black smudge of polished rice increases (Umehara and Nakagawa 1980a). Spores disperse during daytime. The pathogens overwinter on withered grasses such as *Digitaria sanguinalis* and *Setaria viridis.* Grasses withered by herbicides are infected and provide conidia (Umehara and Nakagawa 1981, Yagi and Paketani 1984).

***Alternaria padwickii* (Ganguly) M. B. Ellis**

Alternaria padwickii infects the kernel, on which pale-black spots with dark-brown borders appear on the embryo side. During flowering, conidia are deposited inside the glumes. When the chlorophyll content in the epidermis of the kernels is reduced, cytokinin-like substances decrease and abscisic acid increases, stimulating germination and kernel infection (Tamura 1976). Conidia disperse during daytime, the peak of dispersion being observed from 1100 to 1200 h — coinciding with the flowering of rice (Sreeramulu and Vittal 1966, Tamura 1976). This is also true in *Alternaria* spp., *Curvularia* spp., *Nigrospora* spp., and *Helminthosporium* spp. in ricefields (Kawakubo 1982).

***Bipolaris sorokiniana* (Sacc.) Shoemaker**

Bipolaris sorokiniana was dispersed from a wheatfield close to a ricefield and caused discoloration of hulls and kernels in 1978 in Hokkaido, northern Japan. This fungus grows on grasses such as *Echinochloa crus-galli, Dactylis glomerata,* and *S. viridis.* When plants wither, conidia are produced on them (Sawazaki et al 1982).

CATEGORY 3

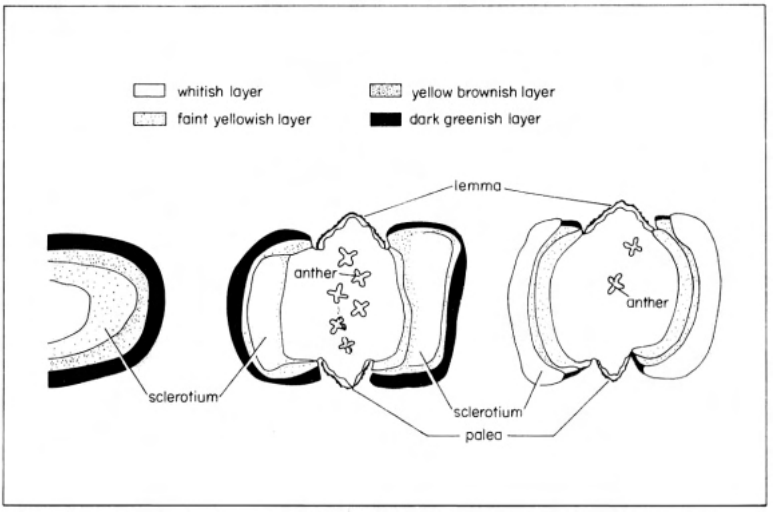
Spores of these fungi contaminate seeds during harvesting and threshing.

False smut *Ustilaginoidea virens* (Cke.) Tak.

A mass of mycelia covered with a gray membrane appears in the joint area of the palea and lemma. The membrane bursts, and yellow to dark-green spore balls grow. Then the surface of the spore balls cracks. The outermost layer is composed of chlamydospores, the next orange layer of chlamydospores and mycelia, and the white inner layer of mycelia, glumes, and anthers. Sclerotia are produced within the ball (Ikegami 1961, 1963) (Fig. 4).

Kernel smut *Tilletia barclayana* (Bref.) Sacc. et Syd.

The glumes become dark, and black pustules burst through them. Sometimes a short, beaklike outgrowth originates from a diseased kernel and protrudes through the glumes. When severely infected, the entire grain is replaced by a mass of spores. Sporidia lodge on the stigma, then penetrate the style and reach the end of the ovary. Hyphae remain between the aleurone layer and the seed coat, digesting the endosperm and producing spores (Mogi 1986, Ou 1985). Kernel smut is a problem during threshing in Chiba Prefecture, Japan.



4. Sclerotium formation of *Ustilaginoidea virens* in the spikelet of rice (Ikegami 1963).

CATEGORY 4

These fungi are thought to be weakly pathogenic or saprophytic. They influence the commercial value of seeds. The following fungi have been recognized to grow on glumes: *Nigrospora* spp., *Phyllosticta* spp., *Fusarium* spp., *Septoria* spp., *Trematosphaerella* spp., *Metasphaeria* spp., *Melanomma* spp., *Sphaeropsis* spp., *Phaeoseptoria* spp., *Diplodia oryzae* Miyake, *Diplodiella oryzae* Miyake, and *Oospora oryzae* Ferraris (Kitani et a1 1970, Ou 1985). The relationship between glume discoloration and infection must be examined.

CONTROL MEASURES

Site selection

To produce clean seed, it is important to select a location that minimizes production of diseased seed. Dry weather during heading and maturation is desirable. Windy conditions and a small fluctuation between day and night temperatures minimize dew and thus inhibit infection. Elevation above 200 m in northern Japan suppresses bakanae (Sasaki 1987).

Sandy soil and peat soil favor severe outbreaks of brown spot.

Fertilizer regulation

Excess N fertilizer has been associated with serious outbreaks of blast. Shortages of N, Si, Mn, Mg, Ca, K, and Fe favor brown spot. Applying revolving furnace slag at 10 t/ha is effective against brown spot and increases rice yield (Ohata et al 1973).

Careful harvesting

When harvesting is by hand, diseased hills can be eliminated.

In machine harvesting, pathogens may be mixed with healthy seed. The speed of the revolving drum should be slow to reduce injury, which predisposes seed to infection during pregermination soaking and seedling growth.

Gravity separation

By using salt or $(NH_4)_2SO_4$ solution, the inoculum density in seed can be reduced (Matsumoto 1971). For preparing a solution with the desired specific gravity — e.g., 1.10 — 210 g salt/liter or 230 g $(NH_4)_2SO_4$ /liter is added. After soaking in this solution, floating seed is discarded, and settled seed is washed with water before use.

Chemical control

Before harvest. Chemical treatment during crop growth, especially at heading, promotes better seed.

To protect against blast, organic compounds such as fthalide (Rabcide), edifenphos (Hinosan), IBP (Kitazin P), tricyclazole (Beam), and isoprothiolane (Fuji-One), and antibiotics such as blasticidine (Bla-S) and kasugamycin (Kasumin) have been used. Granular chemicals (systemic fungicides) such as tricyclazole, isoprothiolane, probenazole (Oryzemate), and pyroquilon (Coratop, Fongorene)

can be scattered in the box nursery immediately before transplanting in areas where blast is ordinarily prevalent. The effect protects plants for more than 30 d in a submerged production field. This type of chemical can be applied about 20 d before heading to control panicle blast.

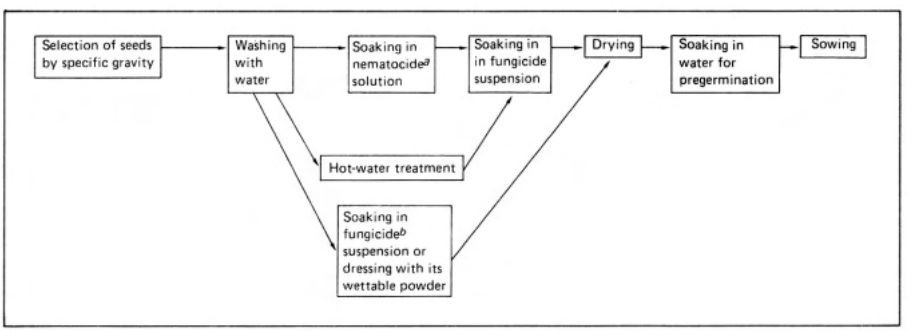
Brown spot can be prevented by using edifenphos, iprodione (Rovral), captan (Orthocide), or thiram (Arasan, Pomarsol Forte) (Sekiguchi and Okamoto 1967), all of which are recommended in Japan.

A spray of benomyl solution is effective against bakanae (Sasaki 1987).

For discoloration of kernels caused by *Curvularia* spp., *Alternaria* spp., and *Bipolaris sorokiniana,* a mixture of edifenphos and polyoxin is effective.

After harvest. A common process of postharvest seed treatment is shown in Figure 5. Benlate T containing 20% thiram and 20% benomyl is effective against blast and bakanae but is inferior to organic Hg compounds against brown spot. Dry seeds are soaked in a suspension of wettable powder at a dilution of 1/20 for 10 min, or at 1/200 for 24-48 h. Dressing with wettable powder at 0.5% of seed weight is effective. This method is useful with fungi that are considerably tolerant of benomyl. After soaking in water, pregerminated seeds should not be disinfected because of phytotoxicity to the buds. The ratio of seeds and Benlate T suspension should be 1:1 or 1:2, and stirring the solution during treatment is necessary. When extra chemicals are added, the suspension can be used several times. Disinfection has the same effect at 10-20 °C. The soaking period should be shorter at temperatures above 20 °C to avoid phytotoxicity (Kinki-Chugoku Region's Technical Corporation 1975, Kobayashi 1975, Umehara et a1 1974). Benomyl by itself is used against blast and bakanae. Thiophanate-methyl - thiram wettable powder is also applied for seed treatment against blast, bakanae, and brown spot.

Equipment has been developed to spray benomyl-thiram (20%-20%) suspension under high pressure onto seeds (Watanabe and Ogawa 1978). A 1/8 dilution is employed at a dosage of 3% of seed weight. The capacity is 1-1.2 t/h. After spraying, the seeds are dried, weighed, and packed. Packed seeds can be stored without reduction of disease control or germination until the next season. The treatment also prevents the spread of soilborne diseases caused by *Trichoderma viride, Fusarium*



5. Typical seed treatment of rice plant before sowing. [a]Ethyl thiocyanatoacetate, MPP, etc. against nematodes. [b]Benomyl - thiram or thiophanate-methyl - thiram against blast, brown spot, and bakanae.

roseum, F. solani, and *Rhizopus* spp. in box nurseries. Zinc-manganese ethylene bisdithiocarbamate (Dithane M-45) gives complete control of seedborne *Alternaria padwickii* (Vir et al 1971).

Dry heat treatment

Dry heat treatment at 75 °C from 1 to 5 d is not sufficient for control of bakanae (Ishii 1978).

Cold-and-hot-water or hot-water treatment

After soaking in water at 20 °C for 16 h, seed is treated with hot water for 15 min at 51 °C, for 7 min at 52 °C, or for 5 min at 53 °C to control against bakanae. There is no reduction of germination using this treatment.

In the hot-water treatment, dry seeds are treated with water at 56-60 °C for 7-15 min. Control is practical at 60 °C, for 10-15 min (Ishii 1978). Hot-water treatment at 54 °C is effective in controlling udbatta (Mohanty 1964).

RESEARCH NEEDS

The infection chain of *Alternaria padwickii* and *Ephelis oryzae* must be made clear. The epidemiology and worldwide distribution of *Sarocladium oryzae* (sheath rot), *Gerlachia oryzae* (leaf scald), *Cercospora janseana* (narrow brown leaf spot), and *Phoma sorghina* (glume blight) must be studied.

In strong parasites, early infection causes insufficient ripening of seed; these grains are discarded during processing and so do not cause spread of the disease. Infection at a later stage is more serious, because the disease can be spread by the mature seed. We recommend studying the time-series detection of microbes on panicles from booting to harvesting, because there is a dynamic succession of microbes, from parasite to weak parasite to saprophyte, on the panicles.

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Grain storage insects

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Storage insects consume the kernels of stored grain and cause weight loss during storage. Their body fragments, feces, webbing, and metabolic products also contaminate stored products. Heat from their metabolism results in the migration of moisture. If seed grain is impaired or destroyed by heating or high moisture, or if either germ or endosperm is damaged, germination is significantly lowered. Granary, rice and maize weevils, lesser grain borers, and Angoumois grain moths are the major internal feeders. They develop inside the kernels, but there is little evidence of their presence until they emerge as beetles or moths; kernels appear to be sound and undamaged even though germ or endosperm has been consumed. Other stored-grain insects develop outside the kernels. They are commonly known as flour beetles, bran beetles, or bran bugs. Newly harvested, uninfested grain in storage may become intested through the granaries and cribs, bins of old grain, accumulation of waste grain and feed, migration of flying insects from nearby injested sources, and field infestation brought into the bins at harvest. In bulk storage, most insect pests are distributed on surface grain. A major difficulty is detecting those that are completely enclosed within the grains. Methods used in monitoring insect infestation in storage facilities are visual examination, sampling with grain probes, and insect traps (card, sticky, light, suction, and pheromone traps). Visual, flotation, staining, X-ray and ninhydrin methods have been developed for detecting pre-adult insects within food grains.

Several hundred species of insects are associated in one way or another with stored grain and its products. Before crops were cultivated, these insects occurred naturally in seeds on wild plants or in seeds gathered by rodents, ants, or other seed-harvesting animals (Linsley 1944). When people began to store grain, these insects moved from their original native habitats to storage areas. They have been carried by commerce to all parts of the world and have become cosmopolitan.

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The loss in weight of the world's supply of stored grain because of insect damage is estimated at 5-10% of world production. In some tropical and subtropical countries, estimates are much higher. Grain losses extend beyond the amount actually consumed and must include the effects of contamination with insect fragments, feces, webbing, ill-smelling metabolic products, and a variety of microflora. Losses must also include damage resulting from insect-caused heating and translocation of moisture with subsequent molding, caking, and sprouting. These pests therefore constitute a major sanitation and quality control problem. If seed grain is impaired or destroyed by heating or high moisture, or if either germ or endosperm is damaged, germination is drastically lowered. Moreover, several species including the lesser grain borer, cadelle, and various dermestids tunnel into the wooden parts of granaries and may weaken their structures.

Insect damage to growing crops may be counteracted to some degree by partial recovery of the damaged plants or by increased yield from the survivors, but insect damage to stored grain is final and without compensatory adjustments.

GROUPS OF STORED-GRAINS INSECTS

Cotton and Good (1937) listed the insects found in stored grain and processed cereal products in four categories:

- *Major pests.* Major pests are species particularly well adapted to life in stored grain. The species listed in Table 1 alphabetically by scientific name are generally accepted as responsible for most of the insect damage throughout the world.
- *Minor pests.* Minor pests include an appreciably larger group of insects (Table 2) that may become abundant locally. Occasionally, some of these

Table 1. Major insect pests of stored grain (revised from Cotton and Good 1937).

Scientific name	Common name	Family
Anagasta kuehniella (Zeller)	Mediterranean flour moth	Pyralidae
Cryptolestes ferrugineus (Stephens)	Rusty grain beetle	Cucujidae
Cryptolestes pusillus (Schönherr)	Flat grain beetle	Cucujidae
Cryptolestes turcicus Grouvelle	Flour-mill beetle	Cucujidae
Cadra cautella Walker	Almond moth/tropical warehouse moth/fig moth	Pyralidae
Ephestia elutella (Hubner)	Tobacco moth/cocoa moth	Pyralidae
Oryzaephilus mercator (Fauvel)	Merchant grain beetle	Cucujidae
Oryzaephilus surinamensis (L.)	Sawtoothed grain beetle	Cucujidae
Plodia interpunctella (Hübner)	Indian-meal moth	Pyralidae
Rhyzopertha dominica (Fabricius)	Lesser grain borer	Bostrichidae
Sitophilus granarius (L.)	Granary weevil	Curculionidae
Sitophilus oryzae (L.)	Rice weevil	Curculionidae
Sitophilus zeamais Motschulsky	Maize weevil	Curculionidae
Sitotroga cerealella (Olivier)	Angoumois grain moth	Gelechiidae
Tenebroides mauritanicus (L.)	Cadelle beetle	Trogositidae
Tribolium castaneum (Herbst)	Red flour beetle	Tenebrionidae
Tribolium confusum Jacquelin du Val	Confused flour beetle	Tenebrionidae
Trogoderma granarium Everts	Khapra beetle	Dermestidae

Table 2. Minor pests most frequently encountered in stored grain (revised from Cotton and Good 1937).

Scientific name	Common name	Family
Ahasverus advena (Waltl)	Foreign grain beetle	Cucujidae
Alphitobius diaperinus (Panzer)	Lesser mealworm	Tenebrionidae
Araecerus fasciculatus (De Geer)	Coffee bean weevil	Anthribidae
Attagenus megatoma (Fabricius)	Black carpet beetle	Dermestidae
Carpophilus dimidiatus (Fabricius)	Corn sap beetle	Nitidulidae
Carpophilus hemipterus (L.)	Driedfruit beetle	Nitidulidae
Caulophilus oryzae (Gyllenhal)	Broadnosed grain beetle	Curculionidae
Corcyra cephalonica (Stainton)	Rice moth	Pyralidae
Cynaeurs angustus (Leconte)	Larger black flour beetle	Tenebrionidae
Gnathocerus cornutus (Fabricius)	Broadhorned flour beetle	Tenebrionidae
Lasioderma serricorne (Fabricius)	Cigarette beetle	Anobiidae
Latheticus oryzae Waterhouse	Loneheaded flour beetle	Tenebionidae
Liposcelis spp.	Psocids	Psocoptera
Palorus ratzeburgi (Wissmann)	Smalleyed flour beetle	Tenebrionidae
Palorus subdepressus (Wollaston)	Depressed flour beetle	Tenebrionidae
Prostephanus truncatus (Horn)	Larger grain borer	Bostrichidae
Ptinus clavipes (Panzer)	Brown spider beetle	Ptinidae
Ptinus villiger (Reitter)	Hairy spider beetle	Ptinidae
Stegobium paniceum (L.)	Drugstore beetle	Anobiidae
Tenebrio molitor (L.)	Yellow mealworm	Tenebrionidae
Tenebrio obscurus Fabricius	Dark mealworm	Tenebrionidae
Tribolium audax Halstead	Black flour beetle	Tenebrionidae
Trogoderma spp.	Grain-feeding dermestids	Dermestidae
Typhaea stercorea (L.)	Hairy fungus beetle	Mycetophagidae

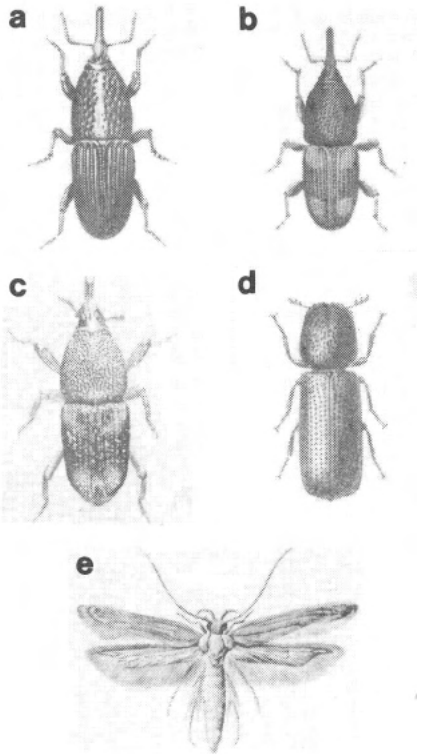
species may approach the status of major pest under favorable conditions. The insects in this group either are associated frequently with a particular environment such as high moisture or temperature, poor sanitation, and poor-quality grain, or occur within limited geographic areas.

- *Incidental pests.* Incidental pests include houseflies, roaches, moths, and other insects attracted to lights, odors, or shelter. They happen to alight on or crawl into grain or grain products. They rarely damage grain except through the contamination resulting from their presence.
- *Parasites and predators.* Parasites and predators of grain-infesting insects are frequently found in stored grain, where they are as unwelcome to grain handlers as are the pests.

REPRESENTATIVE STORED-GRAIN INSECTS

Insects that develop inside the kernels

Weevils, lesser grain borers, and Angoumois grain moths are the major internal feeders; they develop inside the kernels. Weevils deposit their eggs inside the kernels. Lesser grain borers and Angoumois grain moths deposit their eggs on the surface of the kernels, into which the newly hatched larvae promptly tunnel. There is little evidence of their presence inside the kernels until they emerge as beetles or moths. Kernels appear to be sound and undamaged even though germ or endosperm, or both, have been consumed.



1. Adults of: a. granary weevil (body length [BL], 3.5 mm); b. rice weevil (BL, 2.5 mm); c. maize weevil (BL, 3 mm); d. lesser grain borer (BL, 3 mm); e. Angoumois grain moth (wingspan = 16 mm) (Grossmann 1973).

Granary, rice, and maize weevils. The granary weevil *Sitophilus granarius* (L.) (Fig. la), the rice weevil *Sitophilus oryzae* (L.) (Fig. 1b), and the maize weevil *Sitophilus zeamais* Motschulsky (Fig. 1c) are distributed worldwide. They are frequently the most destructive of the insects that attack grain in farm and commercial storage. Granary weevils appear to be better adapted to temperate areas, and rice and maize weevils to tropical and subtropical regions. Both rice and maize weevils occur in the same habitat (Table 3). However, maize weevils are found to be more abundant on brown rice or maize; rice weevils are predominant on rough rice (Peng et a1 1979, 1985).

Their body size depends somewhat on the size of the grain kernel as well as on the species. In small grain such as millet or sorghum, the weevil will be small; but in maize, a particularly favored food, it will attain its maximum size. Generally, granary weevils are larger than rice or maize weevils when they develop on the same host. Rice weevils are the smallest of the three species. But if rice weevils feed on maize, and granary weevils on wheat, they may be of equal size.

Adult weevils can easily be distinguished from other stored-grain insects by their head capsule, which prolongs into a slender snout known as the rostrum, on the tip of which are located tiny but powerful chewing mouthparts (Fig. 2). Their grublike larvae are legless.

Table 3. Relative abundance of *Sitophilus oryzae* and *S. zeamais* recorded on various grains in Taiwan (Peng et al 1979, 1985).

Host grain	Number of		Locality of sample	Collection date
	S. oryzae	*S. zeamais*		
Rough rice	83	75	Hsin-tien, Taipei	17 Dec 1978
	18	39	Hsin-tien, Taipei	13 Apr 1979
	73	1	San-hsiah, Taipei	23 Feb 1977
	42	0	Ta-ya, Taichung	6 May 1977
	33	6	Ta-chia, Taichung	12 Dec 1978
	49	10	Tsao-tun, Nantou	21 Mar 1979
Total	298	131		
Brown rice	0	50	Tsao-tun, Taichung	17 Apr 1979
	47	30	Hsin-kan, Chiai	4 Oct 1977
	1	39	Kung-fu, Hualien	17 Aug 1977
	0	34	Yui-li, Hualien	18 Aug 1977
	0	12	Shui-sui, Hualien	18 Aug 1977
	0	40	Tai-tung	18 Aug 1977
Total	48	205		
Maize	2	86	Tai-tung	6 Sep 1984
	0	33	Tai-tung	5 Oct 1984
	0	22	Tai-tung	2 Nov 1984
	0	121	Tai-tung	7 Dec 1984
	0	23	Tai-tung	22 Jan 1985
	3	132	Tai-tung	22 Apr 1985
	11	270	Tai-tung	3 Jun 1985
Total	16	687		

The adults may be distinguished by the characteristics listed in the following key (Hinton and Corbet 1975, Kuschel 1961):

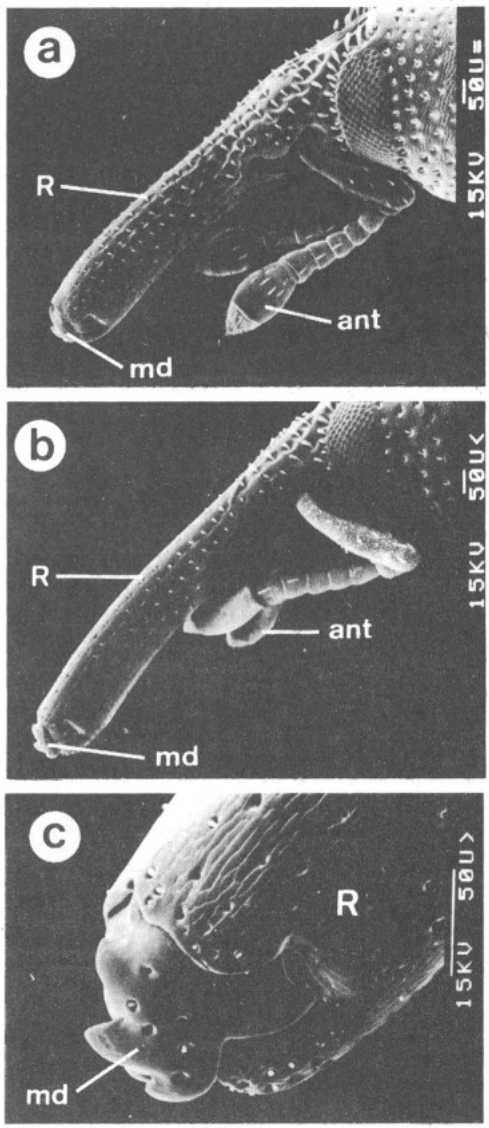
1. Prothorax with punctures distinctly oblong or oblong-oval. Elytra with intervals much broader than striae or strial punctures. Hind wings absent. 3-4 mm . . . . . Granary weevil

   Prothorax very densely set with round or irregularly shaped punctures. Elytra with intervals usually distinctly narrower than striae or strial punctures; elytra usually with four reddish spots. Hind wings always present. 2.3-4.5 mm 2

2. Upper surface of aedeagus evenly conxex, without two longitudinal impressions (Fig. 3). Microsculpture of prothorax and elytra(with high magnification) more alutaceous, dorsal surface consequently rather duller . . . . . Rice weevil

   Upper surface of aedeagus flattened, with two distinct longitudinal impressions. Microsculpture of prothorax and elytra less alutaceous, dorsal surface consequently more shining . . . . . Maize weevil

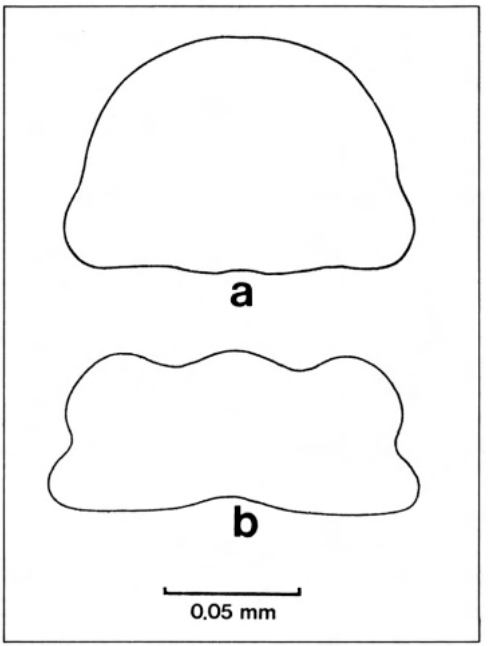
The rostrum of the female is comparatively smooth and shining, and somewhat longer and narrower than that of the male (Fig. 2a,b). In addition, when observed laterally, the male has a downward curve to the tip of the abdomen, whereas the female's abdomen extends straight backward (Halstead 1963, Qureshi 1963).



2. The head of the weevil forms a slender rostrum (R), at the tip of which are located tiny but powerful mandibles (md). ant = antenna. a. Male rostrum: surface rough; shorter and wider. b. Female rostrum; surface smooth and shining; longer and narrower. c. Enlargement of anterior end.

The life history and habits of the three species are similar. Under optimum conditions, rice and maize weevils require 33-49 d to develop from egg to emerged adult; granary weevils require 39-50 d (Sharifi and Mills 1971). Rice and maize weevils live 2-5 mo; granary weevils live longer.

A female weevil may deposit a total of about 400 eggs. She selects a site, chews a narrow cylindrical hole into the kernel, and prepares a cavity in the endosperm in which to deposit an egg (Hinds and Turner 1911). After she deposits a small, soft, whitish egg, she fills the hole with a gelatinous material known as the egg plug, which



3. Cross section of aedeagus of rice weevil (a) and maize weevil (b).

protects the egg from desiccation and, to some extent, from predation. Certain stains will color the egg plug (Frankenfeld 1948, Goossens 1949).

The egg hatches in a few days into a soft, white, legless, fleshy grub, which usually tunnels toward the center of the kernel and feeds on the interior of the grain (Kirkpatrick and Wilbur 1965). On becoming a full-grown larva, it constructs a pupal chamber and changes into a white pupa. Later, it emerges as an adult weevil. The adult may remain in the kernel for several days before chewing an escape hole.

Lesser grain borer. In recent years, the lesser grain borer *Rhyzopertha dominica* (Fabricius) (Fig. 1d) has become increasingly common and destructive in stored grain (Peng 1984, Potter 1935). In heavy infestations, the kernels are so completely consumed that only the bran coverings remain.

The adult is a small, cylindrical beetle less than 4 mm long. When viewed from above, the head is completely covered by the pronotum. Thus, the beetle appears to be structured in two parts. The front margin of the pronotum has numerous tubercles or projections. Unlike the legless weevil grub, lesser grain borer larva has three pairs of thoracic legs.

Each female may deposit 300-400 eggs on the outside of the kernels. Upon hatching, most of the tiny larvae chew their way into kernels, where they pass through four or more instars before emerging as adults (Howe 1949). Some larvae will develop in available flour or nutritious dust outside of the kernels. Under optimum conditions it takes 30 d to complete development.

Both larvae and beetles produce a large number of fecal pellets. The larvae push their pellets, along with some starch particles, out of the kernels. The pellets have a sweetish, musty odor that easily identifies lesser grain borer infestation.

Lesser grain borers have well-developed wings that enable them to migrate readily from one granary to another.

Angoumois grain moth. The Angoumois grain moth *Sitotroga cerealella* (Olivier) (Fig. 1e), a cosmopolitan species, is second in destructiveness only to the weevils and the lesser grain borers as a pest of stored grain. The adult lays its eggs on grain in storage, but in some regions it also infests grain in the field (Agrawal et a1 1977). The soft-bodied moths infest only the surface of the grain in bins.

They are small, delicate moths with an average wingspread of 16 mm. The adult is buff to grayish or yellowish brown. Each forewing has two or three tiny, dark spots, and the apical tip of each hind wing is narrow and pointed. The hind wings are grayish white and are heavily margined with long hairs. The larva is a whitish caterpillar with three pairs of thoracic legs and five pairs of prolegs.

The caterpillar burrows into the kernel and completes its development there, having four to more than eight instars. The number of instars and the length of the life cycle are influenced by the type of food. When germ provides the bulk of larval food, fewer instars and shorter development periods result (Mills 1965). Under favorable conditions the mean length of the development period is 38 d on wheat, 35 d on maize, and 33 d on sorghum (Mills and Wilbur 1967).

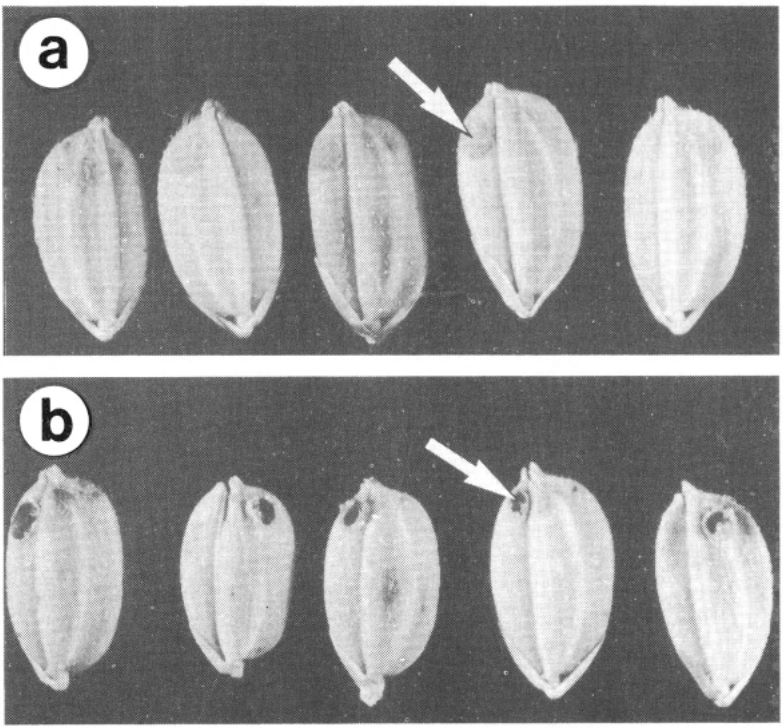
Before pupation, each mature caterpillar makes an escape tunnel to the outside of the kernel, spins a tough silk lining for the cavity, and prepares an escape hatch. Viewed from outside, the escape hatch looks like a glass window on the kernel (Fig. 4). Upon completion of the pupal stage, the moth easily pushes its way through the escape hatch, frequently dragging the cocoon along with it.

Insects that develop outside the kernels

The rest of the stored-grain insects develop outside the kernels, although several species may tunnel into the germ. Eggs are usually laid indiscriminately among the kernels. Larvae and adults feed on broken kernels, the germ portion of grain kernels, grain dust, flour, or other products. These insects are commonly known as flour beetles, bran beetles, or bran bugs.

Flour beetles. The red flour beetle *Tribolium castaneum* (Herbst) (Fig. 5a) and the confused flour beetle *Tribolium confusum* Jacquelin duVal are best known as "flour beetles." They are cosmopolitan species and are the most abundant and destructive insects infesting flour and other cereal products. They also attack dried fruit, nuts, spices, and other stored products. Both species damage stored products — not only by eating them, but also by contaminating them with their dead bodies, cast-off skins, and fecal pellets, which contain uric acid. The beetles have an odoriferous gland that secretes a pungent, irritating liquid containing quinones (Roth 1943). When large populations occur in flour, it turns pink from contamination with beetle secretions. Quinone secretions adversely affect the taste of bread made from *Tribolium*-infested flour and can lower its baking quality (Smith et al 1971).

The two species closely resemble one another in appearance, behavior, and life cycle. However, the distal antennal segments of the red flour beetle suddenly form a prominent club, whereas those of the confused flour beetle enlarge gradually toward the tip (Hinton 1948).



4. a. A mature Angoumois grain moth larva makes an escape hatch and spins a tough silk film on the kernel that looks like a glass window (arrow). b. The moth pushes its way out of the kernel through the escape hatch and leaves a hole (arrow) in the kernel.

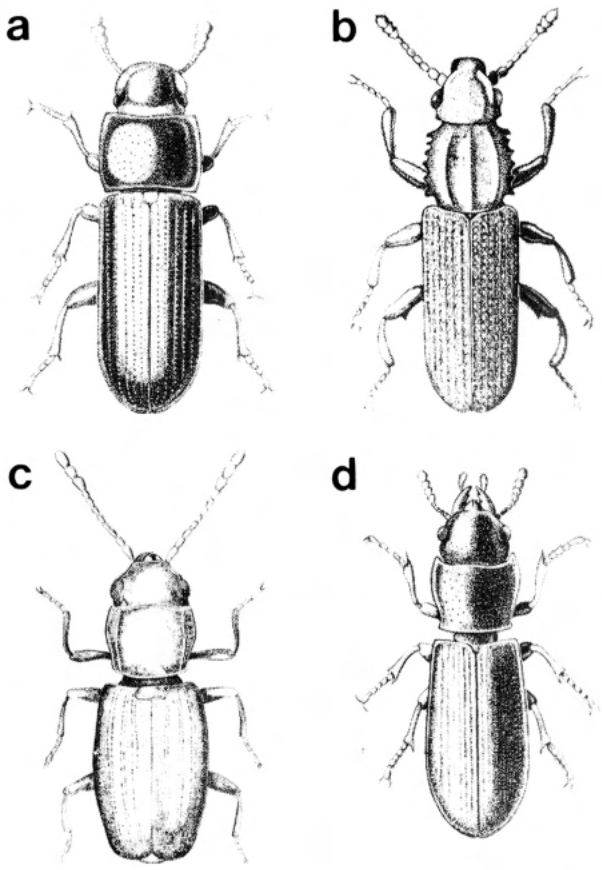
Under optimum conditions, each female deposits 400 or more eggs. The number of larval instars varies from 5 to 12, and the time required to develop from egg to adult is approximately 30 d. The population can increase rapidly, since they have high fecundity and a short development period. They have long been a favorite subject for the study of insect populations. Flour beetles generally limit their populations by cannibalism when food becomes scarce. Both larva and adult consume eggs and pupae.

Sawtoothed grain beetle. The sawtoothed grain beetle *Oryzaephilus surinamensis* (Fig. 5b) is small, flat, and reddish brown. The margin of the prothorax is serrated, with six teeth on each side, and there are three ridges on the surface. Wings are present but rarely used.

Sawtoothed grain beetles are general feeders, eating processed cereals, dried fruit, nuts, cookies, and crackers. The adults feed outside the kernels, but the larvae penetrate the germ area.

Female beetles lay from 50 to 300 eggs. The time required to develop from egg to adult varies from 20 to 75 d under optimum conditions (Howe 1956).

Rusty grain beetle. The rusty grain beetle *Cryptolestes ferrugineus* (Stephens) (Fig. 5c) is reddish brown and about 1.6 mm long — the smallest of the major grain-damaging insects (Cline and Highland 1981). It is distributed worldwide but is



5. Adults of: a. red flour beetle (body length [BL], 3.5 mm); b. sawtoothed grain beetle (BL, 3.5 mm); c. rusty grain beetle (BL, 1.6 mm); d. cadelle (BL, 11 mm) (Munro 1966).

more abundant in wet tropical and warm temperate regions (Howe and Lefkovitch 1957). In these areas, it infests beans, cacao, cassava, cowpea, groundnut, maize, palm kernels, sorghum, rice, and wheat, whereas in cooler, drier regions, it is found mainly in cereals and cereal products. According to Ashby (1961), sound wheat is unsuitable for culturing the beetles, but it becomes suitable with small additions of flour and damaged grain. At 35 °C and 95% relative humidity, the highest value of intrinsic rate (r_m) — 1,000/wk — is obtained (Smith 1965).

Cadelle. At 11 mm long, the cadelle beetle *Tenebroides mauritanicus* (L.) (Fig. 5d) is the largest of the stored-grain insects. It is dark brownish to black. The distal end of the antenna forms a club, and the prothorax narrows at its junction with the elytra to form a collar. The larva is white with a sclerotized black head, a pair of large sclerotized black patches on the prothorax, and two prominent dark projections on the tip of the abdomen.

Cadelles are common destructive cosmopolitan pests of stored grain and cereal. They are predaceous on other insects and are consumers of grain and grain products. They consume not only the germ but also the endosperm of the grain.

Both larva and adult bore deep into the woodwork of granaries, mills, ships, and warehouses, thus weakening the structures. They also gnaw holes through sacks, cardboard, and waxed and other paper containers.

The female deposits more than 3,400 eggs during her lifetime of 1-2 yr (Bond and Monro 1954). Under optimum conditions, the larva matures in 8 wk. However, in the field, an appreciably longer developmental time is required.

SOURCES OF INFESTATION

Newly harvested, uninfested grain in storage may become infested from bins of old grain, granaries and cribs, feed and seed from infested sources, waste grain and feed in any of the buildings, migration of flying insects from nearby infested sources, and field infestations brought into the bins at harvest.

In an intensive survey of storage conditions in central Taiwan, Lin and Li (1984) found that in 25 empty rice warehouses, the average number of insects per square meter of floor in the warehouse was 331.2, with 3.6% alive (Table 4). There were 20 species, most of which were Coleoptera.

Table 4. Average number of insects per square meter of floor in empty warehouses and per liter of rice husks on the bottom of warehouses in central Taiwan (Lin and Li 1984).

Species	Floor		Rice husks[a]	
	Total	Live	Total	Live
Rhyzopertha dominica	109.3	4.9	15.6	0.3
Sitophilus oryzae	81.9	0.6	2.8	0.1
Sitotroga cerealella	59.2	0.1	0.1	0.1
Cryptolestes ferrugineus	17.5	0.2	2.0	0.3
Gnathocerus maxillosus	15.0	1.9	0.2	0.1
Oryzaephilus surinamensis	13.3	0.5	1.1	0.1
Lophocaterus pusillus	11.6	0.7	6.5	0.2
Tribolium castaneum	8.2	0.8	0.4	0.1
Sitophilus zeamais	4.5	0.1	–	–
Tenebroides mauritanicus	2.9	0.1	–	–
Latheticus oryzae	2.4	0.2	0.4	0.1
Murmidius ovalis	1.7	0.2	0.1	0.1
Trogoderma granarium	1.1	0.2	0.1	–
Palorus foveicollis	1.0	0.6	0.1	0.1
Alphitohius diaperinus	0.5	0.2	–	–
Thorictodes heydeni	0.5	0.1	–	–
Trinodes rufescens	0.3	0.2	–	–
Gibbium psyllioides	0.1	0.1	–	–
Anthrenus sp.	0.1	0.1	–	–
Carpophilus obsoletus	0.1	0	–	–
Total	331.2	11.8	29.4	1.6
Live insects (%)		3.6		5.4

[a] – = no data.

In practice, rice husks are spread on the floor of warehouses before rice is stored, to prevent direct contact of the rice with the premises. Lin and Li (1984) also reported that insects averaged 29.5/liter of rice husks, of which 5.4% were alive. Twelve species were found.

A survey of 33 warehouses showed that newly stored rice contained an average of 0.7 insects/kg of rice, of which 0.3 were alive. When the rice had been stored for 4 mo, the number of insects increased to 3.9/kg of rice, with 3.1 alive.

Insect populations increase more rapidly during warm seasons. Population peaks in bagged rice were recorded from July through September for *Rhyzopertha dominica,* in September and October for *Latheticus oryzae,* and in August and September for *Cryptolestes ferrugineus* and *Tribolium castaneum* (Peng 1984). The optimum temperature for these insects is 32-35 °C (Howe 1965).

DISTRIBUTION IN BULK GRAIN

The distribution of insects in bulk grain is influenced by many factors. Various species of moths that infest grain are fragile and weak; they cannot force their way below the surface. Therefore, moth infestations are confined largely to surface grain. Conversely, grain-infesting beetles have strong bodies that enable them to move through grain. Peng's (1978) survey on the distribution of coleopterous pests in bulk storage, in which the grain was piled up to a height of 4 m, reported that 59% of the adults and 67% of the immature stages were distributed on the surface (Fig. 6), 10-13% on the bottom, and only 5-13% in the central parts. Howe (1951) reported that tightness of packing affects the movement of weevils; tighter packing is likely to prevent much of the downward penetration of beetles.

MONITORING AND DETECTION METHODS

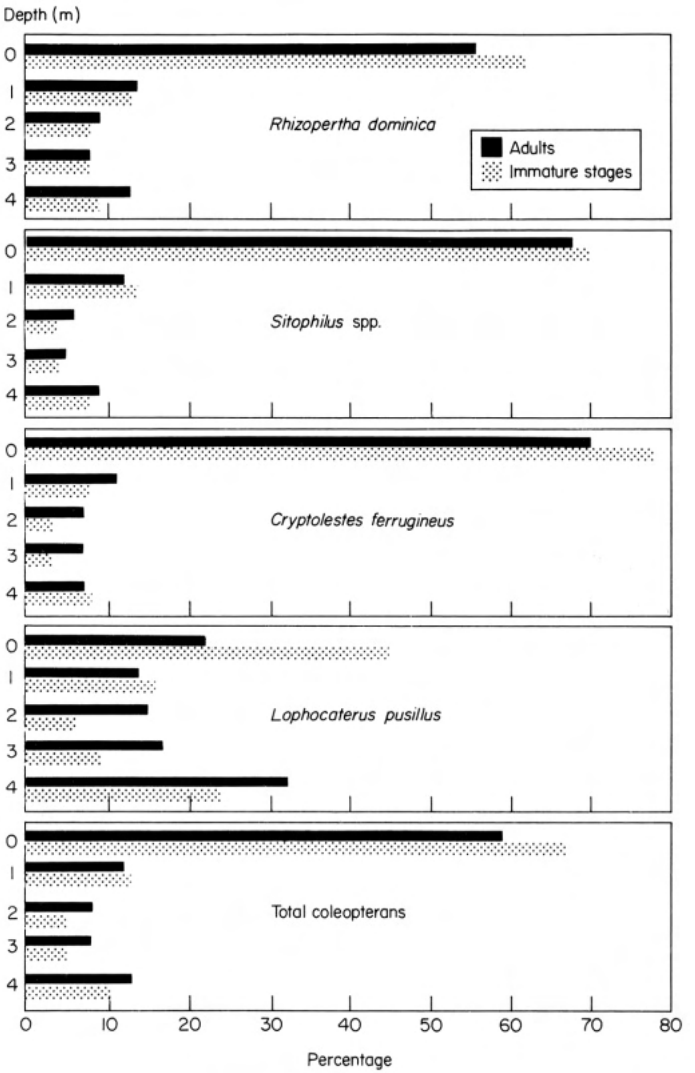
Both on-site and laboratory methods are used in storage insect control.

Monitoring storage facilities

Early detection of the presence of insects in stored grain can prevent the rapid spread of damage that can be expected in the tropics. The methods used in monitoring insect infestation in storage facilities are given below.

Visual inspection of the commodity or its container. Visual inspection is widely used for establishing the presence of infestation in bag stocks, but it cannot be standardized sufficiently to make it entirely reliable for comparisons between different situations and different observers, because it is largely subjective.

Sampling with grain sampling probes. This reasonably reliable method for determining whether or not insects are present in moderate or large numbers in bagged grain serves well for the detection of *Sitophilus* spp. infestation at significant levels, because the assessment can take into account the presence of weevil-damaged grains as well as actual live weevils. It is not very reliable for detecting light infestations unless a very large number of bags are sampled.



6. Distribution of coleopteran pests in bulk rice.

Traps. Many types of traps are in use:

- *Card traps.* Strips of corrugated cardboard (5 × 15 cm) inserted between layers of bags provide a very useful and repeatable method of monitoring infestation changes. The strips provide refuge sites into which moth larvae (*Corcyra* spp. and *Ephestia* spp.) crawl before pupation. Many beetle spp. (including *Tribolium, Oryzaephilus, Cryptolestes, Ahasverus,* and *Carpophilus*) also aggregate in these traps.

- *Sticky traps.* Commercial "fly papers" or strips of plastic fastened to boards with a nonhardening gum make very good traps for flying insects. This method is especially useful for recording the presence of warehouse moths, *Sitotroga* spp., *Sitophilus zeamais,* and hymenopterous parasites at very low population levels. It is probably one of the best early warning trapping systems available at low cost.
- *Light traps.* Light traps in warehouses will attract a wide range of pest species. Some species are more attracted than others, and the color of the light used has an effect on the insects trapped.
- *Food traps.* Small bags made of sack cloth or plastic mesh cloth, filled with grain or a suitable mixture of food grains, can quickly detect insect infestations from the surroundings. After a period of exposure, the bags are collected into plastic sample bags and examined.
- *Suction traps.* Suction traps collect a broad spectrum of insects in the warehouse but are relatively expensive.
- *Pheromone traps.* Pheromones are substances secreted by an individual and received by other individuals of the same species that elicit a specific response. The most common pheromones used for communication by short-lived insect adults are sex pheromones, which are usually produced by the female. In most cases, a sex pheromone produced by the female of a species is specific for the male of that species. However, interspecificity has been shown for pheromones of a number of species. Most examples of nonspecificity occur among the Lepidoptera. Long-lived adults such as grain weevils, grain borers, flour beetles, and grain beetles rely on male-produced aggregation pheromones for long-distance communication. Pheromones used for aggregation to a feeding or mating site are found mainly among certain Coleoptera. Both males and females respond to them. Pheromones can be used along with other insect traps (e.g., corrugated paper trap, grain probe trap).

Laboratory detection methods

To detect initial infestation, especially in commodities fresh from mills and production or storage sites, actual recovery of the insect is essential. This can be done by visual, flotation, staining, and X-ray methods, and the ninhydrin technique.

Visual examination. Visual inspection for eggs, larvae, pupae, or adults in samples is applicable against insects that spend at least part of their lives outside the kernels of grain or flakelike materials.

Cracking flotation method. The use of Na_2SiO_3 (water glass) solution at specific gravity of about 1.19 (Association of Official Agricultural Chemists 1965, White 1956) is time-consuming but gives an accurate assessment of actual insect numbers.

Staining methods. Several staining methods may be used to detect hidden infestation in grain, e.g., acid fuchsin and gentian violet strains (Pedersen et al 1977) and berberine sulfate solution (Milner et al 1950). All of these laborious methods rely on staining the gelatinous egg plugs of weevils.

X-ray method. Immature stages of *Sitophilus* spp., *Sitotroga cerealella, R. dominica,* and other internal feeders can be detected easily with X-ray radiography, but the equipment is expensive.

Ninhydrin technique. Dennis and Decker (1962) described a rapid technique and machine for detecting pre-adult insects using ninhydrin. A roll of filter paper is impregnated with ninhydrin, and grains are crushed against the impregnated paper by being passed through rollers. If the grains are infested, the body fluids of the insects present are absorbed by the paper, and a purple spot develops.

Ashman et al (1970) developed a small machine known as the Ashman-Simon infestation detector to crush the grains on the impregnated paper. The machine will detect 5-10% of eggs and early stage larvae, 40-60% of moderate-sized larvae, and 80-90% of later stage larvae in small cereal grains such as wheat.

The purple spots resulting from insect body fluids are recorded on paper that may be kept for several years at room temperature away from light and may be photocopied if a completely permanent record is required. Costs per test for the ninhydrin technique are only a fraction of those incurred using the X-ray method. The X-ray technique does not detect weevil eggs and early stage larvae and is not significantly better than the new instrument in its estimate of larger larvae present in grains. The ninhydrin technique is designed for use by personnel with little or no training.

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Weeds as rice seed contaminants

J. C. DELOUCHE

Many weeds important in rice culture are not native to the production area but were introduced as impurities in rice seed. The spread of weedy species as contaminants of rice seed within an area and, especially, the introduction of new weeds should be guarded against by regulations and inspection procedures similar to those deployed to guard against insects and diseases. Preventing contamination through rigorous quality control in seed production is the first defense against the spread of weeds as contaminants in crop seed. The proven system of quality control in seed production is seed certification. Decontaminating seed by modern seed cleaning machines is the second line of defense. The seeds of some serious weed pests, e.g., red rice, however, are physically so similar to rice seeds that mechanical separation is impossible. In both defenses, the key technical activities are inspection and testing, for which well-established methodologies are available for use in control programs.

The dissemination of weeds as contaminants of crop seed is well documented. Most serious weeds in North American agriculture, for example, are of foreign origin (Reed 1977, United States Department of Agriculture 1971). Some of the weeds were introduced into North America as ornamentals (e.g., the water hyacinth *Eichhornia crassipes* [Mart.] Solms), potential forage crops (e.g., johnson grass *Sorghum halepense* [L.] Pers.), fiber crops (e.g., hemp *Cannabis sativa* L.), or condiments (e.g., chicory *Chichorium intybus* L.). The majority, however, were inadvertently introduced as contaminants in seed imported or collected from other continents.

Historically, the wide dissemination of weedy species followed the course of exploration and colonization beginning in the 15th century. In modern times, weedy species have been and still are disseminated among the continents and countries — and within countries — as contaminants in internationally traded seed, grain, straw, other packing materials, "bird" seed, whole spices, and many other types of agricultural products. In still more recent times, weedy species have been introduced

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as contaminants in both small- and large-scale movement of seed of improved cultivars and new crops. Weeds of North American origin, for example, have been introduced into Asia and Africa through importation of seed of the so-called Mexican wheats. Similarly, weeds of Philippine origin have been spread widely through exportation of seed of high-yielding rice varieties. Weeds are also being disseminated in the continuing rice seed trade within South America; between South America and North America; among Africa, North America, and Asia; and in most other combinations of trading partners.

Weeds are pests that can be as detrimental to crop production as insects and diseases. The spread of weedy species within an area and, especially, the introduction of new species into an area or country should be guarded against through appropriate regulations and inspection procedures similar to those in place in some countries to guard against insects and diseases.

WEEDS IN RICE AND RICE SEED

Weeds are a serious problem in rice production. The annual loss due to weeds in Asian ricefields has been estimated at about 12% of potential production value, while estimates at IRRI indicate yield losses from weeds of up to 34% in transplanted rice; 45% in direct seeded, rainfed lowland rice; and 67% in upland rice (De Datta 1981). While some weeds are essentially ubiquitous in rice, like *Echinochloa* sp., there is considerable variability in the weed species among geographical areas and types of rice culture (Grist 1959, Kassian 1971, University of the Philippines College of Agriculture 1970). De Datta (1981) has collected and presented extensive lists of the common weeds in tropical lowland and upland rice culture in South and Southeast Asia; the major weeds in ricefields in Taiwan, Japan, and the United States; and the difficult perennial weeds in lowland and upland rice culture in Asia. More than 75 species are included in the lists.

Weed seed contaminants

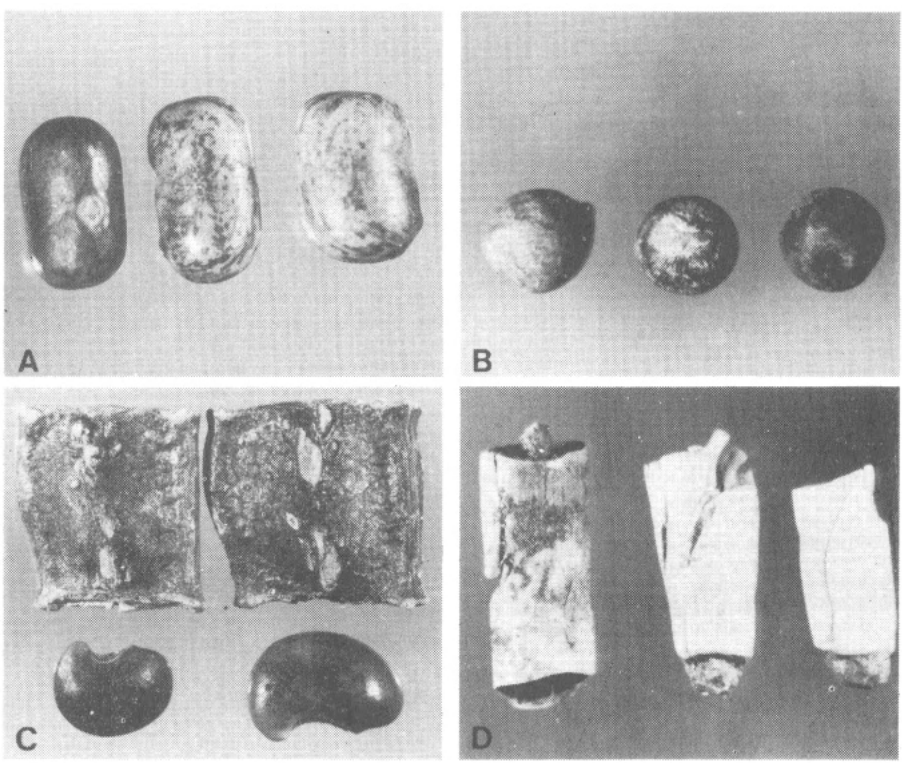
Rice seed can be contaminated with the seeds of any of the seed-bearing weeds that have similar maturity. In most cases the contaminating weed seeds are much smaller or lighter in weight than the rice seeds and can be effectively and efficiently removed by simple cleaning procedures, often just by traditional winnowing. The seeds of some important weeds, however, are so similar in one or more key dimensions or in density to the rice seeds in which they are found that removing them even with the most sophisticated separators is difficult, incomplete, or impossible. In countries with an established seed certification system and related legislation, difficult-to-separate weed seed contaminants are declared noxious and are prohibited or restricted in agricultural seed marketed internally or imported (Association of Official Seed Certifying Agencies 1979).

Difficult-to-separate weed seeds

Weed species with seeds similar in size and density to those of rice cultivars differ substantially among the different areas and types of production. In North and South

America, some of the weed species that fall into the difficult-to-separate category include (see also Fig. 1):

- *Sesbania exaltata* (Raf.) Cory (hemp sesbania): seeds about the same width as U.S. long-grain rice seeds
- *Caperonia castanaefolia* (L.) St. Hil (Mexican weed): seeds about the same width as U.S. long-grain rice seeds
- *Aeschynomene virginica* (L.) B.S.P. (joint vetch): pod segments about the same width as U.S. medium-grain rice seeds
- *Rottboellia cochinchinensis* (Lour.) W. D. Clayton (itchgrass): seeds about the same width, thickness, and length as U.S. medium- and long-grain rice seeds
- *Rhynchospora* sp. (spearhead): seeds similar in width and thickness to U.S. medium- and long-grain rice seeds
- *Brachiaria platyphylla* (Griseb.) Nash. (signal grass): seeds similar in width to U.S. long-grain rice seeds
- *Oryza sativa* L. (red rice): seeds often very similar in all physical properties to those of the cultivars they contaminate



1. Some difficult-to-separate seeds of North American weeds. A. *Sesbania exaltata;* B. *Caperonia castanaefolia;* C. *Aeschynomene virginica;* D. *Rottboellia exaltata.*

PREVENTION AND CONTROL

The most effective means of dealing with weed seed contaminants in rice seed are prevention and decontamination.

Prevention of contamination

It is neither practical nor necessary to attempt to completely prevent contamination of rice seeds with weed seeds. Indeed, in mechanized rice production, i.e., mechanical harvest of standing crop, some degree of contamination with weed seeds is inescapable. The matter of crucial importance is to take the steps necessary to prevent contamination of rice seed with difficult-to-separate weed seeds.

The crucial steps in preventing weed seed contamination of rice seed are 1) careful selection of seed production fields to ensure that the target weeds are not established, and 2) the use of weed seed-free planting seeds. Other important actions include thorough cleaning and inspection of planting and harvesting machines, drying facilities, and transport vehicles; inspection and roguing of seed fields; seed testing; and legal restrictions on the presence of specified weed seeds in rice entered into the market or imported.

Seed certification, testing, and control

Seed certification and related seed control measures are proven systems for accomplishing the crucial steps and important actions for preventing the contamination of planting seed with seeds of specified weeds (Esbo et al 1975, Svensson et al 1975). The strict controls in seed certification and equivalent quality assurance programs on land history, seed source, cleanliness of equipment and facilities, field and seed inspections and standards, and seed cleaning and packaging constitute very effective safeguards against the spread of weed pests as contaminants in crop seeds within a country. Regulations and restrictions relating to imported seeds, which may or may not be a part of general phytosanitary and quarantine regulations, are necessary to prevent the entry of new weed pests into the country.

Effective seed control requires appropriate sanctioning legislation, associated regulations and standards, and rigorous implementation and enforcement programs. The key activities of seed inspection and seed testing are discussed later in this section.

Decontamination

The only practical means of decontaminating large quantities of crop seeds is machine cleaning. Small quantities of seed needed for seed exchange, trials, and demonstrations can, of course, be decontaminated by visual inspection and hand removal.

Basic cleaning. Precleaning or scalping and basic cleaning of rice seed with an air and sieve machine will remove weed and crop seed contaminants that differ substantially from the rice seed in overall size, width, thickness, and density (Boyd et al 1975, Vaughan et al 1968). Contaminant seeds that differ to a lesser degree from rice seeds can often be completely removed – or partially so in terms of percentage

by weight or number — by use of special purpose or fine cleaning machines and separators.

Fine cleaning. The most frequently used fine cleaner for conditioning rice seed is the length separator of either the indented cylinder or disc pocket type. The length separator removes cross-broken rice seeds, and weed and crop seed contaminants that are appreciably shorter than the rice seed being conditioned. A properly maintained and operated length separator can remove seeds of *S. exaltata, C. castanaefolia,* and *B. platyphylla.*

A special rice seed flat screen with separator (Dockins separator) or a general-purpose width and thickness separator employing a rotating cylindrical screen with round or oblong perforations separates contaminants that are appreciably wider or narrower, or thicker or thinner, than the crop seeds. A cylindrical screen with the proper size of round openings for width separation can remove the pod segments of *A. virginica* from most size grades of rice, and a high percentage of *Rhynchospora* sp. and red rice seeds from long-grain rice. A screen with oblong perforations of the proper size for thickness separation will remove the wider and thinner seeds of *Rhynchospora* sp., but not all. Thickness separation would have little effect on red rice contaminants.

Final conditioning of the rice seed over a gravity or density separator would remove a high percentage of contaminating *Rottboellia exaltata* seeds — but not all — along with light, immature, and badly diseased or insect-damaged rice seeds.

Sequence of cleaning operations. When more than precleaning and basic cleaning are required, the sequence of subsequent operations is important in terms of separation effectiveness and efficiency (Veras 1984). The optimum separation sequence is

1. precleaning
2. basic air and sieve cleaning
3. length separation
4. width or thickness separation
5. density separation

Depending on the kind of contaminant, one or more or all of the fine cleaning operations can be omitted.

Seed inspection and testing

Standardized procedures are available for the types of inspections and testing needed in preventing and controlling weed seed contamination in crop seed. The international rules for testing seed (1976) of the International Seed Testing Association (ISTA) prescribe sampling, purity analysis, and related test procedures for essentially all agricultural and horticultural seeds. The relevant tests for determining the incidence of weed seed contaminants in crop seeds are purity analysis and determination of other species by number (i.e., number per unit weight). In purity analysis the amount of other seeds present in the crop seeds is established as a percentage by weight.

The Association of Official Seed Analysts (AOSA) rules for testing seed (198l), which are used in North America, are very similar to the ISTA rules. The AOSA

rules, however, prescribe methods for an examination for noxious weed seeds. This examination is an extension of purity analysis in which a larger quantity of crop seed (500 g minimum for rice) is visually examined to establish the presence (or absence) and rate of occurrence of specific weed seeds. Where weed seed contaminants such as those of the weedy red rices are legally prohibited from rice seed, the objective of the examination is to establish compliance with the prohibition of red rice for seed lots offered for sale.

WEEDY RED RICES

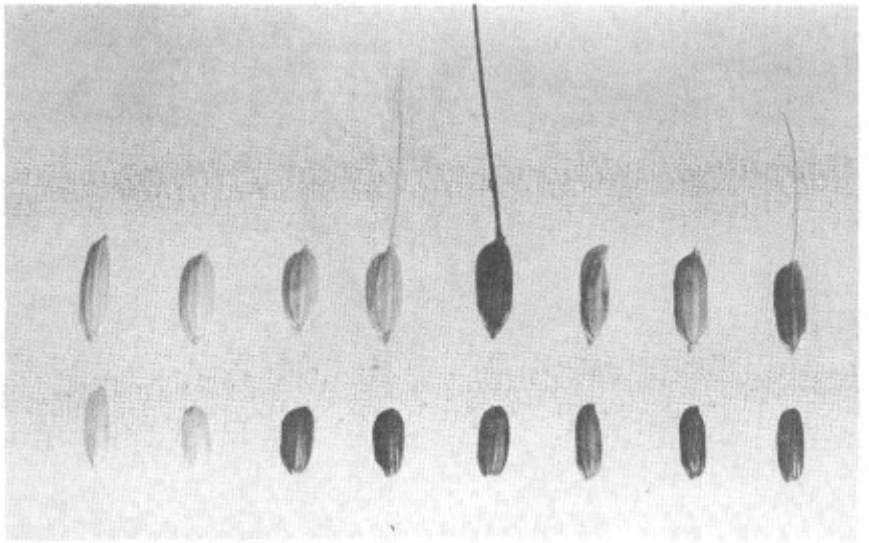
Red rice is the most common and troublesome weed in direct seeded rice culture in the U.S. and South America (Craigmiles 1978, Jorge and Barquin 1980). In Africa the red rice problem is augmented by weedy wild rices such as *O. glaberrima* Steud., *O. longistaminata* Chev. and Roehrich, and several other *Oryza* sp. (De Datta 1981, Grist 1959).

Red rice is of the same species as cultivated rice (*O. sativa* L.) and is distinguished by a red pericarp (Dodson 1898, Huey and Baldwin 1978). Since red rice naturally crosses with cultivated rice (Beachell et al 1938, Jodon 1959), red rice is really an assemblage of ecotypes that, in addition to the red pericarp, share three characteristics contributing to their success as weeds: early and near complete shattering; intense, persistent seed dormancy; and high seedling vigor (Constantin 1960, Do Lago 1982, Hill 1978). Red rice is not only troublesome as a weed but as a contaminant in grain. The value of rice grain is discounted in proportion to the rate of contamination with red rice grains because of the adverse effects of contamination on milling (Huey and Baldwin 1978).

Spread and control of red rice

Red rice is spread primarily as a contaminant in planting seed. "After red rice is once introduced into the field we can account for its spread; but the only reasonable explanation of its origin in a field is that it was introduced there in impure seed" (Dodson 1898). The presence of red rice in U.S. ricefields as early as 1846 is mentioned in reports (Constantin 1960), and four distinct types were noted by the United States Department of Agriculture in 1850. Craigmiles (1978) suggested that red rice was introduced into the eastern U.S. as a contaminant in seed rice during the colonial period.

Red rice is difficult to control because the seeds remain viable in the soil for many years, and it is the same species as cultivated rice, which limits chemical and many cultural control measures. Preventing the initial infestation, therefore, is the best control measure where applicable. In areas of limited rainfall and rigorous control of irrigation, very effective control, if not near eradication, is possible. Bellue (1932) reported there was no red rice in California in 1917, but 28% of samples were infested with red rice by 1932. The present claim is that California is free of red rice. This very favorable situation has apparently come about by the practice of water seeding, which effectively suppresses red rice emergence (Huey and Baldwin 1978, Sonnier 1978), and by the production of red rice-free seed under strict certification procedures.



2. Seeds of 6 red rice ecotypes and 2 cultivars important in Mississippi. Top row, spikelets; bottom row, caryopses.

Although the dominant red rices in an area are generally stable, segregating populations are continuously generated through natural crossing (Jodon 1959, Sonnier 1978). During 1978-82, 16 distinctive, stable red rice ecotypes were collected from Mississippi ricefields; about 90% of the infestations, however, involved only 3 ecotypes (Do Lago 1982). Several hybrid "swarms" from natural crosses between red and cultivated rice were also identified, but most types were not successful as weeds (Fig. 2).

Decontamination

Nunez (1980) and Veras (1984) determined the measurements of seeds of several red rice ecotypes and cultivars to establish an optimal separation strategy. The most consistent difference between seeds of red rice and of cultivated rice in Mississippi is in the width dimension: red rice seeds are consistently wider than the slender long-grain cultivars grown in Mississippi (Table 1). Most (98-99%) but not all red rice contaminants in a long-grain cultivar were removed with a width separator fitted with a screen with 2.88-mm-diameter perforations and operated at a moderate flow rate of 0.27 t/h (Table 2).

Inspection and testing

Inspection and testing procedures for determining the presence and rate of occurrence of red rice seed in rice seed are the same as those described above, with some important additions. Because a red pericarp is the critical distinguishing feature of red rice, the seed sample is hulled for examination. This can be accomplished with the type of hullers widely used by rice breeders. In some cases, the color of the pericarp is ambiguous. This is usually the case where the grains from suspect standing plants are hulled and examined before drying is complete.

Table 1. Average dimensions of seeds (spikelets) of 11 red rice ecotypes and 7 cultivars. Sources: Nunez 1980 and Veras 1984.

Ecotype[a] or cultivar	Seed (spikelet) dimensions (mm)		
	Length[b]	Width	Thickness
	Red rices		
SHA-	7.70	3.29	2.16
R-79/13	7.77	2.82	1.96
R-78/5	7.95	3.10	2.01
SHA+	8.08	3.06	2.06
R-78/8	8.18	2.74	1.85
BHR	8.38	2.99	2.06
R-80/2	8.41	3.36	2.16
R-79/2	8.43	3.24	2.11
R-80/1	8.48	2.46	2.03
R-79/1	8.59	2.61	2.16
R-79/6	8.81	3.38	2.21
	Cultivars		
Nato	8.23	2.99	2.01
Labelle	8.81	2.40	1.80
Starbonnet	8.89	2.42	1.78
Skybonnet	9.02	2.51	1.88
Newbonnet	9.17	2.40	1.85
Lebonnet	9.37	2.60	1.89
LeMont	9.53	2.70	1.96

[a]Red rice ecotypes collected in Mississippi and designated by Do Lago (1982).
[b]Exclusive of awn when present.

Table 2. Effectiveness of a cylindrical screen seed width separator in removing contaminating seed of a medium-grain red rice ecotype (SHA-) and cultivar (Nato) from that of a long-grain cultivar (Starbonnet). Source: Veras 1984.

Screen perforation diameter (mm)	Seed flow rate (t/h)	Separation (%) of seeds[a]						Long-grain cultivar seed loss
		Through perforations			Over perforations			
		Long-grain cultivar	Medium grain		Long-grain cultivar	Medium-grain		
			Red	Cultivar		Red	Cultivar	
2.88	0.54	76.9	1.2	1.9	23.1	98.8	98.1	23.1
	0.27	94.5	1.0	2.0	5.5	99.0	98.0	5.5
	0.14	98.9	2.0	4.0	1.1	98.0	96.0	1.1
2.98	0.54	83.9	2.4	4.6	16.1	97.6	95.4	16.1
	0.27	96.7	1.0	9.0	3.3	99.0	91.0	3.3
	0.14	98.9	1.4	1.5	1.1	87.0	85.0	1.0

[a]Rates of contamination: red rice, 60 seeds/kg; medium-grain cultivar, 60 seeds/kg.

Uncertainty in identifying red rice seed can be resolved by hulling a suspected grain, placing the caryopsis in a small dish, and adding a few drops of 2% KOH. If the kernel is from red rice, the KOH solution turns dark orange or red in a few minutes. There is no color change in cultivated (or white pericarp) rice (Louisiana Seed Testing Laboratory 1980, Rosta 1975).

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Seed-transmitted pests and diseases of legumes in rice-based cropping systems

B. K. VARMA and C. J. LANGERAK

The paper gives an overview of the seedborne pests and diseases of soybean, cowpea, green gram, chickpea, pigeonpea, and peanut, which can all be used in rotation with rice. Insect pests, nematodes, and diseases of common occurrence, potentially important ones that can occasionally become serious, and those that cause great economic losses are listed. The distribution of pests and diseases is also given, along with the rate of seed transmission of important virus diseases and data on crop losses. Safeguards are discussed to check the spread of pests and diseases that can be introduced through exchange of legume seeds, thus countering any benefit likely to be derived from a legume – rice rotation.

Legumes form a very important component of a rice-based cropping pattern in the potentially most productive farming system in the tropics. The important grain legume crops used in rotation with rice are soybean (*Glycine max* [L.] Merr.), cowpea (*Vigna unguiculata* [L.] Walp.), green gram (*Vigna radiata* [L.] Wilczek), chickpea (*Cicer arietinum* L.), pigeonpea (*Cajanus cajan* [L.] Millsp.), and peanut (*Arachis hypogaea* L.). Dovetailing these crops with rice has great potential, as evident from the cropping systems research results at the International Rice Research Institute (IRRI) (IRRI 1983).

The spread of some of the economically important crop pests and diseases is linked with the movement of seeds, which act as their carriers within a country and across national frontiers. Because 90% of all food crops grown in the world are propagated through seed (Neergaard 1979), it is essential for us to know which pests and diseases are likely to be transmitted through the seed, and their world distribution, so that appropriate plant quarantine measures can be taken.

The seeds of legume crops are important carriers of insect pests, fungi, bacteria, and viruses. Together or singly, some of the pests and pathogens constitute a serious threat to the cultivation of legume crops and therefore will affect the use of legumes in a rice-based cropping system. Exotic pests and diseases present a greater hazard than local pests and pathogens to crop breeding and plant introduction programs.

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This paper deals with the major seedborne pests and diseases of legume crops that can be used in rotation with rice, their distribution, economic importance, and control.

INSECT PESTS

Of the insect pests that attack legumes, beetles belonging to the family Bruchidae are important. Bruchids are essentially storage pests, but infestation by some species starts in the field when acrop is nearing maturity. The adults do not damage the seed. They lay eggs singly on the seed surface. The eggs are visible to the naked eye, and the larvae bore inside the cotyledons on hatching. The larvae are internal feeders; their damage to the cotyledons and sometimes to the embryo constitutes a serious germination problem in addition to creating storage losses. The important species recorded as damaging and breeding on dry seed are given in Table 1.

In pulses, *Callosobruchus maculatus* and *C. chinensis* are the most common and destructive pests of dried seed in Asia. The two species attack more than 14 economically important legume seeds worldwide. *C. phaseoli* is a relatively less known species as far as economic damage is concerned, but Southgate (1978) considers it a dominant species in tropical South America. In India, *C. analis* prefers to attack green gram, although it occurs in association uith *C. chinensis. C. rhodesianus* is an important storage pest of cowpea in Africa, and its spread beyond that continent would be serious. Pigeonpea is attacked by the largest number of bruchids. *C. theobromae* and *C. dolichosi* are confined to the Indian subcontinent,

Table 1. Important insect pests recorded on some legume seeds and their distribution.

Crop	Insect species	Distribution
Chickpea, pigeonpea, cowpea, green gram, soybean	*Callosobruchus chinensis, C. maculatus*	Worldwide
Cowpea, pigeonpea, green gam	*Callosobruchus phaseoli,*	Asia, Africa, Europe, USSR, Philippines, West Indies
	C. analis	Brazil, Asia, Africa, Europe, Australia, Indonesia, Japan, Hong Kong, Malaysia, Philippines
Cowpea	*C. rhodesianus*	West Africa, Nigeria, Uganda, Kenya, Tanzania, South Africa
	Bruchidius atrolineatus	Nigeria
	Specularis erythraeus	Kenya
Pigeonpea	*C. theobromae*	India, Sri Lanka
	C. dolichosi	India, Burma
	Acanthoscelides zeteki	Caribbean Islands, Central and South America
	Specularis sulcaticollis	Kenya
	S. erythraeus	Nigeria, Kenya
Peanut	*Caryedon serratus*	Asia, Africa, Middle East, Israel, Mexico, South America, West Indies, Taiwan, Thailand

but the extent of their damage is not well known. However, infestation with *Acanthoscelides zeteki* has been recorded to reach 40% in storage (Southgate 1979) in the Caribbean Islands, while *Specularis sulcaticollis* and *S. erythraeus* are lesser known species, but their association with pigeonpea seeds cannot be ignored.

Caryedon serratus is a major pest of stored peanut, causing considerable damage to undecorticated and decorticated nuts. Unlike other bruchids, which infest stored legumes, the full-grown grub leaves the seed or pod after cutting an exit hole and pupates outside in a papery cocoon. Other insects associated with peanut kernels are *Tribolium castaneum, Oryzaephilus surinamensis, O. mercator, Ephestia cautella,* and *Corcyra cephalonica.* They are cosmopolitan and are therefore not considered serious quarantine hazards. They may, however, carry pathogenic seedborne fungi (Majumder et al 1973) that could be dangerous.

NEMATODES

Seedborne nematodes are very rare in legume seeds. There are only two species of nematodes—the lesion nematode (*Pratylenchus brachyurus*) and the testa nematode (*Aphelenchoides arachidis*)—recorded on peanut pods or seeds from Australia, Africa, Egypt, USA, and Nigeria, and one species—the soybean cyst nematode (*Heterodera glycines*)—on soybean seeds from Egypt, USA, and Japan.

The lesion nematode is a major pest of peanut in the USA. It is found in the roots, pegs, and shells of mature pods but has never been reported in the seeds. Hundreds of nematodes may be present in each dark-colored necrotic lesion on the shells. Their importance is heightened by their association with *Sclerotium rolfsii*, the fungus responsible for peg rot (Minton 1984).

The testa nematode is a facultative endoparasite that is present in numbers up to 25,000 within the tissue of the shell or seed testa. Its presence predisposes the seed to invasion by soil fungi (Table 2).

Seeds of soybean carry cysts of the soybean cyst nematode, either loose or mixed with soil. The losses caused by *H. glycines* have not yet been quantified but may be significant (Epps 1969).

DISEASES

It is considered safer to use seeds than vegetative plant propagules to transfer plant material (Asia and Pacific Plant Protection Commission 1980, Phatak 1981). Nevertheless, there are many seedborne diseases, particularly viruses, in legumes, some of which are classified as dangerous to the crops. The major seedborne diseases of legume crops are given in Tables 2-5.

Soybean

Soybean seeds are associated with many fungal pathogens (Table 4), which deteriorate seeds and impair their viability. Heavy infections of stem canker (*Diaporthe phaseolorum* var. *batatatis*) have resulted in considerable yield losses in Canada (Wallen and Seaman 1962). Dunleavy (1956) reported a 65% field incidence

Table 2. Seed-transmitted soilborne fungal diseases of some important legumes.

Species	Diseases	Crops[a]	Distribution
Fusarium spp.	Root rot	Gm	Worldwide
F. solani	Collar rot	Vu, Vr, Ca	Worldwide
F. equiseti	Wilt	Vu, Vr	Worldwide
F. semitectum	Wilt	Vu, Vr, Cc	Worldwide
F. oxysporum f. sp. *tracheiphilum*	Wilt	Gm	USA, Europe, India
		Vu	USA, Brazil, Africa, Malaysia, Thailand, Australia, India
F. oxysporum f. sp. *ciceri*	Wilt	Ca	Asia, Africa, Mexico, Middle East, USA, South America
F. oxysporum f. sp. *udum (=F. udum)*	Wilt	Cc	Asia, Africa, Mauritius, Trinidad
Macrophomina phaseolina	Ashy stem blight, charcoal rot, seedling rot	Gm, Vu, Vr, Ah	Worldwide
Pythium aphanidermatum	Seed decay, seedling mortality, stem rot	Vu	Nigeria, Tanzania, Brazil
Rhizoctonia bataticola	Dry root rot	Ca	Asia, Australia, Ethiopia, Middle East, USA, Turkey
		Cc	India, Jamaica
R. solani	Damping off, foot and basal stem rot	Gm, Vr, Ah	Worldwide
	Web blight	Vu, Gm	Worldwide
Sclerotium rolfsii	Stem rot	Gm, Vu, Ah	Worldwide
Myrothecium roridum	Collar rot	Vr	India
Sclerotinia sclerotiorum	Stem rot	Gm, Ca	Worldwide

[a] Gm = *Glycine max,* Vu = *Vigna unguiculata,* Vr = *Vigna radiata,* Ca = *Cicer arietinum,* Cc = *Cajanus cajan,* Ah = *Arachis hypogaea.*

of pod and stem blight (*D. phaseolorum* var. *sojae)* in Iowa, USA. In Brazil, the latter pathogen has also rendered sensitive cultivars unsuitable for cultivation (Bolkan et al 1976). Among the foliar diseases, frog eye leaf spot (*Cercospora sojina*) and brown spot (*Septoria glycines*) have caused 15 and 17.9% crop losses, respectively, in the USA; and web blight *(Rhizoctonia solani)* produced 80% crop infection in China (Allen 1983, Williams and Nyvall 1980).

Bacterial blight caused by *Pseudomonas syringae* pv. *glycinea* inhibited germination of soybean seed by 68% in the USA (Sinclair 1975); similar results were obtained in India (Nicholson et al 1973). In the USA, this disease caused great monetary loss in Iowa (Kennedy and Alcorn 1980), but the crop loss due to bacterial pustule caused by *Xanthomonas campestris* was 15% (Laviolette et al 1970). According to Watson (1970), *P. syringae* pv. *glycinea* was introduced into New Zealand through infected seed.

Of the viruses, soybean mosaic virus (SMV) is the most serious and widespread. It has reduced yield by 9-20% in Bulgaria (Bov and Boyadzhiev 1977) and by 20% in

Table 3. Seed-transmitted viruses of major importance in some legume crops.

Virus	Distribution	Transmission (%)	Reference
	Soybean		
Cowpea mild mottle virus	Ghana, Ivory Coast, Thailand, Argentina	<91.7	Allen (1983)
Soybean mosaic virus	India, Korea, China, USA, Canada, France	0.05-10.2	Goodman and Oard (1980)
	Bulgaria, USSR, Brazil, Nigeria, Lebanon, Iran	10.6 -29.1	Suteri (1981)
Tobacco ring spot virus	USA, Canada, Africa, China, Australia	100	Iizuka (1973)
	Cowpea		
Cowpea severe mosaic virus	South America	10	Singh and Allen (1980)
Cowpea aphid-borne mosaic virus	Widespread	0-40	Singh and Allen (1980)
Cowpea mottle virus	Nigeria	3-10	Singh and Allen (1980)
Cowpea banding mosaic virus	India	9-34	Prakash and Joshi (1980)
Cowpea chlorotic spot	Worldwide	4-20	Singh and Allen (1980)
Blackeye cowpea mosaic virus	USA, Brazil, India	13	Zettler and Evans (1973)
Cowpea yellow mosaic virus	America, Africa	1-5	Allen (1983)
	Green gram		
Bean common mosaic virus	Iran, India	8-32	Kaiser and Mossahebi (1974)
	Peanut		
Peanut mottle virus	Worldwide	0-8.5	Kuhn and Demski (1984)
Peanut clump virus	India, West Africa	4-14	Thouvenel et al (1978)
Peanut stunt virus	USA, Europe, Morocco, Japan	0.0073-0.207	Tolin (1984)
Marginal chlorosis virus	New Guinea	71	Van Velsen (1961)
Peanut stripe virus	North America, China, Indonesia, Malaysia, Philippines, Thailand	19.3-37.6	Demski et al (1984a)

Table 4. Seed-transmitted fungal and bacterial diseases of soybean with a worldwide distribution.

Pathogen	Diseases	Seed transmission (%)	Reference
Cercospora kikuchii	Purple blotch, purple speck, purple seed stain		
Colletotrichum truncatum	Seedling blight, anthracnose	15-81	Verma and Upadhyay (1973)
Diaporthe phaseolorum var. *batatatis*	Stem canker, pod and stem blight		
D. phaseolorum var. *sojae* (con. st. *Phomopsis)*	Pod and stem blight	20	Wilcox and Abney (1971)
Peronospora manshurica	Downy mildew		
Pseudomonas syringae pv. *glycinea*	Bacterial blight	3-64	Nicholson and Sinclair (1971)
Xanthomonas campestris pv. *glycines*	Bacterial pustule		

the USA (Ross 1977), and germination by 12-36% in India (Sutheri 1981). The virus predisposes seed to infection by *Phomopsis sojae* (Hepperly et al 1979). Tobacco ring spot virus (TRSV) impairs seed viability and may also reduce yield by 50% (Crittenden et a1 1966), the crop loss depending on the percentage of incidence in seed (Allen 1983). TRSV also infects green gram (Allen 1983, Shivanathan 1979). Cowpea mild mottle virus (CMMV), although a minor disease in cowpea, has been found serious in soybean in Thailand (Brunt and Phillips 1978) and the Ivory Coast (Thouvenel et al 1982), and it appears to be of considerable importance in tropical soybean.

Cowpea

Ascochyta leaf spot *(Ascochyta phaseolorum)* is potentially the most destructive disease of cowpea in Africa, causing severe losses in cooler regions (Williams 1976). In Nigeria, a 75% crop loss due to *R. solani* and *Pythium aphanidermatum* seed infection, a 35-50% yield loss due to anthracnose *(Colletotrichum lindemuthianum*), and 50% seedling mortality due to wilt *(Fusarium oxysporum* f. sp. *tracheiphilum)* were reported (Allen 1983, Singh and Allen 1980). Wilt was responsible for 75% mortality in India (Singh and Sinha 1955). Emechebe and McDonald (1979) and Emechebe (1981) also reported serious cowpea diseases in Nigeria caused by *C. capsici, C. truncatum,* and *Macrophomina phaseolina.*

In India, bacterial blight of cowpea caused by *Xanthomonas vignicola* was responsible for considerable seedling mortality, and 62% disease incidence was observed with an initial seed inoculum of only 1% (Shekhawat and Patel 1977).

There are more than 16 seedborne viruses of cowpea, some of which have high transmission rates and cause more than 50% yield loss in the field. Cowpea aphid-borne mosaic virus (CAMV) was responsible for complete loss of the crop in Nigeria in 1973 (Raheja and Leleji 1974). Other serious, internationally important virus diseases in tropical America, East Africa, and West Africa reported by Allen (1983)

Table 5. Important seed-transmitted foliar fungal and bacterial diseases of some legumes.

Pathogen	Diseases	Distribution
	Soybean	
Cercospora sojina	Frog eye leaf spot	Asia, Guatemala, Venezuela, Brazil, USA, Canada, Cameroon, Europe, USSR, Australia
Septoria glycines	Brown spot	Widespread
	Cowpea	
Ascochyta phaseolorum	Leaf spot	Central and South Africa, Asia
Colletotrichum capsici and C. truncatum	Brown blotch	Nigeria
C. lindemuthianum	Anthracnose	Africa, India, Brazil
Xanthomonas campestris pv. *vignicola*	Bacterial blight, bacterial canker	USA, Puerto Rico, Brazil, India, Africa
	Green gram	
C. capsici, C. truncatum	Anthracnose	India
Elsinoe phaseoli	Scab	America, Zimbabwe, Brazil
Pseudomonas syringae pv. *phaseolicola*	Halo blight	USA, Europe
Xanthomonas campestris pv. *phaseoli* (fuscans)	Fuscous blight	India
	Chickpea	
Ascochyta rabiei	Blight	North Africa, West Asia, Australia, Canada, Mexico, Europe, Middle East, Turkey, USSR
Botrytis cinerea	Grey mold	Argentina, Colombia, Canada, USA, Spain, Asia, Australia
	Pigeonpea	
Phoma sp.	Stem canker	Puerto Rico, Trinidad
Phomopsis sp.	Seedling rot	Puerto Rico
Botryodiplodia theobromae	Seedling rot	Puerto Rico
Colletotrichum cajani	Anthracnose	Puerto Rico, Hawaii, India, Brazil
Xanthomonas cajani	Bacterial leaf blight	India, Panama, Sudan
	Peanut	
Pseudomonas solanacearum	Bacterial wilt	Indonesia, Africa, Japan, USA, China

are cowpea severe mosaic virus (CSMV), cowpea yellow mosaic virus (CYMV), and cowpea mottle virus (CMV), which have caused yield losses up to 80%, 95%, and 75%, respectively. In India, the field incidence of cowpea banding mosaic virus (CBMV) and cowpea chlorotic spot (CCS) varied from 13 to 62%, which reduced the yield up to 41.8% (Sharma and Varma 1975), while in Nigeria, CCS caused a 56% loss (Singh and Allen 1980). More than one virus may occur in cowpea. A mixture of cucumber mosaic virus and blackeye cowpea mosaic virus leads to synergism (Pio-Ribeiro et al 1978) and to consequent stunting and severe crop loss.

Green gram

Seedborne pathogens encountered on green gram (Table 2, 5) are responsible for preemergence and postemergence diseases leading to loss of stand. The bacterial

halo blight disease caused by *Pseudomonas phaseolicola* spreads very rapidly and is widely distributed on beans *(Phaseolus vulgaris)* in temperate regions of the world. A mungbean strain of *P. phaseolicola* introduced with seed in Ohio, USA, caused a 60% yield reduction (Schmitthenner et al 1971). Because halo blight disease can initiate epidemics at a very low level (0.01%) of seed contamination in French bean (Taylor and Dudley 1977) and is transmissible through green gram seed, it can be characterized as a very dangerous pathogen of great quarantine significance. Another important disease of green gram is bean common mosaic virus (BCMV), which reduced yields by 31-75% in Iran (Kaiser and Mossahebi 1974).

Chickpea

Ascochyta blight *(Ascochyta rabiei)* and wilt *(Fusarium oxysporum* f. sp. *ciceri)* are two major seedborne diseases of chickpea. *A. rabiei* has been responsible for severe epidemics in Pakistan, Bulgaria, USSR, and Greece (Nene 1982), the extent of crop loss varying between 20 and 100%; it caused a severe epidemic in the chickpea crop in Canada in 1973, where the pathogen was introduced through imported seed (Morrall and McKenzi 1974). Chickpea wilt caused a 10% crop loss in Uttar Pradesh, India (Mathur et al 1960), while Haware and Nene (1980) found a 24-94% yield loss depending on the crop growth stage during attack.

Pigeonpea

Pigeonpea wilt *(Fusarium udum)* is the most destructive seedborne disease of pigeonpea in India and East Africa. Continuous cropping in the same field may lead to 50% or more plant mortality due to wilt (Sen Gupta 1974). *Rhizoctonia bataticola* in India and *Phoma* sp., *Phomopsis* sp., *Botryodiplodia theobromae,* and *Fusarium semitectum* in Puerto Rico and the Caribbean Islands are serious pathogens of pigeonpea that affect germination in the field. Pigeonpea anthracnose *(Colletotrichum cajani)* is a common disease in Puerto Rico, and as early as 1927 Tucker reported a 36% loss in yield from 87% infected pods.

Peanut

Peanut seeds are affected by several important diseases. Ashworth et al (1961) reported extensive damage by seedborne *Sclerotium rolfsii* and *R. solani;* the former was responsible for 10% diseased pods in the infected plants, and the latter reduced seedling emergence by 30% and yield by 25% in the USA.

Of the virus diseases, peanut mottle virus (PMV) is the most widely distributed and serious seedborne peanut virus in the world. In some areas, 75-90% of the crop can be infected (Paguio and Kuhn 1973), causing a yield loss as high as 30% (Kuhn and Demski 1975). In Georgia, USA, a 5-6% economic loss was estimated from 26% infected plants in 1 yr (Kuhn and Demski 1984)—calculated at US$11 million in 1973 (Smith 1980). PMV can also be transmitted to soybean (Demski 1975) through an infected peanut crop. Peanut clump virus (PCV) has been observed to reduce yield by 60% in India (Nolt and Reddy 1984), and marginal chlorosis (MCV) by 50% in New Guinea (Van Velsen 1961). Peanut stunt virus (PSV) has a very low seed transmission rate (0.2%), but 70-80% crop losses might occur in the USA (Culp and

Troutman 1967), and the disease could be a serious threat to peanut production. A newly reported peanut stripe virus (PStV) may cause yield losses up to 23% in the early stages of infection (Demski et a1 1984a, Demski and Lovell 1985). The virus was isolated from peanut germplasm lines introduced into the USA from China (Demski et a1 1984b). The crop losses caused by various peanut viruses cannot be correlated with the infection rate in seed: PSV, with a very low rate of seed transmission, can cause heavy crop losses, but PStV, with high seed incidence, may cause relatively less damage.

DISCUSSION

Insect pests of legumes do not pose a large hazard if seed is fumigated. The danger could come from the spread of economically important species, such as *Callosobruchus rhodesianus* from Africa and *Caryedon serratus* from the Indian subcontinent, to new areas. However, detection of latent infestation of bruchids inside the seeds by X-ray techniques, and fumigation with methyl bromide at 32 g/m^3 for 4 h under vacuum can control the pests effectively (Varma 1985). Fumigation may not be effective for the control of peanut and soybean nematodes without endangering seed viability. Instead, importation of peanut as kernels rather than pods, and selection of healthy, mature, clean seed from nematode-free areas would assist efforts to prevent the spread of these pests.

Seedborne diseases are more refractory than pests. Soybean viruses CMMV and TRSV, and bacterial pustule are restricted in distribution, and their dissemination could be checked through strict regulatory measures. As an additional safeguard, a growing-on test of imported seed in an insect-proof screenhouse could be followed whenever necessary.

The role of seed treatment in the control of soybean diseases is not very conclusive. Nevertheless, the use of a thiram + benomyl mixture or chloranil can control some of the fungal diseases and improve germination to a great extent (Agarwal 1981, Neergaard 1979).

The seedborne diseases of cowpea, particularly anthracnose and the viruses, provide a major production constraint. The widespread occurrence of CAMV is reflected in its seed transmissibility, and there is every possibility of CSMV, CMV, CBMV, and CYMV finding their way to other countries through seed exchange unless plant quarantine measures, e.g., pre-export inspection of crops, and growing-on tests in the importing country, are rigorously enforced. Unfortunately, chemical seed treatment of cowpea has not been found very effective against major diseases, and therefore the use of resistant lines may be necessary.

In contrast to soybean and cowpea, green gram seed carries fewer pathogens of a serious nature. Halo blight is confined to the temperate regions, and BCMV has very limited distribution in the tropics. Since most world green gram production is in the Indian subcontinent, it would be prudent to check the introduction and spread of these two diseases in Asia. However, halo blight can be controlled by treating the seed with streptomycin or kasugamycin (Taylor and Dudley 1977), which should be required.

Vascular wilt and Ascochyta blight are the most important chickpea diseases, causing substantial crop losses. Fortunately, seedborne inocula of these two diseases can be effectively controlled by seed treatment with systemic fungicides. Thiobendazole, tridemorph, and thiram + benomyl have been found very effective in controlling the seedborne inocula of Ascochyta blight, Botrytis grey mold (Grewal 1982, Reddy 1980, Reddy and Kababeh 1984), and Fusarium wilt (Haware et al 1978); they can be used to disinfect the seed. Similarly, the spread of pigeonpea wilt can be checked through seed treatment with captan (Ellis et al 1977) or a thiram + benomyl mixture (Kannaiyan et al 1980).

Bacterial wilt caused by *Pseudomonas solanacearum* is a potential seedborne disease of peanut in wet soil. Darong et al (1981) reported a 30% loss in China. Strict control of seed movement should be enforced to avoid the spread of the pathogen to disease-free areas.

Peanut viruses PCV, PSV, MCV, and PStV have restricted distribution and, because of their great economic importance, their spread needs to be checked. Peanut seeds must be grown in virus-free areas reinforced by enzyme-linked immunosorbent assay tests for making healthy virus-free seeds available.

CONCLUSION

Given the spectrum of seedborne pests and diseases of these legume crops, seeds of soybean, cowpea, peanut, and green gram constitute a quarantine risk and need controlled introduction. Importing countries can avoid introducing seedborne viruses and bacteria of these crops by importing healthy seed covered by a certificate of seed quality and by a growing-on test in an insect-proof screenhouse. Chickpea and pigeonpea seeds are relatively safer to import if they have had the prescribed seed treatment, which can eliminate the risk of seedborne diseases.

Seed certification in the country of origin, fumigation upon arrival, careful inspection combined with chemical treatment, and postentry quarantine whenever necessary are reasonable safeguards for the import of soybean, cowpea, peanut, and green gram and should be followed.

Fortunately, there are no common seedborne pathogens of legumes and rice, so that growing a legume crop before or after rice should be safe. Nevertheless, the economic efficiency of a legume - rice rotation will depend on the extent to which the legume crop is exposed to the risk of pests and diseases. If the research and development needs of leguminous crops could be met by breeding cultivars resistant to major economic diseases, then it should be possible to achieve a major breakthrough in organizing a more efficient legume-based cropping system in rice without danger from introduced pests or diseases.

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Seedborne and seed-transmitted diseases of maize in rice-based cropping systems

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Fungal, bacterial, and viral pathogens of maize cause root rots, leaf spots, streaks, blights, stalk rots, and ear and seed rots. A few are also pathogenic on rice. This paper reviews their effects on seed quality (germination, vigor, and appearance), the significance of infected seed as a source of inoculum, seed treatment as a means of reducing seedborne inoculum, and methods for detecting the pathogens in seed.

Maize is a widely distributed crop throughout the world, with more than 100,000 ha grown in each of 70 countries. It is produced in a range of environments from the equator to 50º latitude and from sea level to 4,000 m elevation. Most of the world's production is in the temperate regions, with about 50% of this in the USA. Maize is also grown extensively in rice-growing regions in tropical and subtropical Asia and Latin America, either in rotation with rice or in areas not under rice production, such as those at higher elevations.

There are more than 100 recognized pathogens of maize. Only a few of these also attack rice. About 50 maize diseases are seedborne. This paper discusses the effects of seedborne pathogens on seed quality (germination, vigor, appearance), the significance of infected seed as an inoculum source for the new crop, seed treatment (if any) as a means of reducing seedborne inoculum, and methods for detecting the pathogens in seed.

LEAF DISEASES

Most maize diseases caused by fungi in genus *Helminthosporium* are leaf diseases, but stalks and ears may also be affected.

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H. maydis causes southern corn leaf blight and is prevalent in hot, humid maize-growing areas. It comprises two established races. Race O is the more common and causes minor crop losses. Race T, on the other hand, caused massive losses in the U.S. corn belt in 1970 by attacking crops with Texas male sterile cytoplasm. Ears and stalks, as well as leaves, were affected. Both races are seedborne, but most of the information on this relates to race T, which produces a black, felty mold on the seed, can reduce germination (Kommedahl and Lang 1971), and can be transmitted by seed to seedlings (Boothroyd 1971, Kommedahl and Lang 1971). Various fungicides can reduce the inoculum on seed (Lim and Kinsey 1973). There are several methods of detecting seed infection with blotters and culture plates (Kulik 1971, Singh et al 1974). A new race, race C, has recently been reported in China (K. J. Leonard, pers. comm.).

H. turcicum causes northern corn leaf blight, which is worldwide in distribution. Severe outbreaks may occur in susceptible varieties grown under cool temperatures and heavy, frequent dews. It is not seedborne (Ullstrup 1954).

H. carbonum, which causes carbonum leaf spot, is common worldwide in humid areas at intermediate temperatures. A new race, designated 3, has developed in the U.S. and is considered potentially important. The pathogen can cause seed discoloration (Koehler 1960), but detrimental effects on germination are not known. There is no record of transmission to the new crop. Seed treatment information is confined to laboratory studies on artificially inoculated seed, with a thiram formulation proving to be the best of five fungicides tested (Leonard 1976). A culture plate test can detect the pathogen on seed (Levic and Penvic 1983).

H. rostratum causes rostratum leaf spot, a disease of minor importance in the U.S. and Asia. Seed infection has been recorded at the rate of 85% in Texas (Whitehead and Calvert 1979). Seeds show pink banding, and germination can be reduced (Whitehead and Calvert 1979). Seed transmission has not been reported. Culture plate and blotter tests exist for detecting this pathogen on seed (Chidambaram et al 1973, Whitehead and Calvert 1979).

Curvularia spp. cause a damaging leaf-spotting disease in tropical areas. Some species also attack rice. They are extensively seedborne (Aulakh et al 1976; Handoo and Aulakh 1979, 1982), but seed transmission has not been reported. Control has been achieved by seed treatment with thiram and captan (Grewal and Payak 1976). Fungicide sprays have also been tested but are not economic. Several seed health tests, including blotter, culture plate, rolled towel, and seed washing techniques, have been reported (Aulakh et al 1976; Handoo and Aulakh 1979, 1982).

Physoderma maydis causes brown spot, resulting in leaf spotting and stalk rots in areas of abundant rain and high temperature. Twenty percent crop losses have been recorded in India (Lal 1976). There are unconvincing reports that the pathogen is seedborne (Broyles 1962, Lal and Chakvarti 1975).

Rhizoctonia solani f. sp. *sasaki* causes banded leaf sheath, which is particularly severe in mountain valleys at 1,100-1,500 m in India. Seed infection levels up to 60% have been detected (Michail et al 1977). Infected seeds are small, with sclerotia found under the pericarp (Ahuja and Payak 1982). Seed transmission to the new crop has not been detected. A blotter test can detect the pathogen on seed (Michail et al 1977).

Two other leaf-spotting diseases that are seedborne but of minor importance are caused by *Alternaria alternata* and *Exsersohilum prolata.*

ROOT, STALK, AND EAR ROTS

Of the several soilborne root-rotting pathogens of maize, one of the most prevalent is *Pythium* sp., which causes serious stand establishment problems in cold, wet soils. It is not seedborne, but seed treatment is used extensively to protect seedlings in the field.

Macrophomina phaseolina causes charcoal rot on roots and has a very broad host range. It is a problem on maize only in hot, dry areas; it develops best at 37°C. The pathogen causes black discoloration of the kernels (Thirumalachar 1953), and there is some evidence of seed transmission (Semenuik 1944), although unconvincing. A culture plate test can detect infected seed (Singh et al 1974), and pycnidia can sometimes be seen on the kernels (Thirumalachar 1953).

R. solanii was, until recently, considered a minor root pathogen but is now recognized as an important component of the root rot complex on irrigated maize in Georgia, USA (Sumner and Bell 1982, Sumner et al 1985). Seedborne infection levels up to 60% have been recorded (Michail et al 1977), but adverse effects on seed germination, and transmission of the pathogen by seed have not been reported. *R. solani* can be detected on seed by a blotter test (Michail et al 1977). Several seed treatment fungicides are labeled for control of this pathogen.

R. zeae is a minor ear rot pathogen but has been implicated in the root rot problem on irrigated maize in Georgia (Sumner and Bell 1982). It is seedborne (Voorhees 1934), but seed transmission has not been reported. It can be detected on seed by a culture plate test (Voorhees 1934).

Seedborne pathogens that may cause root rot but primarily cause stalk rot are discussed below.

Cephalosporium maydis causes late wilt, a late-season disease of widespread incidence and severity in Egypt, where 100% infection has been reported in some fields (Samra et al 1962). It has also been found in India. It is extensively seedborne (Mohamed et al 1967), but seedborne inocula have not been shown to reduce seed quality or to be transmitted to the new crop. A culture plate test can detect seedborne inocula (Mohamed et al 1967).

C. acremonium causes black bundle disease, a minor late-season disease. The pathogen is usually considered a secondary invader but is a primary invader in Egypt (Sabet et al 1962). It produces an ear rot, and seed infection levels up to 60% have been reported (Sabet et a1 1962). It does not affect seed germination but has been reported to be transmitted to the new crop (Sabet et al 1962). Several fungicides applied to seed can reduce the seedborne inoculum (Raju and La1 1977). Culture plate and blotter tests exist for detecting the pathogen on seed (Tuite 1961, Yap and Kulshrestha 1975).

Fusarium moniliforme commonly causes ear and stalk rot in many graminaceous hosts, including rice. It is widespread on seed, with infection levels up to 100% (Singh and Singh 1977, Sumner 1968). It can cause rotting and white streaks

on seeds. However, the effects of this fungus on seed germination and vigor are inconsistent (Kulik and Schoen 1982). Whether systemic infection from seed occurs is also controversial (Foley 1962); it has been reported in studies in sterile soil (Kommedahl and Lang 1971) but not in the field (Sumner 1968). Seed treatments to reduce infection include fungicides (Gilbertson et al 1983, Raju and Lal 1977), aerated steam, and dry heat. Culture plate and blotter tests exist for detecting the seedborne inoculum (Singh et al 1974).

Gibberella zeae (*Fusarium graminearum*) is a common and destructive ear and stalk pathogen that also attacks rice. Seed infection has been detected up to 66% (Foley 1983). The organism rots the seed, and germination is reduced (Brodnik 1975), but the seed does not seem to be a significant source of inoculum. Seed treatments include captan and biological antagonists (Kommedahl and Mew 1975). There are several seed health tests (Singh et al 1974).

A broad range of seedborne *Fusarium* spp. causes root rots, although *F. culmorum* is recognized as the main cause of maize stalk rot in Europe (Cook 1978). Although seed infection levels up to 38% have been recorded for some of these species, there is little evidence that they affect germination or are transmitted through seed. Several fungicides can reduce root infection (Falloon 1982). There also are several seed health tests (Handoo and Aulakh 1979, Pelhate 1981).

Diplodia maydis is an important ear and stalk rot pathogen worldwide. It is commonly seedborne, having been detected in the embryo and endosperm (Melchers 1952). Germination can be reduced (Nwigwe 1974), and transmission to the new crop can occur, resulting in seedling blight (McNew 1937). Seed is recognized as an important inoculum source (McNew 1937). Seed treatment chemicals can improve germination and reduce seedling blight (Koehler 1960, Kruger 1965). Several seed health tests exist (Kruger 1965, Nwigwe 1974).

D. macrospora is a minor disease in the southeastern U.S. but is more serious as a leaf and ear disease in Central America. Seed infection levels have been detected up to 5% (Larsh 1938). The organism produces a gray discoloration on seed and may cause rotting (Eddins 1930). Seed transmission is not known. Culture plate tests exist to detect the pathogen on seed (Marasas and Van der Westhuizen 1979).

D. frumenti, the cause of Physalospora ear rot, is of no economic importance, having been detected only in Brazil and Florida, USA. It is seedborne, causing blackening and rotting of seed (Eddins 1930a, b); nothing else is known about the seedborne phase.

Botryodiplodia theobromae causes ear and stalk rot in tropical countries. It appears to be of little economic importance. Seed infection levels up to 10% have been recorded (Handoo and Aulakh 1979, Singh et al 1974, Yap and Kulshrestha 1975). The pathogen causes blackening and rotting of seed (Del Rosario 1954). Laboratory studies suggest seed transmission (Mehta et al 1972). Seed health tests exist (Handoo and Aulakh 1979, Singh et al 1974, Yap and Kulshrestha 1975).

Colletotrichum graminicola, the cause of anthracnose stalk rot, is a serious disease in tropical and temperate regions. It is extensively seedborne, with infection levels up to 8% (Warren 1977). Seeds are discolored, and germination may be reduced (Warren and Nicholson 1975). The pathogen appears to be seed-transmitted. Seed treatment chemicals have improved emergence and reduced

seedling infection (Warren and Nicholson 1975). Several seed health tests exist (Warren and Nicholson 1975, Yap and Kulshrestha 1975).

Nigrospora oryzae is a relatively minor ear and stalk rot disease of maize that is also a pathogen of rice. Seed infection up to 13% has been detected. Seed discoloration can occur (Koehler 1960), and germination is reduced (Reddy 1933). There is circumstantial evidence that seed transmission occurs (Reddy 1933). Chemical and biological seed treatments have been shown to be effective (Reddy 1933). Several seed health tests exist (Melchers 1956, Pelhate 1981).

Physalospora zeae, the cause of gray ear rot, is commonly found in the U.S. but is considered to be of no economic importance. It also is found in Europe and southern Africa. Seed infection up to 10% has been found (Yap and Kulshrestha 1975). Infected seeds are discolored and can become rotten (Ullstrup 1945). Seed transmission has not been reported. A blotter test for detecting seed infection exists (Yap and Kulshrestha 1975).

Penicillium spp. are common ear-rotting pathogens. Extensive infection occurs in the field, but it may develop further in storage, causing the condition known as blue eye, where the fungus fruits below the pericarp. The organism is also one of the causes of molding in maize stored at high moisture content. Seed infection up to 100% has been detected (Handoo and Aulakh 1979). The pathogen can reduce germination and cause seedling blight (Hosni et al 1968). Infected seed is a minor inoculum source in the field. Several seed health tests exist (Handoo and Aulakh 1979, Mohamed et a1 1967).

Aspergillus flavus causes an ear rot known as yellow mold. Like *Penicillium* spp., it is a storage fungus. It is extensively seedborne, with infection levels up to 79% (Handoo and Aulakh 1979, Hesseltine et al 1976), and can reduce germination (Lopez and Christensen 1967). Systemic infection of seedlings from inoculated seed has been reported (Kelly and Wallin 1984), but seed is not considered an important source of inoculum. Several seed health tests exist (Christensen and Kaufmann 1968, Sauer et al 1984). The ear rot condition is of minor economic importance; of greater concern with this pathogen is the production of the potent carcinogen aflatoxin, which can develop in grain either before or after harvest.

A. niger causes black mold, an ear rot that can occur worldwide, particularly under moist conditions. It has been detected up to 62% on seed (Frutchey 1936), causing discoloration or rotting (Taubenhaus 1920). Seed transmission has not been demonstrated. A blotter test for detecting the pathogen on seed exists (Handoo and Aulakh 1979).

Storage molds are caused by a range of fungi in genera *Aspergillus* and *Penicillium* that can invade maize seed stored at moisture levels above 13%. All types of seed, including rice, are susceptible. In severe cases the seed is completely destroyed. Most effective control is achieved by controlling seed moisture content, The pathogens can best be detected in culture plate tests (Christensen and Kaufmann 1968, Sauer et al 1984).

Several other seedborne pathogens causing root, stalk, or ear diseases exist in genera *Cladosporium, Epicoccum, Gonatobotrys, Rhizopus, Botrytis, Sclerotinia, Sclerotium,* and *Trichoderma,* but they are of minor economic importance.

SMUTS

Ustilago maydis, which causes common smut, is a well-known maize disease worldwide. Although readily found, it is not considered to cause serious crop losses. It is seedborne only as unattached spores in the seed lot. Infected seeds on the plants are turned into galls, filled with black, sooty spores. Seed is not an important inoculum source (Christensen 1963). Carboxin and benomyl seed treatments show promise as means of reducing the seedborne inoculum. Spores in a seed lot can be detected by a seed washing procedure (Handoo and Aulakh 1982, International Seed Testing Association 1966).

Sphacelotheca reiliana, the cause of head smut, results in minor losses in some temperate and subtropical areas. As with common smut, it is seedborne only as unattached spores in the seed lot. Usually no seed is produced on affected ears. It has been shown to be transmitted by seed (Bressman and Barrs 1933). Effective seed treatment can be achieved with carboxin and baytan (Stienstra et al 1985). A seed washing test for detecting the pathogen exists (International Seed Testing Association 1966).

Ustilaginoidea oryzae, which causes false smut, is also a pathogen of rice. This is a very obscure disease on maize, occurring rarely in hot countries (Sharma and Verma 1979). Seed infection has been recorded (Richardson 1979).

ERGOTS

Claviceps gigantea causes a condition known as horse's tooth. It occurs only in the high humid valleys of Mexico, where it is endemic (Fucikovsky and Moreno 1971, Fuentes et a1 1964, Ullstrup 1973). Up to 53% infected ears have been found. Infected seeds are replaced by sclerotes, which produce the inoculum for the next crop by releasing ascospores. Infected seeds are detected by appearance, i.e., shaped as a comma or a horse's tooth.

DOWNY MILDEWS

The eight major downy mildew diseases cause leaf streaks with downy growth, tassels or ear abortion, and stunting. Some are restricted to areas in Southeast Asia and are therefore significant with respect to worldwide plant quarantine regulations. All the major diseases are seedborne.

Seedborne inocula can be transmitted to new seedlings. However, transmission normally occurs only from freshly harvested or high-moisture seed. Seed treatment with metalaxyl and chloroneb has been found in some diseases to reduce the seedling infection after planting by protecting against inocula from sources other than seed. Seed health testing can usually be done only by histological examination of seed. Table 1 provides detailed information for the individual pathogens.

Table 1. Maize downy mildews.

Disease	Pathogen	Distribution	Seedborne	Seed-transmitted	Seed treatment	Seed health test
Java downy mildew	*Perenosclerospora maydis*	Indonesia, Australia	Yes (Semangoen 1970)	Only before seeds arc dried (Semangoen1970)	None	Histological exam (Semangoen 1970)
Philippine downy mildew	*Perenosclerospora philippinensis*	Philippines, Indonesia, India, Nepal	Yes, in embryo and endosperm (Dalmacio and Exconde 1969, Weston 1920)	Yes at 36% moisture, no at 14% (Advincula and Exconde 1976, Dalmacio and Exconde 1969)	Metalaxyl, chloroneb (Sharma et al 1981)	Histological exam (Dalmacio and Exconde 1969)
Sugarcane downy mildew	*Perenosclerospora sacchari*	Taiwan, Fiji, India, Philippines, New Guinea, Australia	Yes, in embryo (Singh et al 1967)	Yes, only at moisture above 20% (Chang 1970)	Metalaxyl, chloroneb (Lal et al 1979)	Embryo test (Singh et a1 1967)
Sorghum downy mildew	*Perenosclerospora sorghi*	America, Africa Asia, Europe	Yes, in pericarp and scutellum (Jones et al 1972, Summartaya et al 1975)	Yes, only on freshly harvested seeds (Jones et al 1972, Summartaya et al 1975)	Metalaxyl, but some phytotoxicity (Odyody and Fredcricksen 1984)	Histological exam (Jones et al 1972, Kruger 1965)
Green ear	*Sclerospora graminicola*	Israel, USA	No	No	None	None
Crazy top	*Sclerospora macrospora*	America, Africa, Asia, Europe, Australia	Yes, in endosperm and embryo (Ullstrup 1952)	Yes, only on freshly harvested seeds (Ullstrup 1952, Ullstrup 1970)	Terrazole in inoculated seeds (Segura 1979)	Histological exam (Ullstrup 1952)
Brown stripe downy mildew	*Sclerospora rayssiae* var. *zeae*	India, Nepal, Pakistan, Thailand	Yes, in embryo (La1 et al 1980)	Yes (Singh et al 1967)	Metalaxyl (La1 et al 1980)	Embryo text (Singh et al 1967)
Spontaneum downy mildew	*Perenosclerospora spontaneum*	Philippines, Thailand	Not known	Not known	None	None

BACTERIA

Erwinia chrysanthemi causes bacterial stalk rot in tropical and subtropical countries. It is particularly severe at high temperature and humidity. There is only one, unconvincing report that it is seedborne (Prasad and Sinha 1978).

E. stewartii, which causes Stewart's wilt, has been a major disease of maize for many years. Seed infection does occur (Frutchey 1936, Rand and Cash 1933), but whether or not the pathogen is transmitted by seed is controversial (Frutchey 1936, Pepper 1967). The corn flea beetle is the most important inoculum source. Several seed treatments were tested from the 1930s up to 1950 (Pepper 1967, Williams 1957); some controlled wilt symptoms on seedlings but not adult plants, and many were phytotoxic.

Pseudomonas lapsa causes a stalk rot of little economic importance in the U.S. and India. It was isolated from 12% of the seed in 1 seed lot (Rangarajan and Chavravarti 1967). Seed appears to be a significant means of transmission.

P. rubrilineans causes a minor leaf streak disease in India. It is seedborne. In one study (Dange et al 1978), diseased seedlings developed when seed from diseased plants was planted in sterile soil.

Xanthomonas maydis is reported to be a significant disease in India (Ranganathaiah et al 1983). It is seedborne and was transmitted to seedlings when infected seed was germinated on blotters (Ranganathaiah et al 1983).

VIRUSES

Maize dwarf mosaic virus is the only important maize virus convincingly shown to be seed-transmitted. The pathogen is also known as sugarcane mosaic virus, and occurs in many regions of the world. It is seedborne, having been detected to a level of 0.5% (Hill et al 1974, Mikel et al 1984). One report indicated adverse effects of seedling growth from infected seed (Panayotou 1981). Transmission to seedlings has been clearly demonstrated in sterile soil (Hill et al 1974, Mikel et al 1984).

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Seedborne and seed-transmitted diseases and insects of potato in rice-based cropping systems

F. H. CISNEROS

Major diseases, nematodes, and insect pests of potato occurring in tropical and subtropical climates that can be transmitted or dispersed by tubers are briefly described.

Potato is a component of rice-based cropping systems. Although it originated in the high altitudes of tropical South America, the potato is making its way into the medium and lower tropics. Potato production has doubled in the developing world over the last 20 yr, with the largest increases in Africa, Asia, and Central America. In India, a traditional cereal (wheat and rice) producer, potato has had the most rapid rate of increase as a food crop (Swaminathan and Sawyer 1983).

The *Compendium of potato diseases* (Hooker 1981) lists 23 viruses, 38 fungi, 6 bacteria, 2 mycoplasmas, and 1 viroid—most transmitted by tubers; a few are also truly seedborne. In addition, 68 nematode and 128 insect and related pest species have been reported. Most nematodes and a few insects can also be dispersed by tubers. New organisms may swell this list as potato cultivation expands in the tropics. Most of the following information on diseases has been extracted from the *Compendium* and reviewed by E. French, head of the Pathology Department, International Potato Center.

SEEDBORNE AND SEED-TRANSMITTED DISEASES

Many diseases of potato can be tuber-transmitted and can cause damage in the growing crop, during transport. or in storage, or, when tubers are used as seed, can contaminate the fields. Tuber-borne pathogens include bacteria, fungi, viruses, viroids, and mycoplasmas.

Bacterial diseases

Bacteria are readily transmitted in or on tubers. The possibility of true seed transmission has not been exhaustively studied, and so far, only *Erwinia carotovora* ssp. *carotovora* has been shown to be transmitted by seed (Table 1).

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Table 1. Bacteria, fungi, mycoplasma-like organism, viruses, and viroid affecting the potato and their transmission by tuber or botanical seed.

Scientific and common names	Transmitted by	
	Tubers	Seed
Bacteria		
Erwinia carotovora ssp. *carotovora* and ssp. *atrospetica* = blackleg and soft rot	Yes	Yes
Corynebacterium sepedonicum = ring rot	Yes	No
Pseudomonas solanacearum = bacterial wilt or brown rot	Yes	No
Mycoplasma-like organism		
Purple top (mycoplasma-like organism)	Yes	No
Fungi		
Alternaria solani, A. alternata = early blight	Yes	No
Botrytis cinerea = gray mold	Yes	No
Colletotrichum atramentarium = black dot	Yes	No
Fusarium oxysporum, F. roseum = dry rot	Yes	No
F. solani = dry rot and wilt	Yes	No
Helicobasidium purpureum = violet root rot	Yes	No
Helminthosporium solani = silver scurf	Yes	No
Macrophomina phaseolina = charcoal rot	Yes	No
Phoma andina = phoma leaf spot	No	No
P. exigua var. *foveata* = gangrene	Yes	No
Phytophthora erythroseptica = pink rot	Yes	No
P. infestans = late blight	Yes	No
Polyscytalum (Ooospora) pustulans = skin spot	Yes	No
Puccinia pittieriana = common rust	No	No
Pythium debaryanum, P. ultimum = leak	Yes	No
Rhizoctonia solani = stem canker and black scurf	Yes	No
Rosellinia sp. = black rot	Yes	No
Sclerotinia sclerotiorum = white mold	Yes	No
Sclerotium rolfsii = stem rot or southern blight	Yes	No
Septoria lycopersici = septoria leaf spot	No	Yes
Spongospora subterranea = powdery scab	Yes	No
Streptomyces scabies = common scab	Yes	No
Synchytrium endobioticum = black wart	Yes	No
Thecaphora solani = smut	Yes	No
Verticillium albo-atrum, V. dahliae = vercillium wilt	Yes	No
Viruses		
Beet curly top virus	Yes	No
Alfalfa mosaic virus = potato calico	Yes	No
Andean potato latent virus	Yes	?
Potato leafroll virus	Yes	No
Potato mop-top virus	Yes	No
Potato virus A	Yes	No
Potato virus M	Yes	No
Potato virus S	Yes	No
Potato virus T	Yes	Yes
Potato virus X	Yes	No
Potato virus Y	Yes	No
Potato yellow dwarf virus	Yes	No
Potato yellow vein virus	Yes	No
Tobacco necrosis virus	Yes	No
Tobacco rattle virus	Yes	No
Tobacco ringspot virus	Yes	No
Tomato black ring virus = pseudo-aucuba	Yes	No
Tomato spotted wilt virus	Yes	No
Viroid		
Potato spindle tuber viroid	Yes	Yes

Bacterial wilt or brown rot caused by *Pseudomonas solanacearum* E. F. Smith is the most serious bacterial disease of potato in the lowland tropics. It is widely distributed in the warm-temperate, semitropical, and tropical zones and may limit potato cultivation in warm areas. Seed grown at high altitudes may have latent infection. Infected tubers are an important factor in the distribution and severity of the disease. The bacteria survive for extended periods in some soils, while in others they may not survive 1-6 mo of fallow. Yellowing, stunting, and wilting of foliage are characteristic of infected plants. The bacteria occur in a wide range of pH and soil textures. Other important economic hosts include tobacco, tomato, pepper, eggplant, peanut, banana, and some ornamentals and weeds.

Black leg and bacterial soft rot are caused by two strains of *E. carotovora:* ssp. *carotovora* (Jones) Dye and ssp. *atroseptica* (Van Hall) Dye. The black leg alludes to the black decay of the stem and the soft rot to the moist decay of the tuber at harvest or while in storage. *Erwinia* is favored by warm temperatures (25-30 °C), poor aeration, soil flooding, washing of tubers, and high N fertilization.

Bacterial ring rot caused by *Corynebacterium sepedonicum* (Spieck and Knott) Skapt and Burhk has symptoms somewhat similar to those of brown rot, but bacterial ring rot is more restricted to mild soil temperatures (18-22 °C) for disease development. Infection decreases at high temperatures. The only natural host is potato. The bacteria overwinter primarily in infected tubers.

Fungal diseases

Many of the fungal diseases of potato are tuber-borne, but none is known to be seed transmitted (Table 1). Some of the diseases prevalent or occurring in warm conditions are briefly described.

Late blight caused by *Phytophthora infestans* (Mont) de Bary is probably the most important disease of potato worldwide except in hot, dry, irrigated areas. It can reach epidemic proportions each growing season. Damage to foliage in advanced stages includes necrotic lesions that kill leaflets and eventually the entire plant. Where distinct seasons occur, the fungus overwinters as mycelia in unharvested or stored tubers. Once primary infection has occurred, further spread of the fungus takes place by airborne or waterborne sporangia. High-temperature strains of the fungus have been reported. Late blight also affects tomato and other Solanaceae.

Early blight caused by *Alternaria solani* Sorauer is distributed worldwide, damaging both foliage and tubers. Leaflets show concentric rings of necrotic tissue and eventually desiccate without abscising. The fungus persists in infected tubers, crop debris, soil, and solanaceous hosts. Primary infection may occur on older foliage early in the season, but in many locations the disease develops in senescing plants. Other hosts include tomato and other Solanaceae.

Charcoal rot caused by *Macrophomina phaseoli* (Manbl.) Ashby (= *Sclerotium bataticola* Tamb.) is worldwide but economically important only in warm regions where soil temperatures exceed 28 °C. Damage in stems causes yellowing and sudden wilt. Infection of tubers may occur before harvest and in storage. At first no external symptoms are evident while the fungus develops under the surface. Later, internal cavities are filled with black mycelia and sclerotia. The fungus can survive saprophytically or as microsclerotia. Infected tubers rot in warm storage. Infections

become latent under refrigeration but resume development when returned to warm temperatures. The fungus can attack the underground parts of a wide range of cultivated and wild plants.

Rosellinia black rot caused by *Rosellinia* spp. is prevalent under warm and moist conditions, particularly in Central and South America. Infected plants become stunted and wilt. Stems, roots, and stolons become covered by a mat of mycelia. At harvest, infected tubers are also covered with mycelia. Many tubers rot before harvest. The disease is favored by poor soil drainage and becomes a problem when potato is not rotated with other crops. Other hosts affected include carrot, beet, *Brassicae, Amaranthus, Rumex,* and *Polygonum* spp.

Thecaphora smut caused by *Angiosorus solani* (Barrus) Thrium and O'Brien (= *Thecaphora solani* Barrus) was originally restricted to high elevations in South America, but now occurs at low levels and warm temperatures. Usually no aboveground symptoms are found. Infected tubers have warty external swellings and dark brown internal areas. Thecaphora smut is favored by high soil moisture. The spores are believed to be long-lived in the soil. The fungus is introduced by planting infected tubers. It may also be carried in irrigation water and infested soil. *Datura stramonium* also has been reported as a host plant.

Black dot caused by *Colletotrichum atramentarium* (Berk and Br.) Taub. has been reported in many parts of the world. It is regarded as a low-grade pathogen, interacting with other pathogens or plant stresses. Infected plants have black sclerotia of dotty appearance on tubers, stolons, roots, and stems. Yellowing and wilting of foliage are coupled with rotting of underground plant parts. Severe invasion of cortical tissue causes sloughing of the periderm. Sclerotia may develop on the upper surface of the tuber, and in storage, grayish areas of the surface may resemble silver scurf. The fungus overwinters as sclerotia on the surface of tubers or in plant debris in the field. Black dot seems to be favored by low N, high temperature, poor soil drainage, and light, sandy soil. Other hosts include tomato, eggplant, pepper, and other Solanaceae and weeds such as *Physalis peruviana* and *Datura stramonium.*

Silver scurf caused by *Helminthosporium solani* Durt and Mont. (= *Spondylocladium atrovirens* Harz.) is present in many parts of the world. Infected tubers show small, localized, light brown, circular spots with distinct borders that may enlarge to cover a great part of the tuber. A distinct silvery sheen is observed when the affected surface is wet. Silver scurf symptoms somewhat resemble black dot blemishes; they may occur together, but silver scurf does not have sclerotia. High humidity and temperature favor the development of the disease in the field and in storage. No other hosts are known.

Verticillium wilt caused by *Verticillium albo-atrum* Reinke and Berth and *V. dahliae* Kleb. is distributed throughout the world, producing early senescence of plants (early dying or early maturity). Infected tubers usually develop a light brown discoloration in the vascular ring. The fungi survive poorly in soil without suitable hosts. *V. dahliae* is favored by warmer soil temperatures (22-27 °C). The inoculum is reduced when cereals, grasses, and legumes are rotated. The main sources of inoculum are field soil and the soil adhering to the tuber. The fungi infect over 50 species of plants in 23 families, including cultivars and weeds.

Fusarium wilts and dry rots are caused by several species of *Fusarium. F. solani f. eumartii* (Carp) Snyd and Hans, *F. oxysporum* Schl., and *F. avenaceum* (Corda ex Fr.) Sacc. cause wilt in the field. *F. solani* (Mart) Snyd and Hans and *F. sambucinum* Fuckel cause storage rot of potato. These diseases are widespread and most severe under warm or hot and dry conditions. Infected plants wilt as a result of cortical decay of the roots and lower stems. Purpling of aerial parts, including aerial tubers, occurs. The diseases are typically soilborne and are transmitted from inoculum within and on seed tubers. The fungi survive in the soil for long periods.

Stored tubers infected with dry rot have dry lesions, sometimes in concentric rings. Under humid conditions, lesions may become slimy and black because of bacterial contamination.

Rhizoctonia canker or black scurf caused by *Rhizoctonia solani* Kuhn is widespread in traditional potato-growing areas. The fungus affects underground sprouts, producing poor stands of weak plants. Cankers may develop, girdling the stem partially or totally. Purpling of leaves and aerial tubers, and other symptoms may occur. Infected tubers present black or dark brown sclerotia on the surface. The fungus also survives in plant debris in the soil, being favored by low temperature and high moisture.

Viral and viroid diseases

All potato viruses are readily transmitted by tubers. Varying degrees of transmission by botanical seed occur only with potato spindle tuber viroid (PSTV) and the potato virus T (PVT), whereas contradictory results were obtained with Andean potato latent virus (APLV).

Potato leafroll virus (PLRV), distributed worldwide, is the most damaging virus disease of potato. It is tuber-borne and is also transmitted in a persistent manner by aphids, mainly by *Myzus persicae* Sulz. Young leaves of plants infected by aphid transmission stand upright, roll, and turn slightly pale. Plants from infected tubers show rolled lower leaflets and slightly pale higher leaves. Leaves are stiff and leathery. In *S. tuberosum* ssp. *andigena* cultivars, rolling of the lower leaves is often absent, whereas upright growth, stunting, and marginal and interveinal chlorosis of leaflets are characteristic, especially of dwarfed upper leaves. Hosts other than cultivated Solanaceae species include *Physalis floridana* and *Datura stramonium.*

Potato virus A (PVA) is widespread, causing a mild mosaic. Mottled areas vary in size and lie both on and between the veins. PVA is transmitted by aphids, including *Myzus persicae,* in a nonpersistent manner. Many cultivars are resistant. All hosts are Solanaceae, including *Nicotiana tabacum.*

Potato virus M (PVM) is widely distributed, although its importance seems to be restricted to Eastern Europe and the USSR. Symptoms range from very slight to severe. PVM is transmitted by aphids in a nonpersistent manner. Other hosts include species of Chenopodiaceae and Leguminosae.

Potato virus S (PVS) is widespread. It is almost symptomless in most common potato cultivars. It is readily transmitted mechanically and by aphids in a nonpersistent manner. Its effect on yield reduction is controversial. Many other hosts are reported: *Datura, Physalis, Capsicum, Lycopersicon, Nicandra, Nicotiana,* and *Chenopodium.*

Potato virus T (PVT) occurs in the Andean Region without producing obvious symptoms, except for cases where mild mottle, slight vein necrosis, and chlorotic spots are present. It is mechanically transmitted by true seed but not by aphids. Other hosts include *Phaseolus* and *Chenopodium.*

Potato virus X (PVX), the most widespread virus of potato, is readily transmitted mechanically. Symptoms vary from absent to severe and rugose mosaic with dwarfing of the plant and reduced leaflets or top necrosis. Hosts other than Solanaceae are Chenopodiaceae, Amaranthaceae, and certain Leguminosae.

Potato virus Y (PVY) is widespread, although strains vary in their distribution. Symptoms vary from weak to severe foliage and tuber necrosis, to death. The virus is readily transmitted by aphids in a nonpersistent way. It causes large yield reductions and is even more destructive when combined with PVX. Other hosts include *Nicotiana, Physalis,* and *Datura.*

Tobacco rattle virus (TRV) is sparsely but widely spread and transmitted by stubby root nematodes (*Trichodorus* spp.). The virus causes stem mottle of potato and spraing (annular or crescent-shaped necrotic areas) on the tubers; it infects more than 400 monocotyledonous and dicotyledonous species in more than 50 families.

Tomato spotted wilt virus (TSWV) is widespread and transmitted by thripids (thrips and *Frankliniella*), which acquire it only at immature stages and transmit it as adults. Infected plants have necrotic leaf spots, and stem and top necrosis, and eventually die. The tuber may appear normal or may be malformed, with internal rusty or dark necrotic spots. The virus infects dicots and monocots belonging to more than 30 families.

There are many other potato virus diseases of minor importance because of their restricted area of distribution or small economic effect on potato. These include the following:

- Alfalfa mosaic virus (AMV): widespread, transmitted by aphids in a nonpersistent manner
- Cucumber mosaic virus (CMV): transmitted mechanically and by aphids in a nonpersistent manner
- Sugar beet curly top virus (SBCTV): transmitted by the leafhopper *Circulifer tenellus*
- Tobacco mosaic virus (TMV): transmitted mechanically
- Tobacco necrosis virus (TNV): transmitted by zoospores of *Olpidium brassicae* (Woronin) Dang.
- Tobacco ringspot virus (TRSV): occurs in the Andean Region; transmitted mechanically and by several vectors, including *Xiphinema,* thrips, and *Epitrix*
- Tomato black ring virus (TBRV): occurs in Europe, transmitted by *Longidorus* spp. nematodes
- Andean potato latent virus (APLV): common in the Andean Region, readily transmitted by contact between plants
- Andean potato mottle virus (APMV): occurs in the Andean Region, readily transmitted by contact between plants
- Potato aucuba mosaic virus (PAMV) or tuber blotch: widespread but not common, transmitted mechanically and by aphids in a nonpersistent manner

- Potato yellow vein virus (PYVV): restricted to Ecuador and Colombia; vector has not been identified
- Potato yellow dwarf virus (PYDV): occurs in North America; the only known virus borne by leafhoppers (*Aceratagallia* and *Agallia*) that is also transmitted mechanically
- Potato mop-top virus (PMTV): occurs in the Andean Region and Europe, survives inside the fungus *Spongospora subterranea,* resting in spores for several years; transmitted by zoospores

PSTV has special quarantine importance. Damage in commercial plantings has been reported in North America and the USSR. PSTV is readily transmitted mechanically, by chewing insects, and also by pollen and true seed. Among other symptoms, infected plants have stems and blossom pedicels that are slender and longer than normal, remain upright, and have restricted growth. Tubers are elongated and round in cross-section, sometimes with pointed ends. Many solanaceous plants are infected but symptomless. Tomato and *Scopolia sinensis* show symptoms. Infection may also occur in many other families: Amaranthaceae, Borraginaceae, Campanulaceae, Caryophylaceae, Compositae, Convolvulaceae, Dipsacaceae, Sapindaceae, Scrophulariaceae, and Valerianaceae.

TUBER-BORNE AND TUBER-DISPERSED NEMATODE AND INSECT PESTS

Nematodes

Potato seed tubers are important sources for the dissemination of nematodes. These parasites may be present on or inside the tuber, in some cases in the form of a cyst or other resting condition together with soil adhering to the tuber.

Potato cyst nematodes (PCNs)—*Globodera pallida* and *G. rostochiensis* (Woll)—are the most important nematode pests of potato in temperate and cool subtropical regions (Scurrah and Franco 1978). Having originated in the Andean Region, PCNs have spread to Europe, Asia, North and South Africa, Central America, New Zealand, the Philippines, and elsewhere. The nematodes infest roots and tubers. The round-shaped females are initially white and yellow, and later turn brown and become cysts that contain eggs. Large populations cause stunting, early senescence, and reduced yield. Several solanaceous plants, including tomato and eggplant, have been recorded as hosts.

Root-knot nematodes (RKNs)—*Meloidogyne* spp. —are polyphagous and widely distributed in warm environments; their importance is increasing as potato is introduced into the tropics. The diagnostic symptoms of RKN attack on potato are galls on roots and tubers. Yield and tuber quality are reduced. In addition, RKNs interact with other pathogens, particularly with *Pseudomonas solanacearum,* producing more severe damage. RKNs attack numerous other plant species.

Root lesion nematodes— *Pratylenchus* spp. —are widely distributed throughout the world (Jensen 1978). Infested underground parts of the plant show necrotic lesions and partial destruction of secondary roots. As a result, yield and tuber quality are reduced. The nematodes are involved in interactions with other pathogens,

especially *Verticillium* spp., enhancing wilting and causing important economic damage.

Several other nematodes that infest potato plants are more restricted in their distribution or are of minor incidence.

- The false root-knot nematode *Nacobbus aberrans* is an important pest in the high Andean plateaus of Peru and Bolivia, and has recently been reported in warmer areas in Argentina, Ecuador, and Mexico. Egg masses and immature females withstand desiccation (Jatala 1978).
- The potato tuber rot nematode *Ditylenchus destructor* and the potato stem nematode *D. dipsaci* are important in certain areas (Winslow 1978).

Insects

The potato tuber moth (PTM) *Phthorimaea operculella* (Zeller) is the most injurious direct pest of potato in the field and in storage in warm climates (Haines 1977). Other species with similar biological characteristics, occurring in the neotropics, are *Symmetrischema plaesiosema* (Turner) (Sanchez and Aquino 1986), *Scrobipalpula absoluta* Meyrick, *Scrobipalpoxis solanivora,* and *Eurysacca melanocampta* Meyrick.

In the field, PTM larvae produce blotch mines on the leaves and bore into the stems. Later generations infest the tubers. Adult females take advantage of cracks in the soil to lay eggs on the tubers; or the larvae may migrate from the stems. At harvest, eggs may be laid in large quantities on the exposed tubers. The larvae initially mine under the skin but later tunnel through the flesh. Damage is most severe in years with low rainfall and high temperature.

In storage, the insects continue to reproduce as long as the potato contains enough food for larval development.

POTATO QUARANTINE AND TESTING

Nearly all potato diseases can be distributed in or on tubers, and some by true seed. It is therefore essential to take precautions when potatoes are shipped for any reason. Plant introductions can be safe if special procedures are followed. Stem cutting during propagation (with indexing of cut ends) minimizes the spread of pathogenic bacteria and fungi. Testing for viruses by serology and indicator plants can assure freedom from known viruses. PSTV can be assayed with near certainty by a combination of gel electrophoresis and indicator plant methods, and most recently by means of the highly sensitive nucleic acid spot hybridization test (Salazar et al 1983). Electron microscopy may reveal particles of unknown viruses.

Botanical seed dissemination of viruses and viroids can be prevented by a clear understanding between the provider and the recipient. Either one (or both, for greater safety) must take adequate precautions. The provider can test the parents before crossing or a sample of the progeny, whereas the recipient can assay the progeny.

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Preharvest and postharvest treatments to improve rice seed health

C. ANSELME

The quality of a seed lot depends on factors affecting both the physiology and the pathology of the seed plants. Evaluation of germination capacity, vigor, and dormancy is as important as information about infection by bacteria, fungi, insects, nematodes, and viruses, and about infestation by weed seeds. Protection of seed plants in the field employs resistant cultivars and weed control. Because rice seed lots are produced and stored under very different environmental conditions, preharvest and postharvest treatments conserve or improve their quality. Preharvest treatments are fertilizers and pesticides applied to plants or the soil. Posthrvest seed conditioning is done to improve seed storage or to facilitate good sowing conditions, emergence, and stand of plants, and to avoid the development and dissemination of seed-transmitted or soil-borne pathogens. Standardized seed health testing is needed to facilitate information for users in the international seed trade or in genebank exchanges. The International Orange Certificate of the International Seed Testing Association is particularly helpful.

Preharvest fertilizer and pesticide applications affect the plant from its emergence until harvest. They are used for plant improvement and protection to maintain the plant population in the field in the best growing condition and to produce the highest grain yield.

Postharvest conditioning is done to improve quality and viability during storage, and to manage diseases at sowing and at different crop growth stages. Postharvest measures include eliminating small, light, and shrivelled seed; drying; and protective treatments. Postharvest treatments may be physical (e.g., heating to break dormancy or improve vigor) or chemical (e.g., to control seed-, soil-, or waterborne pests and diseases; to balance abnormal plant growth caused by *Gibberella fujikuroi* [Sawada] Ito; or to serve as herbicide antidotes).

In some cases, postharvest seed treatments are combined with soil amendments or seedling protection at emergence.

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PREHARVEST TREATMENTS

Preharvest treatments are performed to improve germination, vigor, and seedling stand, or to protect against soil- and seedborne pathogenic bacteria, fungi, insects, and nematodes during the vegetative phase.

Improving the intrinsic quality of seed or plants

The best preharvest control of seed quality is the use of resistant cultivars. Some rice cultivars are resistant to more than one race of *Xanthomonas campestris* pv. *oryzae* (Ishiyama) Dye (Xco), and some are resistant to bacterial blight (BB) as the plants grow (Zhang and Mew 1985).

Seed ripened at 30 °C has lower dormancy than seed ripened at 25 °C because cracks in the outer and inner layers of the seed coats that ripen at the higher temperature allow entry of O_2, which inhibits germination (Hayashi and Hidaka 1979).

Improving soil conditions can increase disease resistance. Powdered silica fertilizer at 1.50-2.25 t/ha on light clay soils improves the disease resistance of rice; the effect does not appear before panicle formation, but there is an action on plant size and leaf color (Zhang et a1 1984). Adding P to soil where *Cochliobolus miyabeanus* (Ito and Kumb.) Drechsler ex Daston is endemic reduces disease intensity (Kaur et al 1982). Green manure can reduce the sclerotial viability of *Corticium solani* Kühn (*Rhizoctonia solani*) (Dath l982), while organic amendments (rice chaff, mustard cake, sawdust, etc.) can reduce seedling sheath blight infection (Kannaiyan and Prasad 1983).

Kato et al (1983) observed that oxidized fatty acids are important in protecting rice against *Pyricularia oryzae* Cav. Blast (Bl) incidence in the nursery at the 4-leaf stage can be reduced to less than 10% in an ultraviolet-absorbing vinyl film greenhouse (Honda and Nemoto 1985).

Protecting growing plants

Spraying a combination of liquid N and foliar fungicide reduces the application cost of fungicide by avoiding an eventual depressive effect (Lee et al 1983). Chemical treatment to prevent rice yellow mottle virus in Niger is not practical because of the high cost of insecticide, the ecological and toxicological problems with which they are associated, and the difficulty of killing the insects before they transmit the virus (Rechaus and Amadou 1986). Complementary measures such as draining fields between two consecutive seasons and regular weeding to eliminate possible host plants are recommended.

The most common, if not always the most harmful, cryptogamic rice disease is Bl. Infection more than 3 wk after heading causes little damage to seed quality, and fungicide can control early infection (Katsube and Koshimizer 1971). Early foliar application of benomyl reduces Bl incidence (Sinclair 1981). The effectiveness of pentachlorobenzyl alcohol against *P. oryzae* is increased by a reduction in particle size, with <5 µm being required for good performance (Nakamura et al 1981). The importance of the frequency of fungicide application was emphasized by Rao and

Muralidharan (1986), who estimated that 4 treatments with benomyl followed by carbendazim at 7-d intervals can effectively check B1 when the disease is not severe. More sprays at higher concentration might be necessary under conditions extremely favorable for B1. All formulations of carbendazim effectively reduce foliar or neck B1 with significant yield increase, and a soil drench of carbendazim is advocated for rice B1 control wherever possible or economically feasible (Tewari and Row 1986).

Sheath blight caused by *Rhizoctonia solani* Kühn (perfect stage *Corticium solani* or *Thanatephorus cucumeris* [Frank] Donk) is the most damaging disease of rice in Arkansas, USA, and burning rice straw has only a limited effect on the number and viability of overwintering sclerotia (Lee and Courtney 1982). As a control measure, burning is most effective as part of an integrated program involving foliar application of suitable fungicides on tolerant cultivars. The disease develops more extensively on the semidwarfs because of the shorter distance between the waterline and the panicles (Marchetti 1983). Fungicide treatments against *C. soloni* reduced infection on plants and tillers but did not give a significant difference in the field between treatment and control (Kueh and Teo 1982), while foliar sprays of organic As and Sn have been used for several years in Japan to inhibit lesion enlargement and mycelial growth (Lee and Rush 1983); the addition of Fe to the preparation is necessary to reduce the phytotoxic effects of As. The effects of fungicides in soil against *R. solani* have often been noted, and Lakshmanan and Nair (1986) estimated that 50 µg carbendazim/g soil reduces the viability of sclerotia. The pathogen survived only up to 60 d in soil treated with benomyl and up to 90 d in soil treated with chloroneb or carboxin, compared with up to 450 d in untreated soil (Kannaiyan and Prasad 1986).

Rhynchosporium oryzae Hashioka and Yokogi has proved harmful in Liberia, where Thomas et al (1985) reduced field infection with 3-5 applications of benomyl at 0.5 kg ai/ha. This pathogen may be eliminated more easily with benomyl by both foliar and seed treatments (soaking in 2,500 ppm ai benomyl solution in water for 30 min with no harmful effect on seed viability).

Fertilizer application may also have an effect on diseases. Cha et al (1982) reported a higher incidence of Xco in fields with high rates of N application — the disease severity depending on the degree of maturity of the cultivar. Umehara (1982) studied the effect of fertilizer on discoloration and rusty color of rice kernels caused by fungi, and Nakagawa and Umehara (1982) demonstrated that seedling blight caused by *Trichoderma* sp. and *Fusarium* sp. developing in nursery boxes can be controlled by soil incorporation of organic matter.

POSTHARVEST TREATMENTS

Seed can be treated before sowing or during storage to improve germination and seedling stand or to prevent damping-off or dissemination of seedborne or soilborne pathogens at an early stage.

Improving the intrinsic quality of seed

Hot-water treatment of seed at 50 °C affects germination and initial seedling growth

depending on the cultivar (Sasaki 1981). Kundu and Biswas (1985) improved the productivity of IR50 and CR237-1 by soaking 5-mo-old seed for 2-5 h in salt solutions. NaCl gave the best grain yield (3.1 t/ha compared with 2.5 t/ha for the control). The number of panicles per square meter was increased by the treatment. Simple hydration of seed increased yield by about 10% over the untreated control. Water stress is important for germination, water uptake, and early seedling growth (Singh and Singh 1983).

Salt solutions may have fungicidal effects. Seed treatment with KCl and $(NH_4)_2HPO_4$ resulted in considerable reduction in seedling infection by brown spot (*Helminthosporium oryzae* Breeda de Haan) and B1 (Kannaiyan and Radhakrishman 1982). Rice seed soaked in a 10 or 20% solution of $(NH_4)_2SO_4$, NH_4NO_3, KH_2PO_4, or KNO_3 provided significantly higher grain yield than untreated seed (Barthakur et a1 1973). Methods commonly used by Japanese farmers include physical and chemical treatments for the selection of better seed and for seedborne disease control (Fujii 1983).

Hot-water or dry-heat treatments and saltwater selection by the brine density gradient method are used to control nematodes and bacteria in seed for sowing in nursery boxes in Japan. The increasing use of transplanting machines in the last 15 yr has produced favorable conditions for the transfer of seedborne pathogens and has caused more concern for better seed treatments and systematic nursery soil disinfection. Soaking rice seed in 1% NaOCl solution before sowing is beneficial (Webster et a1 1973). The major benefits of chemical treatment of wet-seeded rice are the cost savings resulting from reduced sowing rates — which far exceed the cost of treatment — more uniform stands, higher yields, and elimination of replanting. Moreover, Inouye and Ito (1973) demonstrated the stimulation of mesocotyl elongation by high-temperature pretreatment of seed at 40 °C for 10 d.

Zinc-treated seed produced taller plants than untreated seed; treatment with water or Zn increased grain yield from 2.4 to 2.9 t/ha (Barbosa Filho et a1 1983). In laboratory and field experiments, treating rice seed with an electromagnetic field followed by softening before sowing raised yield 5-14% (Irkha and Kochetov 1980).

Seed treatment can be used to overcome deficiencies that contribute to disease development on weakened plants. Grain yield was increased with application to the seed of a 6% Zn-EDTA solution, indicating that improvement of the germination capacity and sowing quality of seed results in a better stand of plants in the field and gives them a better chance to escape infection by seedborne and soilborne organisms (Mengel et al 1979). Treating rice seed with 0.5% H_2O_2 increased germination percentage and yield, and improved the sowing quality of the resultant seed (Velichko and Shabel'nikow 1979). The optimum sowing rate of treated seed was 33% lower than that of untreated seed.

Growth regulators have been also tried as seed treatments. In pot trials, soaking seed in indoleacetic acid and gibberellin increased panicle number, leaf area, grain yield, and straw yield (Verma and Singh 1979). Rice sown at 6 cm depth when the soil moisture content was 15% (dry basis) failed to germinate; when seed was soaked in 100 ppm gibberellin solution for 24 h and sown at 6 cm depth in soil with 15% moisture content, plumules elongated to 7.8 mm at 14 d after sowing (Ueyama 1976).

When the soil moisture content reached 64%, no difference was observed between the treated seed and the control.

Breaking dormancy is important for germination and for good seedling growth. When rice seed with a moisture content of 25-28% was soaked in water at 25-40 °C for 14-48 h and stored at 3540 °C in water-saturated air, dormancy broke rapidly (Hayashi 1977). At higher temperature and moisture content, seed damage occurred. Agarwal et a1 (1977) described storage conditions that may reduce seed quality and noted the importance of prestorage seed treatment to the viability of rice seed, which must sometimes be stored for two successive seasons.

Controlling seedborne and soilborne pathogens

Many pathogen attacks during the vegetative phase through panicle maturity originate from seed infection and produce abnormal seed that lacks vigor. *P. oryzae* present in seed testa and embryos generally gives rise to abnormal seedlings that develop poorly or die (Zad and Zakeri 1981). Hiremath and Hedge (1981) collected seed from panicles infected by brown spot caused by *Drechslera oryzae* Subr. and Jain *(Cochliobolus miyabeanus)* and showed that infection produced rotten seed or seedlings that succumbed to preemergence damping-off. Hot-water treatment (52 °C for 10 min) produced healthy seedlings, but most seedlings from infected, partially developed seed died before reaching maturity. Imolehin (1983) stressed the importance of seedborne *D. oryzae* together with bakanae (Bak) caused by *Fusarium moniliforme* Sheld. *(G..fujikuroi*), which discolors seed, reduces germination, and produces poor-quality seed in Nigeria. The problem is heightened by *Aspergillus* sp. and *Rhizopus arrhizus,* surface contaminants that deteriorate stored seed, reduce germination, and are of economic importance. Benlate T (20% thiram + 20% benomyl) aqueous soak seed treatment at 1 µg/ml gave effective control against Bak (Yu and Yang 1978), while immersing seed in 0.1% methoxyethyl-mercury chloride for 48 h controlled infection (Kauraw 1981). *Curvularia lunata,* which causes glume and kernel discoloration, is also a serious pathogen when conditions are favorable. The most widely used chemicals for rice seed disinfection against Bl, Bak, and brown leaf spot are Benlate T and Homai (30% thiram + 50% thiophanate) (Nakamura 1986). Host sensitization to induce resistance against *D. oryzae* has been initiated with phytoalexin inducers (Sinha and Hait 1982). Seed treatment with sodium selenite and thioglycollic acid persisted up to 8 wk after sowing and was more effective than spray treatment.

Sheath blight, which generally develops during the vegetative phase, is frequently seedborne. Treating infected seed of ADT31 with fungicide increased germination, seedling growth, and vigor even if some chemicals (chloroneb and fentin acetate) slightly inhibited germination (Kannaiyan and Prasad 1982). Often, it is necessary to take general and preventive measures against soil parasites, as in pluvial rice production in the lvory Coast, where chemical seed treatments improved the first stages of vegetation by controlling fungi, insects, and nematodes (Sauphanor and Notteghem 1986); treated (carbosulfan + benomyl + captafol) seed sown at 30 kg/ha gave 400 kg/ha higher yield than untreated seed sown at 60 kg/ha. Slurry or spray treatments of captafol and captan, allowed to dry on the seed before

soaking, were more effective against seed rot and seedling diseases caused by *Achlya klebsiana* and *Pythium* sp. than applying after soaking or adding the chemical to the soak water (Webster et al 1973). Fentin chloride applied dry or as a slurry eradicated Xco from Taichung seed and increased germination percentage (Singh and Rao 1982). Nevertheless, no fully effective chemical has been found for spraying on infected plants or for treating seed. Because seed transmission is not as important as alternate hosts and water transmission, more attention should be paid to *Pseudomonas glumae*, the agent of bacterial grain rot, and *P. fuscovaginae*, which can both be controlled with Kasumin C (captan 30% + kasugamycin 3%) by seed disinfection or soil treatment in nursery boxes (Goto et al 1988).

Insect control by seed treatment has been the object of much research. Seed treatment with organophosphate or carbamate insecticides is effective against the rice water weevil *Lissorhoptrus oryzophilus* in countries where rice is direct-seeded (Nakamura 1986). Where rice is transplanted, seed treatment is not useful. Treating the seedling box with γ–HCH or cartap (100 g Padan/box) at transplanting controls larvae. Protection of seedlings against termites (*Cornitermis* sp.) is sometimes achieved by treating seed with a 50:50 aldrin-chlorfenvinphos mixture at 400 g/160 kg seed (de Souza and Ramiro 1972).

COMBINATION OF PREHARVEST AND POSTHARVEST TREATMENTS

The choice of a preharvest or postharvest treatment depends on the biology of the pathogen and the economics of the treatment. In many cases both treatments are worthwhile to ensure better yield. Ingale and Sonar (1982) obtained increased yield with soil-water saturation 15 d before sowing seed coated with hydrated $FeSO_4$ and Fe-EDTA. Phosphorus and Mn uptake into the grains was favored by presowing irrigation, and Fe uptake by seed coating.

Multiple treatment is also effective against the nematode *Aphelenchoides besseyi* Christie, the agent of white tip. The nematodes overwinter in seed but enter the glumes at heading, so control may be by seed and foliage treatments. Treatment with chemicals plus gamma irradiation at 1,000 rads was more effective in controlling *A. besseyi* than chemicals or irradiation alone (Aleksandrova 1981). Martins et al (1976) have been successful with furadan — and Ribeiro (1977) with carbofuran — in eradicating nematodes totally by seed dressing, while Nakamura (1986) used fenitrothion sprayed on diseased heads. For different pests and diseases (Bl, BB, Helminthosporium leaf spot), it seems necessary to use a combination of seed treatment and chemical or fertilizer application in the field or soil drench.

RESEARCH AND TRENDS

Treatments to control well-defined pathogens in specific environments must consider the vulnerability of the pathogens, the economics of the treatments, and general protective measures that ensure good growing conditions for the plants. Integrated pest control utilizes resistant cultivars, rotation schemes, and cultural manipulations. Limitation of the primary inoculum is of particular importance in the production of high-quality seed lots. This can be achieved by chemical spray on

the heads of plants for preventive control, and by seed dressing as a curative measure. Applying fertilizer to foliage or to soil is a complementary means to strengthen plants during growth. Diseased seedlings must also be rogued from nursery beds. Surveys on weeds that are hosts of rice pathogens are important in determining chemical weed control, as in *Leersia* sp. — the rhizomes of which generally host Xco — or *Zizania aquatica,* which is susceptible to rice diseases (Bowden and Eschen 1986). Traditional cultural practices like burning stubble or long rotation are no longer useful to achieve total eradication of pathogens plus high productivity. The objective now is to obtain lasting protection throughout the plant growth cycle and during seed storage by one timely, efficient, and economic action on either the seed, the soil, or the foliage. Research is thus necessary on systemic chemicals and those that can be used at low concentration like the essential oil of *Peperomia pellucida,* which showed in vitro fungicidal action against *D. oryzae* at 2,000 ppm (Singh et al 1983), and on bacterization of rice seed by strains of *Pseudomonas fluorescens* to control Xco (Sakthivel et al 1986).

Testing seed lots

To ensure that the necessary measures have been adequately performed, and to provide information to users, standardized methods should be used for evaluating seed lot quality, particularly health status. The information on seed health must be verifiable by the recipient. Seed health testing is usually done when seed lots are produced under certification schemes or when quarantine measures are applied in the importing country. Professional organizations (canning industries, market gardeners, etc.) are generally aware of the importance of seedborne pathogens and of the necessity to know when to dress seed with chemicals. Genebanks, especially, need to know the seed health status of the samples they receive and store, and they must inform users of seed health when samples are requested. The basic requirement to provide information on seed health is thus the use of standardized methods, which should be described when results are reported, so that laboratories can reproduce the results within a statistically tolerated range. Hewett (1981) emphasized, on the one hand, that dissemination of seedborne pathogens generally originates from the many exchanges of small seed lots throughout the world and, on the other, the importance of setting up seed health standards for disease control.

Exchanging information on seed lot quality

The International Seed Testing Association (ISTA) has promoted many seed health testing methods, some described in Chapter 7 of the Annexes of ISTA Rules and others in Part 2 of the Handbook (working sheets) (Anselme 1983). The Handbook also includes an annotated list of seedborne diseases with supplements (Richardson 1979) and an introduction to methods of seed health testing (de Tempe and Binnerts 1979). At the 20th ISTA Congress in Ottawa, Canada, in 1983, methods for detecting *Pyricularia oryzae, D. oryzae,* and *Trichoconis padwickii* were introduced into the Rules.

To ascertain that technical information has been obtained by standardized and reproducible methods, the ISTA created in 1933 the "International Orange Certificate" issued by accredited seed testing laboratories. An ISTA Certificate is

issued for one seed lot only, from which a small part has been sampled according to ISTA Rules.

Progress in seed production necessitates information about the health status of seed lots at different periods. Such information should be dispatched to users as a matter of course in national and international seed exchange.

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Facilities for seed health testing and research

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The basic requirements for seed health testing are outlined. Essential facilities for seed health units that test for quarantine (plant protection services) and sanitation (seed testing stations) and do seed pathology research (seed technology centers) are discussed. Significant quantitative and qualitative factors that influence required size, layout, and staffing are evaluated to underscore what should be known before planning or expanding a seed health unit. Attention is given to the relations among the different activities of a seed health unit to attain the most efficient layout and the balanced use of available technical provisions and equipment. Sketches and tables are presented to illustrate units fully or partly involved in detecting seedborne fungi, bacteria, viruses, and nematodes.

Seed health testing has become an essential branch of quality testing of seed for sowing. It deals with policies on seed improvement, seed exchange, and plant protection (Neergaard 1979).

L. C. Doyer's pioneering research in seed pathology in 1918 at the Government Seed Testing Station in Wageningen, the Netherlands, was many years before seed transmission of plant pathogens and parasites was considered a ubiquitous factor in disease development and control (Neergaard 1985). In the 1950s, the Plant Disease Committee of the International Seed Testing Association (ISTA) began to coordinate development and standardization of detection methods. International seed exchange increased considerably with extended trade activities, accompanied by increased risk of introducing pests and diseases into importing countries. To minimize such risks, the Food and Agriculture Organization (FAO) organized the International Plant Protection Convention in 1951 to institutionalize the International Phytosanitary Certificate (FAO Certificate).

Regardless of the intended or real value of the FAO Certificate (Anselme and Mathys 1977), it has become the most prevalent certification for international seed transport and is now used all over the world. It is not only required to accompany

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commercial seed lots but is also used for the transfer of very small consignments of seeds from genebanks to breeders. Its use has changed our options on seed health testing and, ultimately, has initiated and stimulated seed pathology research.

The introduction of biochemical and serological techniques has enabled the detection of seedborne bacteria and viruses in seed lots and the setting of quarantine regulations. Hence, seed pathology has received increased attention in the last decade. The comprehensive list of seedborne diseases compiled by Richardson (1979, 1981, 1983) on the initiative of the ISTA illustrates this clearly. It is anticipated that many seed health units (SHUs) will be established to cope with the increasing demand for basic information about seed health. Moreover, new developments in seed technology aimed at improving seed quality will not only intensify the testing in existing laboratories, but will also add new dimensions to the methods of testing. New techniques and procedures will be incorporated in testing programs, and special facilities will consequently be required. This paper outlines the basic requirements for a modern SHU capable of responding to such demands.

TESTING OBJECTIVES AND REQUIRED FACILITIES

Testing may satisfy quarantine regulations requiring the absence of a certain pathogen or parasite. Testing for sanitation is less stringent if the aim is to find ways to improve seed or grain stocks following certification schemes; testing will then estimate the degree of infection or contamination to advise on planting value, need for treatment, or fitness for consumption. In research programs, one might test seeds to estimate the occurrence, spread, or economic importance of a seedborne pathogen or parasite, or to measure varietal resistance; testing can also support fundamental studies on the etiology of a seedborne disease.

In all these situations, objectives affect sampling methods, handling of samples before testing, sample size, testing procedures, treatments, and interpretation of results. Objectives, test procedures, and sample sizes are given in Table 1 for seed health tests required of the SHU at the Government Seed Testing Station in Wageningen, the Netherlands (Langerak 1983).

Testing for quarantine

Excluding dangerous pathogens from small portions of particularly valuable seed requires a closed quarantine setup such as a greenhouse or growth chamber especially equipped for postentry growing-on tests. This facility should be connected to a laboratory specialized in isolating and identifying pathogens and parasites. Good sterilization and destruction equipment is required for the quarantine organisms.

Such a closed system is superfluous when testing to see if a seed lot or sample is “substantially” free from pathogens and parasites and if very low degrees of infection are tolerable. It is then necessary to allot space and equipment to the kind of tests to be carried out. For detecting traces of fungi, the washing, blotter, agar, embryo count, and growing-on tests can be applied. Serological and indicator tests are suitable for detecting bacteria and viruses, and a washing-sedimentation test is adequate for nematodes.

Table 1. Seed health testing methods applied in the Netherlands for detecting fungi (F), bacteria (B), viruses (V), nematodes (N), insects (I), and weed seeds (W).

Detection method	Group	Seeds tested (no./sample)	Certificate [a]		
			National	FAO	ISTA
Seedling symptom test	F	200 - 400	+		
Blotter test	F	200 - 400	+	+	
Freezing blotter test	F	200 - 2,000	+	+	+
Agar test	F	200 - 400	+	+	+
Growing-on test	F B V	500 - 2,000	+	+	
Indicator test	B V	500 - 5,000	+	+	
Washing test	F	500 - 10,000	+	+	
Washing sedimentation test	N	1,000 - 5,000		+	
Embryo count test	F	1,000 - 2,000	+	+	+
Serological test (IF)	B	2,000 - 5,000	+	+	
Serological test (ELISA)	V	2,000 - 5,000	+	+	
Dilution plating test	B	2,000 - 5,000	+	+	
Direct visual inspection	F N I W	2,000 - 30,000	+	+	+

[a] + = test required for that certificate.

Testing for sanitation

Testing may support seed stock improvement in a local certification scheme. The aim of seed health tests will then be an accurate, rapid recording of the presence of pathogens or parasites. Consequently, sufficient space and manpower are needed for preparing selective agar media and for blotter tests. The time required to complete all the tests can be short if the cropping cycle takes only a few months. Similar facilities are required for testing seed quality to assess planting value, need for seed treatment, or fitness for consumption.

Testing research

Research activities dealing with the development or standardization of detection methods will generally require a relatively small but well-equipped laboratory.

THE ROLE OF THE SEED HEALTH UNIT

The terms of reference of a SHU depend on its disposition, location, and function within a particular organization or institution. The facilities depend on those available or the institution's potential to establish such a unit. The same holds true for the availability of special provisions and equipment.

Seed testing stations

A SHU at a testing station follows the goals of the station, such as testing for purity, moisture content, germination, and vigor. The unit may contribute to a national seed certification scheme or to testing for the International Orange Certificate of the ISTA. Generally, the basic facilities required for detecting fungi, nematodes, and insects are available; those for detecting bacteria and viruses are often lacking. On the other hand, there are usually excellent facilities for sampling, subsampling,

purity analysis, seedling and growing-on tests, and sometimes training. Testing research sometimes occurs.

Seed technology centers
A seed technology center is often linked to a university or may operate within a research institute. The SHU is a specialized service department within such a center. Exceptions are SHUs in the United States and Western Europe, which also perform special routine quality tests for seed companies. Training and research can be part of the functions of such a SHU, making use of existing facilities.

Research units in the seed industry
The larger seed companies have their own research units to support their breeding programs, seed production, seed processing, and distribution, since seed health is critical. The facilities of such a SHU vary from very simple to very sophisticated.

Plant protection services
Within governmental plant protection services are found various types of SHUs. Testing to detect quarantine organisms such as diagnostic work on fungi, bacteria, viruses, nematodes, and insects requires good equipment and qualified staff. These SHUs must be equipped to do closed quarantine work.

Training centers
The Danish Government Institute of Seed Pathology for Developing Countries provides training in all aspects of seed health testing. Similar SHUs adapt their facilities to the objectives of their training programs.

FACTORS AFFECTING SIZE, LAYOUT, AND STAFFING

The quantitative factors that determine the size, layout, and staffing of a SHU relate to its expected activities, capacity, and functions (Table 2). Other factors of a qualitative nature are related to the purpose of testing and the methods used.

Quantitative factors
Number of samples. The number of samples influences the floor area required for reception, registration, subsampling, final storage of remnant seeds, testing, and staff. The size of the storage room and incubation area are directly proportional to the number of samples. Registration, subsampling activities, and staffing are not directly proportional, because a larger number of samples may be tested more efficiently.

Volume of samples. The volume of samples will particularly affect the floor area for prestorage and poststorage, and the size of the registration desk. Samples of large-seeded legumes, beets, cereals, etc. will require much more space than samples of small-seeded vegetables.

Number of tests per sample. This aspect is related to the qualitative factors discussed below. It will influence the layout, size, and staffing of the SHU.

Table 2. Yearly testing activities of the SHU of the Government Seed Testing Station, Wageningen, 1983-86.

Activities	Species (no.)		Tests (no.)	Seeds analyzed or tested (no)[a]
	Seeds	Pathogens		
Official testing of samples				
Subsampling for viruses	2	3	400	20 × 100
bacteria	2	2	400	5 × 1,000
Preparative work and analysis for				
fungi	40	60	4,000	2 × 100
bacteria	2	2	600	5 × 1,000
viruses	2	3	400	20 × 100
Research				
Surveys forfungi	10	20	1,000	2-3 × 100
bacteria	4	5	100	5 × 1,000
viruses	2	2	100	16 × 1,000
Testing methods development for				
fungi	5	6	500	Various
bacteria	4	5	> 1,000	Various
viruses	3	4	> 1,000	Various
Seed treatment	5	7	400	Various
Training and courses				
Demonstration material	15	20	300	Various

[a] 20 × 100 = 20 subsamples of 100 seeds each.

Number of seeds per test. This factor interacts with the nature of the test methods. Some tests on thousands of seeds per sample — e.g., embryo count tests, visual inspections for the presence of admixtures, and serological tests for bacteria and viruses — need less space than tests where mere hundreds of seeds have to be plated or sown and incubated to detect pathogenic fungi.

Sample differentiation. The more seed species submitted for testing, the more complicated the layout of the SHU will be, especially when several different tests are done.

Duration of tests. Short tests require less incubation capacity than long tests, but duration does not influence the layout and staffing of the SHU.

Period of testing. This factor can influence incubation capacity and staffing when all tests have to be finalized within a fixed period.

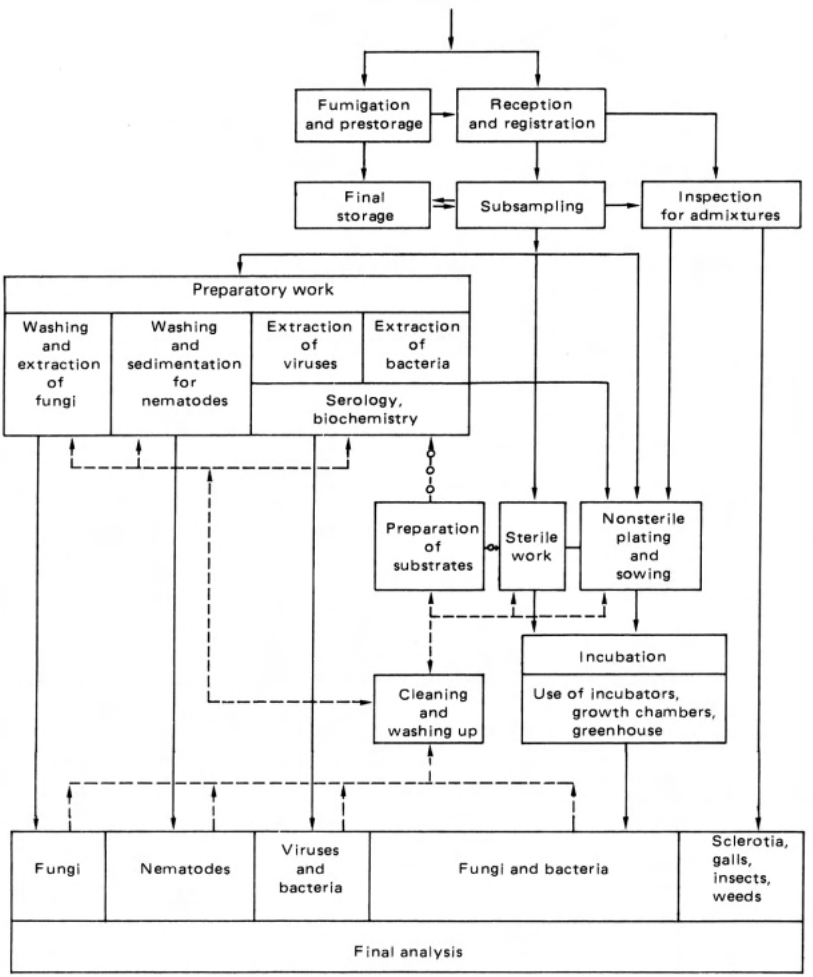
Qualitative factors

Nature of pathogens. The kind of pathogens tested for strongly influences the staffing, layout, and area. Testing for bacteria, fungi, and viruses requires sterile areas and special rooms for preparing media and substrates. Working with bacteria and viruses also requires more sophisticated equipment than that needed for mycological and nematological work. Tests for nematodes in seed, fungal spores on the seed surface, and mycelia inside the seed (embryo) require an area in the unit where washing with water does not disturb other tests.

Type of tests. A consequence of performing many different tests in one unit is that more equipment is needed, which in turn influences the size, layout, and staffing of the unit.

TESTING ACTIVITIES AND REQUIRED FACILITIES

The basic factors discussed earlier must be evaluated before any decision is made about establishing a new SHU or enlarging an existing one. The next step is to estimate whether the nature and scope of testing activities will be subject to change. If so, it must be decided whether and to what extent to incorporate such options in the planning. For example, a SHU may be initiated to test at first for fungi only but



1. Scheme of activities in a multifunctional seed health testing unit.

with the idea that testing for bacteria or viruses may be added. It is a matter of efficiency to situate facilities for sterile work, substrate preparation, and incubation in the proper spot from the beginning. Special attention should be paid, for this reason, to the functional relations among various activities and required facilities (Fig. 1).

In seed health testing, four main groups of activities can be recognized: 1) sampling, reception, registration, and storage of samples submitted; 2) preparation of working samples; 3) various kinds of preparatory work to put the working samples into final shape for testing; and 4) analysis. The first two stages may be left out of a SHU when it forms part of a seed testing station in which such activities are centralized in support of all other testing departments. Nevertheless, attention should be paid to these activities, because they are obviously an essential part of the whole testing procedure.

Sampling, reception, registration, and storage

Seed submitted for a seed health test has generally not been treated with chemicals. Samples may require fumigation prior to any further handling inside the SHU. Basic fumigation equipment, its use, and some guidelines were reviewed by Oudejans (1982). After leaving the prestorage facility, samples arrive at the area intended for unpacking, labeling, and registration. The number of consignments submitted per day determines whether a special reception room is needed. A simple desk might be sufficient. The room or desk should be close to the area where subsampling is planned and to the place where remnant seed material is stored. The storage facility may require special attention when loss of seed viability is expected because of high temperature or humidity. Air conditioning may overcome such problems. Precautions should be taken where animal or insect damage may occur.

Preparation of working samples

Subsampling usually takes place after registration to prepare smaller working samples for the tests. A description of recommended and prescribed procedures for any type of seed and the equipment needed for this work can be found in the Rules of the ISTA (1985).

A stable bench or table is required to hold balances and dividing apparatus in a vibration-free and level position. Modern laboratories often have subunits with exhaust hoods or cupboards to protect the staff from the irritating and hazardous effects of either the seed itself (e.g., chili species) or chemicals present on the seed surface. Efficient cleaning of the equipment is easy when a connection for high pressure air is present.

Additional work on the working sample is sometimes necessary. A quick mechanical cleaning process or visual inspection may help remove unwanted seeds, seed parts, or other admixtures that might hamper the tests. This kind of activity can also be seen as a part of the health test when the impurities removed are pathogenic or parasitic (sclerotia, ergots, noxious weed seeds, nematode galls, insects, etc.). Because of its similarity to purity testing, this activity of the SHU of the Government Seed Testing Station in Wageningen is left to its Purity Department, because it is

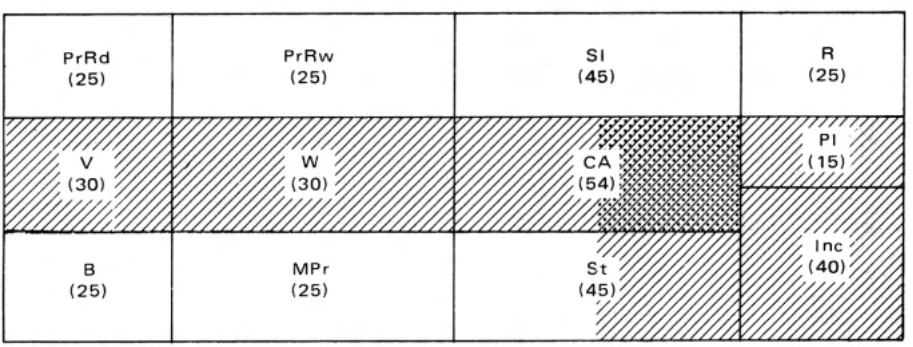
equipped with specially designed analysis tables, described by Van der Burg et al (1983). Suspicious impurities are identified by the SHU itself.

Preparatory work for final analysis

Tables 1 and 2 demonstrate the possible operations in a multifunctional SHU involved in testing for fungi, bacteria, viruses, and nematodes. A number of these activities require the same kind of facility. In planning a SHU with a fixed floor area, operations should be arranged in the most efficient way to avoid unnecessary movement of material and reduce the risk of cross-contamination with pathogens and saprophytes. Such an approach also ensures optimal use of the equipment. Naturally, the same holds true for a unit that employs more than one laboratory room and may undergo expansion. Some of the most important factors influencing such layouts follow.

Preliminary treatment of seed. Seed samples can be prepared for final analysis in various ways. Whether specialized rooms are needed or the work can be done at one particular location in the main laboratory depends on the number of samples. It is essential to concentrate all activities of a similar nature in one spot. Thus, activities that require water in large volumes belong in one place (PrRw in Fig. 2); those that produce dust (PrRd) belong in another. It is also preferable to keep the distance between preparatory work and final analysis activities as limited as possible.

Washing up. Cleaning of trays, dishes, glassware, etc. should be done in a central place close to the areas where the items are used. It is best to clean and wash away from the spot where sterile media or substrates are prepared to avoid contamination. In situations where it is desirable to destroy material infested with quarantine organisms, an autoclave or destruction oven is needed in the cleaning area.



2. Schematic floor plan of a seed health testing unit including central inspection room and mycology laboratory (CA); bacteriology laboratory (B); incubation area (Inc); room for weighing chemicals and preparation of media (MPr); area for plating on blotters or in sand or soil (PI); room for wet preparatory work (PrRw); room for dry preparatory work (PrRd); reception and registration (R); area for subsampling and seed inspection (SI); area for sterile work and incubation (St); virology laboratory (V); and area for washing up (W). Floor area is given in parentheses in m^2. (Expansion of work area in the Government Seed Testing Station, Wageningen, devoted to seed health testing: dotted area = original area in 1918, shaded area = after addition of bacteriology, virology, and other routine testing in 1975-85. Unshaded areas are rooms situated elsewhere at the station because of communal management with other departments.)

Preparation of media and substrates. Prerequisites include a chemical storeroom and a place for weighing the chemicals adjacent to the area where media and substrates are prepared, sterilized, and stored. The place should be equipped with a fume hood for handling dangerous chemicals and a suitable bench or table for precise weighing. The media preparation room (or corner) needs a high-voltage power supply for heating and sterilization apparatus. The room should be ventilated, preferably air-conditioned, when heating apparatus is used frequently, to overcome problems with thermoresistant bacteria. The best place for such a room is close to the place where the media are used.

Sowing and plating of seeds. Seeds should be sown or plated on blotters and in sand or soil close to the incubator to reduce contamination during movement. When many samples must be plated at once, it is advisable to equip this area with a vacuum seed counting device, provided that the seed species lend themselves to such handling.

Sterile work. Sterile work — e.g., plating of seeds on agar, pouring agar plates and tubes, transferring bacteria and fungi — can be done in a laminar flow cabinet or a specially equipped room with ultraviolet lamps and low air turbulence. Nevertheless, a high-voltage air-cleaning system, sometimes in combination with temperature conditioning, is best. When temperature is controlled simultaneously, the room may have a second use, such as for incubation, provided that shelves or cupboards are present. This may save space elsewhere. The sterile setup should be close to the places where sterile media are prepared, incubation is planned, and final assessments will be made of the incubated material.

Incubation. Cooling will be required for several reasons. Refrigerators, freezers, and cool rooms should be located near where they are needed, eventually under air conditioning to save energy and prolong the life of the equipment. Larger units for temperature and light-controlled incubation can be separate incubators or chambers with specific heating or cooling and illumination.

The best location is close to where the first steps in the test procedure are carried out, keeping in mind that the distance to the benches on which final visual or microscopic inspection takes place should also be short.

Analysis

The last stage of seed health testing requires various facilities, depending on the nature of the pathogens and parasites tested for.

Testing for fungi can mean examining dry seed for admixtures like sclerotia, ergots, and discolorations, with microscopical inspection of isolated embryos or spore washings obtained after soaking the seed. Similar inspections can be made on sediments obtained from tests for nematodes. The requirement is a lighted place, preferably under a window, through which no direct sunlight shines on the bench. The final step for fungal inspection is microscopic examination of incubated seed on blotters or agar. The previously described facilities can be used, but the place for inspection under a low-power microscope with sufficient artificial illumination is less critical. The place for inspection should be close to where the material comes from and where final washing up is planned.

Inspection for symptoms in seedling blotter tests, growing-on tests, and indicator tests requires very good illumination. A dazzle light mounted on a bench or laboratory table radiating diffuse light from underneath through frosted glass is ideal for this and for other purposes such as visual inspection of microtiter plates used in enzyme-linked immunosorbent assay (ELISA) tests and the study of serological precipitation reactions. Generally, serological tests for detecting bacteria and viruses require a clean room, preferably dust-free and air-conditioned, and

Table 3. Equipment required for various test procedures.

Activity	Pathogens tested for				Equipment required[a]
	Fungi	Bacteria	Viruses	Nematodes	
Sampling	x	x	x	x	1, 2, 7
Reception, registration, storage	x	x	x	x	5, 6, 8
Subsampling	x	x	x	x	2, 3, 4, 7, 11
Preparative work prior to analysis					
grinding		x	x		8, 11, 13, 14, 16
soaking		x		x	13, 18, 19, 37
washing-sedimentation	x			x	9, 15, 18, 31
maceration	x	x	x		13, 14
embryo extraction	x				10, 16
weighing chemicals	x	x	x		7, 8
preparation media	x	x	x		7, 18, 19, 20, 21, 22, 37
sterilization	x	x	x	x	14, 20, 22, 23
cleaning, washing up	x	x	x	x	12, 21, 22
plating/sowing seed	x				8, 17, 21, 37, 39, 40, 41
plating extracts	x	x	x		21, 34, 40
preparing microscopic slides	x	x		x	14, 21, 34, 36
preparing ELISA plates, etc.	(x)	(x)	x		14, 33, 34, 31
incubation without light:					
< 0° C	x	x	x		27
0-10°C	x	x	x		25, 26
10-30°C	x	x	x		24, 25
incubation with light:					
10-35°C	x	x			24[b], 25
Analysis					
visual inspection of seeds, plates	x	x	x	x	8, 32
microscopical inspection for					
seeds	x				28, 29
extracts	x	x		x	19, 28, 29, 30, 31
reading biochernical tests	(x)	x	x		14, 18, 32, 35

[a]Numbers refer to the following items: 1. stick or sleeve trier (Nobbe trier); 2. conical divider (Boerner type), soil divider (Riffle type), centrifugal divider (Garnet type); 3. air-screen cleaner (Clipper), indented cylinder machine, specific gravity separator; 4. seed counters; 5. numbering machine; 6. administration card; 7. balances; 8. fume hood; 9. "Baermann" hopper; 10. "Fenwick" can; 11. sealing apparatus; 12. washing machine; 13. coffee mill; 14. stopwatch or clock; 15. centrifuge; 16. set of sieves; 17. vacuum counting device, 18. tube stirrer (vibrator); 19. shaking device; 20. water bath; 21. distillation apparatus; 22. gas ring, hotplate; 23. autoclave, high-pressure cooker, drying oven; 24. incubators; 25. incubation chamber; 26. refrigerator; 27. freezer; 28. steroscopic microscope with magnification of 60X; 29. high-power microscope with magnification of 1,000X; 30. fluorescence microscope with magnification of 1,000X; 31. haemocytometer; 32. ultraviolet lamp and safety goggles; 33. washing device for multititer plated; 34. multipipettes; 35. multiscanner for ELISA plates; 36. electric hair dryer; 37. filtration apparatus; 38. pH meter; 39. gas burners; 40. electrostatic air cleaner; 41. clean bench/laminar flow. [b]Lighted.

various equipment (Table 3). Immunofluorescence (IF) tests require a room that can be darkened. Dark conditions are also needed for reading agar plates on which fluorescing bacterial colonies must be traced under ultraviolet light.

FACILITIES FOR SEED HEALTH TESTING

It is not easy to outline the floor area required for a SHU, its furnishings, and technical provisions such as gas, water, electricity, and air conditioning. Nevertheless, we have tried to approximate these points; the SHUs of the Government Seed Testing Station in Wageningen and of the International Rice Research lnstitute (IRRI) served as examples (Fig. 2).

Floor area

Since seed health testing in Wageningen started in 1918, the SHU has moved several times inside the building, its size increasing gradually. Some of the most important changes can be explained by the schematic floor plan in Figure 2, representing the most ideal multifunctional unit in which all aspects previously discussed have been worked out.

The floor area used in 1918 was equal to half of unit CA (dotted area) in Figure 2. With increasing testing activities after 1950 to issue FAO Certificates, the floor area reached about the size of CA + P1 + Inc + 1/2 St. Gradual incorporation of bacteriological and virological research and routine testing after 1975 resulted in 1985 in a unit covering the shaded area, apart from a renovated greenhouse with automatic control of illumination and temperature in 4 compartments of 36 m^2 and 2 of 10 m^2. The latter two small compartments and one large adjacent compartment are aphid-tight and suitable for quarantine experiments. The SHU will acquire four fully air-conditioned and illuminated growth chambers. Storerooms and rooms R and SI are situated elsewhere at the station because of communal management with other departments. A new SHU, scheduled for the early 1990s, may lead to the overall plan presented in Figure 3. This plan has to some extent already been realized at IRRI.

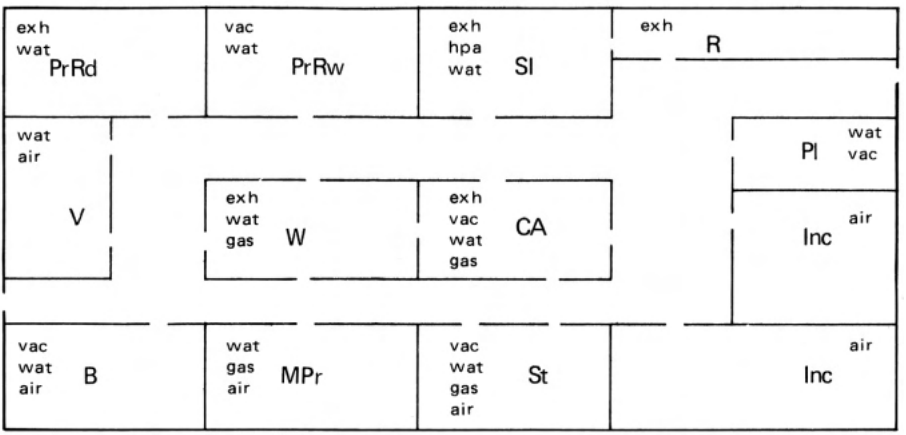
Furnishings and provisions

The furnishings of the SHU — *viz.,* floor, benches, shelves, and cupboards — must be easy to clean. Hard and smooth surfaces that are resistant to detergents and disinfectants are highly recommended. Blind corners should be avoided to exclude dust traps, which are sources of contamination of sterile media.

Required technical provisions such as gas, water and sinks, vacuum devices, high-pressure air, air conditioning, and exhaust units (fume hoods) are marked in Figure 3.

Apparatus, equipment, tools, and materials

A comprehensive list of apparatus and equipment used in a SHU is given in the footnote to Table 3. Smaller tools, materials, and chemicals used in seed health testing are described in Working Sheets of the ISTA by Neergaard (1979) and de



3. Schematic floor plan of a seed health testing unit including central inspection room and mycology laboratory (CA); bacteriology laboratory (B); incubation area (Inc); room for weighing chemicals and preparation of media (MPr); area for plating on blotters or in sand or soil (PI); room for wet preparatory work (PrRw); room for dry preparatory work (PrRd); reception and registration (R); area for subsampling and seed inspection (SI); area for sterile work and incubation (St); virology laboratory (V); and area for washing up (W). Required provisions: exhaust device (exh); vacuum service-pipe (vac); water (wat); gas; air-conditioning (air); and high-pressure air (hpa).

Tempe and Binnerts (1979); they can also be found in various handbooks and laboratory guides dealing with microbiology.

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The Philippine rice seed production system

J. M. SILVA IV, P. S. CASTILLO, and E. L. JAVIER

In the Philippines, rice seed production is a collaborative effort between the private sector and the government aimed at expanding high quality seed utilization and ensuring sufficient seed supply at reasonable cost. Its first phase is varietal improvement research — composed of cultivar development, testing, and basic seed (breeder and foundation) multiplication — by the Ministry of Agriculture and Food, other national institutions, and the International Rice Research Institute. The other phases of the system are certified seed multiplication, processing, storage, and marketing, all of which require the strong participation of the private sector. Recommendations on strengthening the national rice seed production system are presented.

An efficient seed production system requires a high level of technical expertise, sophisticated processing equipment, and a well-organized distribution network. As a result, economies of scale and relatively high break-even costs of multiplication and processing are required to produce high-quality seed. These constraints have led to a seed production system dominated by government in developing countries to ensure low-cost seed for small farmers. In the Philippines, however, the rice seed production system is a collaborative effort between the private sector and government. This joint venture aims to expand high-quality seed utilization and ascertain the adequacy of seed supply at reasonable cost.

The objectives of this paper are 1) to review the rice seed production system in the country, focusing on varietal improvement, seed multiplication, processing, storage, and marketing; and 2) to provide recommendations on strengthening the joint effort between the private sector and government.

VARIETAL IMPROVEMENT

Varietal improvement research is the first phase of the seed industry. It involves cultivar development, evaluation, and basic seed (breeder and foundation) multi-

Laguna Seed Growers' Association, Manila, Philippines; Institute of Plant Breeding, University of the Philippines at Los Baños (UPLB), Laguna, Philippines; Department of Agronomy, UPLB.

plication. Rice cultivar development in the Philippines is pursued by the Maligaya Rice Research and Training Center of the Ministry of Agriculture and Food (MAF), the University of the Philippines at Los Baños (UPLB), and the International Rice Research Institute.

Promising lines generated by breeding centers are entered in the National Cooperative Testing Program, an interagency, multidisciplinary, and multilocation endeavor. Its objective is to test, evaluate, and recommend to the Philippine Seed Board (PSB) rice selections that could be released as commercial varieties. There are two levels of tests in the program: advanced trials and on-farm adaptation trials. An advanced trial is composed of tests for yield, insect resistance, disease resistance, and grain quality. Many entries grouped according to culture and days to maturity are tested at the experimental stations of the agencies involved. An on-farm adaptation trial is composed of the most promising lines from an advanced trial and is conducted in provinces other than those where advanced trials are established unless the province is a "hot spot" for a certain problem (e.g., a pest). It is conducted in large plots in farmers'fields and has a loca1 check together with a recommended variety. The testing approach intensifies the communication feedback system among researchers, extension workers, and farmers.

A rice selection may be recommended to the PSB as a commercial variety for all regions of the country (national recommendation) or for specific regions/sites (regional/ site-specific recommendation). Prior to variety recommendation, the breeding institution sponsoring the selection is required to turn in breeder seed to the Bureau of Plant Industry (BPI) of the MAF for foundation seed production.

SEED MULTIPLICATION

The production of certified seed is in private hands. Provincial seed growers' associations are federated into regional associations. The federations assist the government in monitoring seed supply and demand, and undertake both national and international seed shipment.

Private persons or entities desiring to become seed producers are screened and monitored by the BPI and are then referred to the provincial seed producers' associations where their seed farms are located. The supervisory function of the BPI provides a control mechanism that ensures a balance between supply and demand for certified seed. More importantly, it provides a properly functioning quality control system to ascertain that registered seed producers sell only seed that has undergone rigid quality control tests conducted by the BPI's Seed Quality Control Services.

Seed producer-participants in the national seed program receive their allocation of foundation or registered seed from the BPI based on target areas prepared by program planners. Certified seed production plots are subjected to International Seed Testing Association field inspection procedures and requirements. Any seed production plot that does not pass the field inspection standards is rejected by the BPI seed inspector. Grain harvested from rejected seed production plots is sold only as commercial grain.

PROCESSING AND STORAGE

Harvested seed that has been field inspected and duly approved for sampling by the BPI seed inspector is processed either in the seed producer's own facilities or in government seed processing centers. Processing involves cleaning and drying. Samples of these seed lots are then taken by the BPI seed inspector to the BPI Seed Quality Control Services for quality analysis (purity, germination, etc.). Upon approval, identifying tags are issued. The seed inspector supervises the tagging and sealing of bags in the seed producer's warehouse.

MARKETING

The Philippines' marketing and distribution system encourages market development by seed producers themselves, either individually or collectively through their associations. Private sector efforts in seed disposal are supplemented by specific government programs, such as 1) the Rehabilitation Program for Calamity-stricken Farmers, wherein seed generated by bonafide producers is bought by the government and distributed to farmers at half the prevailing price; 2) the "no seed-no 1oan" scheme under the Intensified Rice Production Program, wherein participating farmer-borrowers are required to buy certified seed from bonafide seed producers within their localities; and 3) the Export Promotion Program for Certified Seeds, wherein the exportation of seed that is no longer needed for domestic requirements is facilitated and coordinated by the BPI.

Certified seed that is not marketed through government-sponsored programs is sold to individual farmers. One popular marketing system is the "one-stop shop," which links up seed producers'efforts with those of fertilizer and pesticide dealers. This concept allows farmers to buy all their input requirements from the same store. Another popular approach is to have oneself accredited as a certified seed supplier of a financing institution that services farmers. These marketing schemes do not entail additional subsidies from the government for warehouse losses, spoilage due to a loss in viability while the seed is in storage, delivery costs, salaries for supervision, or warehousing.

Certified seed is sold at acceptable prices, providing long-term viability for the seed producer. This system — coupled with regular tripartite dialogues involving seed producers. farmer end-users, and government — has resulted in a certified seed utilization level of 15% of the total national requirement. Sufficient buffer stocks for use during periods of calamity or for export have also been made available to end-users whenever necessary.

RECOMMENDATIONS

The Philippine approach to seed multiplication and marketing needs periodic assessments of strengths and weaknesses, and occasional modification to fine-tune the system to continuously changing market conditions. New goals must be set and the system strengthened to meet them.

The following recommendations are given to assess, modify, improve, and strengthen the existing seed production system in the Philippines.

Market study

Because certified seed marketing and distribution have reached only 15% of the total requirement, a thorough market study by an independent entity is recommended. Since provincial seed producers' associations and individual seed producers are presently not in a position to fund this undertaking, the industry may have to request the assistance of the government or other institutions.

Monitoring

Current monitoring by the BPI and other institutions is inadequate; reporting is often delayed. Strengthening the monitoring system would ensure that precise and reliable data are available at the time they are needed. As a first step, seed producers' associations should be required to submit existing inventory levels on a weekly basis, and these data should be promptly recorded in MAF regional offices.

Provincial seed producers' associations

The Philippines' seed multiplication system has been characterized by supply imbalances. Certain regions of the country have a constant oversupply of certified seed, while other regions do not have enough. The latter is common in the small island provinces, where transportation is cumbersome. Imbalances exist because there are not enough seed producers in some areas of the country. The MAF should promote the establishment of seed producers' associations in areas of need.

Processing and storage

Existing regional seed processing and storage facilities are effectively utilized only by nearby seed producers. Those located far from the plant site are economically and operationally disadvantaged. It is therefore proposed that small- and medium-scale processing facilities, generally mobile in nature, be developed and strategically located. These facilities can be attached to small storage facilities and deployed in target areas, subject to repayment or rental.

Training

Seed producers are supposed to possess a high degree of expertise in production, quality control, and marketing. However, many of them either have not been trained at all or have not undergone recent training. These producers may be unaware of new technologies. The government, in cooperation with international institutions and the academe, should design continuing training programs for the various participants in the seed program to update seed producers and government technicians on current developments in the seed industry.

Quality control

At present, the BPI performs quality control functions up to the time the certified seed is tagged and sealed. When seed is exported, quality control tests are repeated.

Certified seed for sale in the domestic market does not undergo these verification tests. To safeguard the interests of the buying public, periodic quality control tests should be performed while seed is in storage. Tags should contain expiry dates or "Use before . . ." provisions so that nonviable seed does not find its way into the market.

Packaging

At present, progressive seed producers package their certified seed in tamper-proof containers, which contribute to longer shelf life. However, some producers use second-hand bags. It is recommended that the BPI define minimum packaging standards and prescribe penalties for violation to protect bonafide seed producers from unscrupulous operators and dealers. Furthermore, research institutions should work to continuously improve packaging techniques.

Information campaign

Present pricing constraints do not allow seed producers to earmark funds for advertising and promotions highlighting the importance of certified seed utilization. Neither do the producers have the means to explain that the cost of seed in relation to the total production cost is minuscule, especially if the resultant benefits are considered. As a result, many farmers remain uneducated or misinformed, refusing to use certified seed. Furthermore, many farmers, especially marginal ones, are totally unaware of newly released superior varieties and where their seed may be bought.

It is therefore imperative that a comprehensive information package be designed to answer all possible queries regarding certified seed. In addition, a sustained information campaign covering all important aspects of certified seed should be undertaken by government extension personnel.

"No seed-no loan" program

The effects of an information campaign on the advantages of certified seed will not be immediately felt on overall productivity. As a complementary measure, the "no seed-no loan" component of government financing programs should be strengthened, and loopholes in the implementing guidelines corrected.

The standard feature of the "no seed-no loan" program allows farmers to experience for themselves the advantages of using certified seed. However, because of numerous exemptions in the existing guidelines, a substantial number of farmer-borrowers are unable to benefit from the use of certified seed. This in turn becomes the cause for higher input requirements when less disease-resistant varieties are used, or lower productivity when "saved" or "kept" seed that should already have been replaced is used. The end result is a poor loan repayment record.

Rice seed production in India

Y. Y. RAO

To improve the infrastructure facilities for seed production, processing, and storage in India, a comprehensive strategy called the National Seeds Program was launched in 1976 with the assistance of the World Bank. Breeder seed is produced primarily by institutions under the Indian Council of Agricultural Research and by agricultural universities. Breeder seed plots are inspected by a monitoring team. Foundation seed is produced by the agricultural universities, the National Seeds Corporation (NSC), the State Farms Corporation of India (SFCI), and the State Seed Corporations (SSCs). Certified seed is produced mainly by SSCs, NSC, and SFCI. The area under high-yielding varieties of rice increased from 0.89 million ha in 1966-67 to 22.78 million ha in 1984-85. The annual rice seed requirement for 10% replacement with certified seed and for buffer stocks is 0.14 million t. The anticipated production during 1986-87 is 0.13 million t. The total rice seed requirement can be met by governmental agencies and through the seed village system. Governmental agencies can supply 10% of the requirement every year; the remaining 90% can be produced by the cooperatives under the seed village system in a phased manner.

India has the largest area under rice in the world — 42.4 million ha — and is second in production, with 92.2 million t of paddy contributing 19.7% of the world's total. However, the average yield of 2.2 t/ha is one of the lowest among the major rice-growing countries of the world (Food and Agriculture Organization 1986). The target for rice production in India during 1986-87 is 64.5 million t, which is 29.8% of the total targeted food grain production of the country.

High-yielding varieties (HYVs) of rice were introduced in the country during the mid-1960s. The area under HYVs increased from 0.89 million ha in 1966-67 to 22.78 million ha in 1984-85. The target recommended for the coverage of HYVs by the Working Group of the Planning Commission for the terminal year of the Seventh Five-Year Plan is 29.26 million ha (71.1% of the rice area). Although the increase in area under rice between 1964-65 and 1983-84 was about 13.1%, the

Andhra Pradesh State Seeds Development Corporation Ltd., Hyderabad, Andhra Pradesh, India.

Table 1. Rice area, production, productivity, and area under high-yielding varieties (HWs), India, 1984-85. [a]

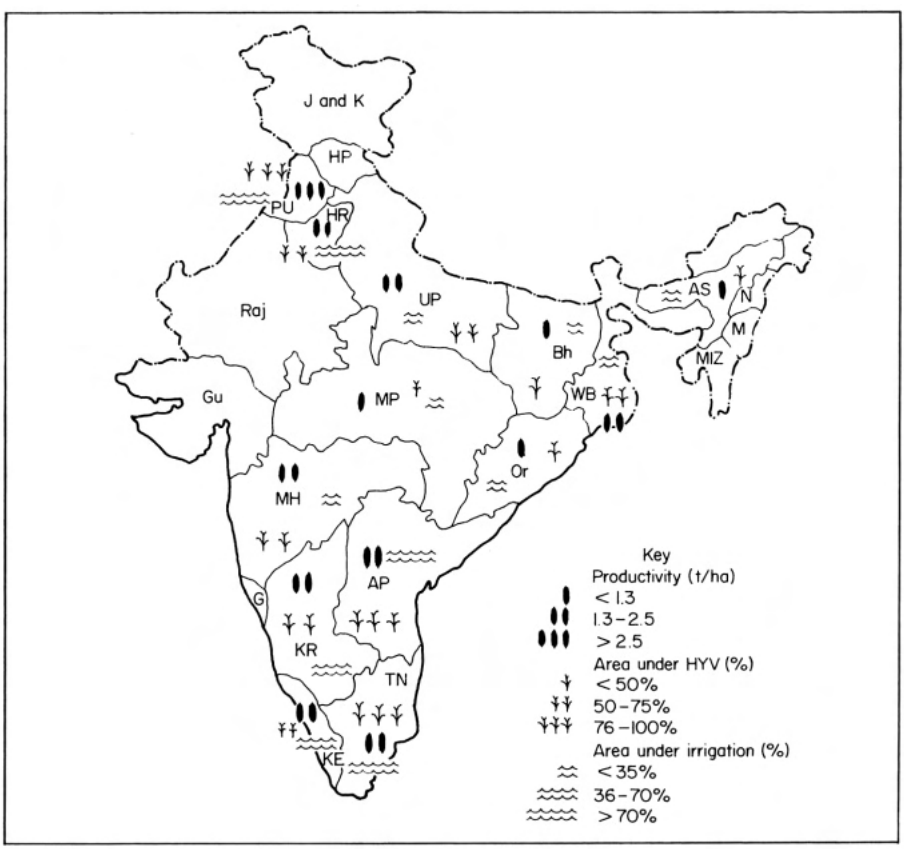
State	Area (million ha)	Production (million t)	Productivity (t/ha)	Area under HYVs (million ha)	Area under HYVs (%)	Area under irrigation, 1982-83 (%)
Low productivity states						
Assam	2.32	2.42	1.0	1.03	44.39	33.8
Bihar	5.17	5.32	1.0	2.30	44.48	33.7
Orissa	4.37	4.53	1.0	1.52	34.78	28.4
Madhya Pradesh	4.84	3.67	0.8	1.75	36.15	18.4
Uttar Pradesh	5.54	7.18	1.3	3.51	63.35	28.3
West Bengal	5.20	8.09	1.6	1.92	36.92	26.8
Kerala	0.74	1.23	1.7	0.25	33.78	35.8
Maharashtra	1.52	1.94	1.3	1.01	66.44	26.3
High productivity states						
Andhra Pradesh	3.53	6.98	2.0	3.04	86.11	94.2
Tamil Nadu	2.52	5.39	2.1	2.36	93.65	90.5
Punjab	1.65	5.06	3.1	1.58	95.75	98.5
Haryana	0.56	1.36	2.5	0.47	83.92	92.2
Karnataka	1.16	2.37	2.1	0.87	75.00	60.6
Others	2.04	3.10	1.4	1.13	55.39	-
All India	41.16	58.64	1.4	22.74	55.24	41.9

[a] Source: Directorate of Economics and Statistics, Government of India, New Delhi.

increase in rice production was as high as 52.9% (Directorate of Economics and Statistics 1986). This can be attributed largely to the high yield potential of HYVs coupled with the use of fertilizer and plant protection measures. Obviously, making quality seed of HYVs available has played a pivotal role in increasing production. Where productivity is low, coverage under HYVs is low (Table 1, Fig. 1).

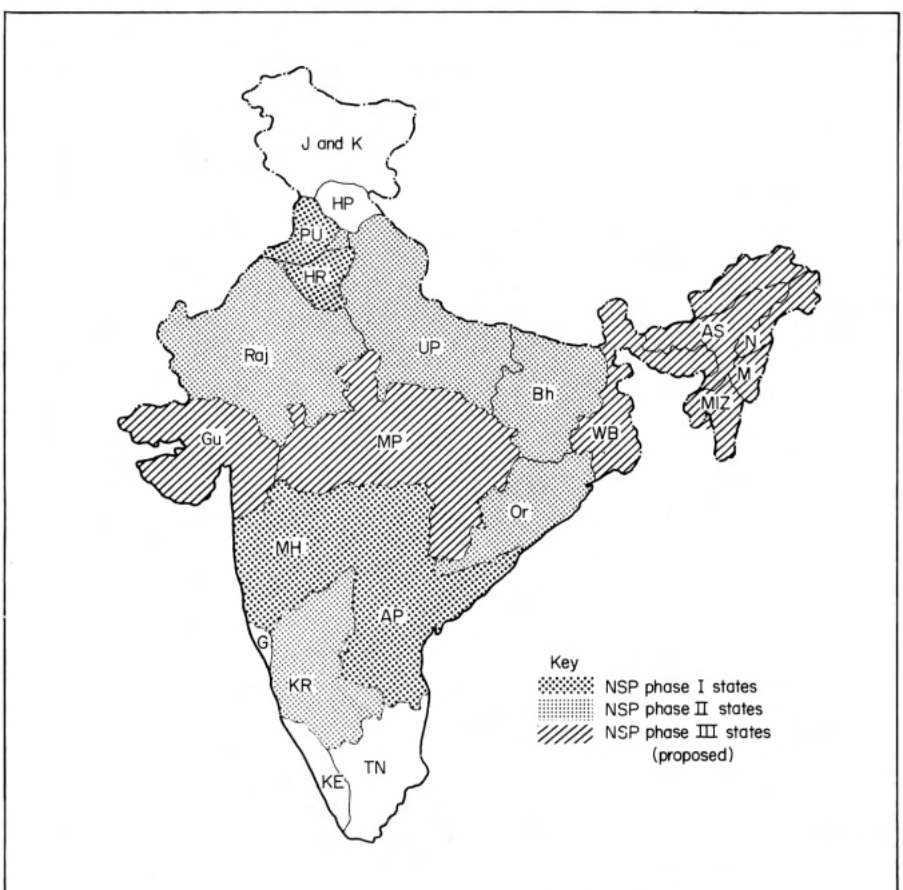
SEED PRODUCTION AND DISTRIBUTION PROGRAM

The reports of the Royal Commission on Agriculture of 1928, the Famine Inquiry Commission of 1945, and the Grow More Food Program Committee of 1952 emphasized the need for multiplying and distributing quality seed of improved varieties. Although seed farms were established by the state Departments of Agriculture during the 1950s in each Community Development Block (Department



1. Productivity, HYV coverage, and irrigation coverage, India. J and K = Jammu and Kashmir, HP = Himachal Pradesh, PU = Punjab, HR = Haryana, Raj = Rajasthan, UP = Uttar Pradesh, Gu = Gujarat, MP = Madhya Pradesh, Bh = Bihar, AS = Assam, N = Nagaland, M = Manipur, Miz = Mizoram, WB = West Bengal, Or = Orissa, MH = Maharashtra, G = Goa, AP = Andhra Pradesh, KR = Karnataka, KE = Kerala, TN = Tamil Nadu.

of Agriculture and Cooperation 1984), the production and distribution of quality seed of improved varieties were enhanced by the establishment of the National Seeds Corporation (NSC) in 1963. Rice seed is produced in three distinct classes, viz., breeder seed, foundation seed, and certified seed. The Tarai Development Corporation and the State Farms Corporation of India (SFCI), established in 1969, helped to increase the production of certified seed. The National Commission on Agriculture (NCA) in its recommendations of 1971 stressed the need for maintaining seed purity. A National Seeds Program (NSP) was formulated by the Joint Working Party set up by the Government of India in 1974 at the instance of the Seed Review Team and NCA. According to the program formulated, and for which World Rank assistance is being provided, coverage of the entire country with the production and distribution of quality seed was proposed in a phased manner. The coverage of the states under the NSP is depicted in Figure 2. The distribution of certified quality seed, after implementation of the NSP, increased to 0.56 million t during 1985-86 compared with a modest 0.02 million t in 1953-54. The targets provisionally fixed for



2. States of India under the National Seeds Program (NSP). Legend: see Figure 1.

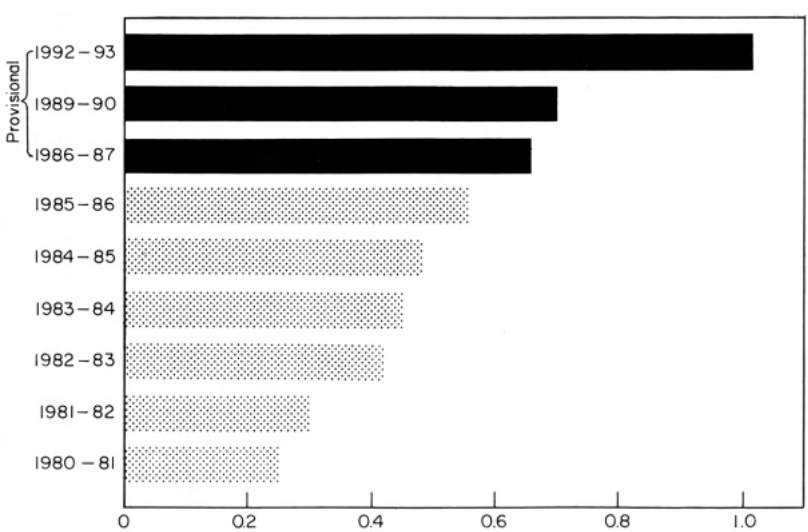
1986-87, 1989-90 (the terminal year of the Seventh Five-Year Plan), and 1992-93 (the terminal year of the proposed NSP phase III) are 0.66, 0.70, and 1.10 million t, respectively (Fig. 3).

Commensurate with the expansion of seed production, seed processing capacity was developed from 0.28 million tin 1976 to 0.5 million t at the end of NSP phase II. At the end of NSP phase III (1992-93), the processing capacity is likely to increase to 0.68 million t, capable of processing 63.6% of the total seed targeted for distribution. Similarly, the seed storage capacity was increased from 0.01 million t in 1976 to 0.13 million t in 1986. This is likely to be increased to 0.34 million t, enough to hold 31.5% of the total seed proposed for distribution by 1992-93. The seed processing and storage capacities in India are shown in Figure 4 (Department of Agriculture and Cooperation 1986). Although the NSP envisaged the interstate marketing and production of foundation seed by NSC and the production of certified seed and intrastate marketing by the State Seeds Corporations (SSCs), at present both are free to produce both foundation and certified seed and market it anywhere in the country.

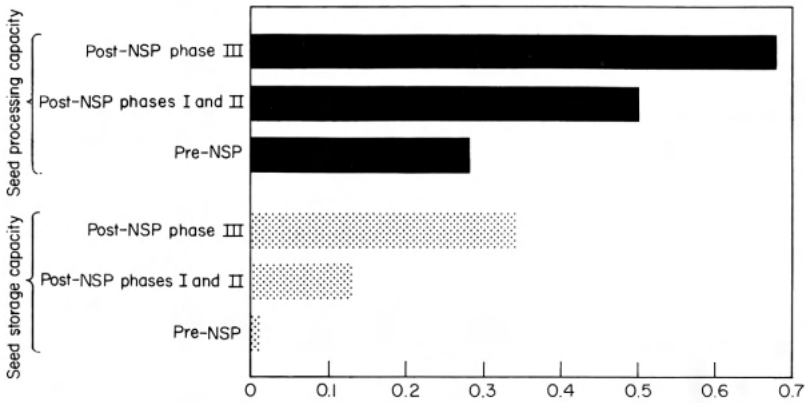
To ensure seed quality, the Seed Act was enacted in 1966, and the rules under the Act were framed in 1968. Subsequently, seed was declared an essential commodity, and the Seeds (Control) Order was issued in 1983.

RICE SEED REQUIREMENTS

The rice seed requirement of 30 kg/ ha for an average area of 41.0 million ha works out to about 1.23 million t. During the Seventh Five-Year Plan, it is intended to cover 10% of the rice area with certified seed every year to increase production. Thus, the annual seed requirement comes to 0.12 million t. Rice seed production increased from 0.05 million t in 1980-81 to 0.13 million t during 1986-87 (Table 2).



3. Distribution of certified quality seed (million tons) of different crops, India



4. Processing and storage capacities (million tons) for seed, India. NSP = National Seeds Program.

Table 2. Production and distribution of certified quality rice seed, India, 1979-80 to 1986-87.

Year	Production (million t)	Distribution (million t)
1979-80	–	0.04
1980-81	0.05	0.06
1981-82	0.07	0.06
1982-83	0.07	0.09
1983-84	0.09	0.09
1984-85	0.12	0.08
1985-86	0.10	0.10
1986-87 (anticipated)	0.13	0.15

Of 0.12 million t of rice seed produced in India during 1984-85, 65% was produced in Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, Orissa, Bihar, and Uttar Pradesh (Table 3). Of the 0.08 million t of rice seed distributed during 1984-85 in the country, Andhra Pradesh, Karnataka, Tamil Nadu, and Uttar Pradesh alone accounted for 54.5%, suggesting less use of certified quality seed in the northeastern and other states.

Breeder seed

Breeder seed is produced by the agricultural universities, institutions under the Indian Council of Agricultural Research (ICAR), and the Directorate of Rice Research. NSC and SFCI are also permitted to produce breeder seed. Breeder seed production plots are inspected by a monitoring team consisting of the producing breeder, another breeder (sponsoring breeder), a representative of NSC/SSC, and a nominee of the Seed Certification Agency. Golden yellow tags are fixed to breeder seed containers giving details of purity, etc. The Government of India obtains the orders for the seed of released varieties 18 mo ahead of supply. All agencies send their orders to the Seeds Division, Government of India, through the respective

Table 3. Production and distribution of certified quality rice seed by state, India, 1984-85.[a]

State	Production (t)	Distribution (t)
Andhra Pradesh	15,682	15,284
Assam	–	6,085
Bihar	7,290	5,595
Gujarat	2,200	1,345
Haryana	3,405	2,206
Karnataka	9,635	7,328
Kerala	3,000	3,000
Madhya Pradesh	2,055	2,529
Maharashtra	1,120	1,101
Orissa	5,617	3,472
Punjab	4,347	2,141
Tamil Nadu	20,932	14,143
Uttar Pradesh	15,900	9,383
West Bengal	3,700	8,247
Manipur	1,300	228
Others	24,154	2,577
All India	120,337	84,664

[a] Source: Seeds Division, Department of Agriculture and Cooperation, Government of India, New Delhi.

State Department of Agriculture. The orders are passed on to ICAR for production through the agricultural universities. After crop harvest, ICAR indicates the quantity of seed available to the Government of India, which in turn allots the seed to the ordering agencies. The breeder seed requirement of rice to cover 10% of the rice area is estimated to be 13.0 t.

Foundation seed

Foundation seed is produced from breeder seed by agricultural universities, NSC, SFCI, and SSCs either on their own farms or on private farms through contracts with SSCs. When there is a scarcity of breeder seed, stage I foundation seed is multiplied to produce stage II foundation seed and used for certified seed production. The foundation seed requirement of rice to cover 10% of the area (including the requirement for buffer stock of certified seed) is estimated to be 1,080 t.

Certified seed

Certified seed is multiplied from stage I or II foundation seed, mainly by SSCs. SSCs organize certified seed production on a contract basis in farmers' fields.

Prerelease varieties

The Government of India felt that, while distributing improved strains identified at the annual workshops of the coordinated projects on different crops for minikit demonstrations, it is also desirable to have these strains multiplied by governmental agencies like SFCI and SSCs to build up seed stocks before they are released. This helps to reduce the time gap between identification of a strain and its release.

Varieties that are not released are packed as "labeled seed" by the seed producers by affixing a "truthful label" giving the genetic and physical purity standards.

SEED PRODUCTION IN THE STATES

Rice seed production is organized in almost all the rice-growing states. In the northern and northeastern states, production is mostly during kharif. In the southern states of Andhra Pradesh, Tamil Nadu, and Karnataka and in West Bengal, production is in both kharif and rabi. In Andhra Pradesh and Tamil Nadu, where the climatic conditions are congenial and irrigation is available, production is also during summer.

In Andhra Pradesh, varieties like Phalguna, Surekha, Prakash, IR36, Rasi, Saket-4, Pusa 2-21, Jyoti, IR20, and Jaya are produced on a large scale for supply to West Bengal, Orissa, Maharashtra, Bihar, Assam, Kerala, and other states. The NSC also produces most of its rice seed requirements for other states in Andhra Pradesh. The details of varieties grown in the states are given in Table 4.

In areas where rabi seed requirements for short-duration varieties are met from the preceding kharif, cyclonic weather often affects the production and quality of seed. In addition, the interval between harvest of the kharif crop and sowing of the rabi crop is so short that seed from kharif cannot be dried and processed properly in the cloudy and humid weather. Seed with a high moisture content, at times unprocessed, is often used. In addition to the acute shortage of seed, it is sold at very high prices. To overcome this difficulty, seed of important rabi short- and medium-duration varieties such as Rasi, Tella Hamsa, IR20, IR36, and IR62 will be produced in the preceding rabi or summer seasons in dry areas of Andhra Pradesh and Tamil Nadu. The seed from these crops will be available at least 3-5 mo before sowing of the rabi crop begins.

Table 4. Important rice varieties grown in the states of India.[a]

State	N latitude	Rainfall (mm)	Varieties
Andhra Pradesh	12° 30' to 20° 0'	731 - 985	Phalguna, Swarna, Swarnadhan, Manasarovar, Vajram, Surekha, Jaya, Prabhat, Tellahamsa, Dhanyalakshmi, Rasi
Arunachal Pradesh	26°45' to 29°30'	3612	Jaya, Pusa 2-21, Rasi, Sattari, Ngoba, Khonorulu
Assam	24°15' to 21°45'	2265	Pusa 2-21, IET2508, Ratna, IR8, Jaya, Cauvery, Jayanthi, Sona
Bihar	22°00' to 27°30'	1229 - 1361	Manasarovar, Swarnadhan, Jayashri, Sugandha, Pankaj, Rajendradhan 201, Sujatha, Vishnu, Kiran, Rajendradhan 202

Continued on opposite page

Table 4 continued

State	N latitude	Rainfall (mm)	Varieties
Goa, Daman, Diu	14°45' to 15°45'	583- 2748	Vikram, Pankaj, Phalguna, Jaya, Triveni, Jyoti, Vaigai, Rohini
Gujarat	20°15' to 24°30'	583 - 819	Gaur 3, GR101, Jaya, IR20, Ratna, GR4, SLR51214
Haryana	27°40' to 30°45'	641	Jaya, PR106, PR4141, PR103, CSR5
Himachal Pradesh	30°30' to 33°15'	1808	Jaya, Himadhan, Himalaya 1, IR579
Jammu and Kashmir	32°30' to 37°15'	1076	K84, K78-13, PC19, Jaya
Karnataka	11°30' to 18°30'	790 - 3336	Phalguna, Pankaj, Intan Mutant, Jaya, Vani, IR20, Prakash, Mangala, Mandya vani, Vikram, Shakti
Kerala	8°30' to 12°45'	2824	Kayamkulam 1, Vytilla 2, Bhadra, Sabari, Annapurna, Triveni, Rohini, Jyoti, Bharati
Madhya Pradesh	17°45' to 26°45'	1056 - 1371	Tripti, Abha, Poorva, Kranti, Ratna, Sona, Pragathi, Jaya, IR36, Surekha
Maharashtra	15°40' to 22°15'	700 - 1139	Phalguna, IGP1-37, Karjat 14-7, Ratnagiri 24, Radhanagari 185-2, Tuljapur 1, Prabhavati, Panvel 1
Manipur	23°45' to 25°30'	2004	Ratna, Jaya, Rasi, Punshi, Phow-oubi
Meghalaya	25°00' to 26°15'	2265	Jaya, Pusa 33, Pusa 2-21, Ngoba, Khonorulu
Nagaland	25°15' to 27°0'	2004	Pusa 2-21, Khonorulu, Pusa 33, Jaya, IR20, IR25
Orissa	17°45' to 22°30'	1456	Savitri, Utkal Prabha, Pankaj, Kalinga-3, Parijat, Supriya, DR92, Ramakrishna, Pratap, Shakti, Kalinga 1, Kalinga 2
Pondicherry	11°45' to 12°15'	1017	Puduvaiponni, Punithavatti (PY2), Bharathidasan (PY3)
Punjab	29°30' to 32°30'	619	PR103, PR106, Jaya, Punjab Bas 1, PR4141
West Bengal	21°30' to 27°15'	1484 - 2981	Laxmi, Baku, Swarnadhan, Manasarovar, Sasyashree, Jaladhi, Munal
Rajasthan	23°0' to 30°0'	327 - 719	Chambal, BK190, BK79
Tamil Nadu	8°15' to 13°30'	1017	Karuna, Amaravathi, IR20, Rasi, Kanchi, Vaigai, IR10, Ponni, Bhavani, CO 36, Jaya, Mahsuri, Bhagavathi, Kannagi, ADT31, MDU1, Paramakudi-1, MDU2
Tripura	22°45' to 24°30'	2004	Bala, Cauvery, Pusa 2-21, Ratna, Jaya, Jayanthi
Uttar Pradesh	23°45' to 31°30'	931 - 2023	VL18, Majhera 3, VLK Dhan 206, Ratna, Jaya, IR24, Saket-4, Cauvery, Sudha, Sarjoo 50

[a]Source: Directorate of Rice Research, Rajendranagar, Hyderabad, India.

BUFFER STOCKS

Seed shortages in different crops occur now and then in the country. The fluctuation in seed supply affects the price and quality of seed. To meet the sudden demand for seed of various crops in times of drought and flood, the Government of India began the buffer stock scheme in 1978-79, under which the carry-over costs of the seed — such as interest on procurement value, storage charges, revalidation charges, storage losses, and obsolescence charges — are reimbursed. The total expenditure is shared equally by the national and state governments. This amount is released to SSCs through NSC.

The buffer stock requirements are worked out on the basis of 10% for rice, sorghum, bajra, and maize, and 5% for wheat, pulses, and jute over the previous year's seed distribution.

Thus, the total requirement of rice seed, including the buffer requirement, is 0.14 million t.

SUGGESTIONS TO MEET RICE SEED REQUIREMENTS

The total rice seed requirements of the country can be met by governmental agencies and the seed village system.

Governmental agencies

The annual seed requirements of 0.14 million t for 10% replacement with certified seed, including buffer stocks (0.012 million t), could be produced and distributed by governmental agencies such as NSC, SFCI. SSCs, and the state Departments of Agriculture. This demand for seed could easily be met by 1989-90, the terminal year of the Seventh Five-Year Plan.

Seed village system

The Government of India is laying emphasis on the seed village system, which can produce 90% of the total seed requirement — 1.11 million t. Under this system, the seed of recommended location-specific varieties can be multiplied in a compact area of two or three villages in each Community Development Block (Panchayat Samithi) or at the divisional level of the Block, the Revenue Mandal. In central places of these villages, a seed processing plant with a capacity of 1.0 t/h can be established. This will help to process 2,700 t of seed/yr, which can be produced in an area of 720 ha. Thus, 1.11 million t of seed can be produced in 411 clusters covering an area of 0.30 million ha. The foundation seed requirement of 8,880 t for producing certified seed in these clusters every year can be supplied by NSC, SFCI, and SSCs.

Seed production, processing, and storage under the seed village system can be entrusted to the multipurpose cooperative societies already existing. The societies can arrange for distribution of foundation seed and can provide the credit, fertilizer, and pesticides required for seed production plots. In Andhra Pradesh, some of the cooperative societies have begun seed production programs, including processing and storage facilities. Until these societies meet the full requirements of 1.11 million t of seed, the exchange of seed from farmer to farmer may continue.

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The rice seed production system in Colombia

D. MUÑOZ and M. J. ROSERO

The production of rice seed in Colombia started in 1965 and is now highly developed. The accelerated rate of the commercial seed industry is due mainly to the existence of a dynamic rice breeding program that integrates the efforts and resources of national and international programs; the periodic release of high-yielding varieties widely accepted by farmers; an integrated team approach that adjusts the technological package for each variety to be grown in a specific region; and the transfer of this technology to the farmers. Eighteen seed enterprises with 24 processing plants spread throughout the rice-growing areas produce and distribute certified seed. Seed marketing laws protect the consumer. Seed law enforcement technologists are independent of the seed enterprises. In 1985, the percentage of the rice area covered with certified seed was 77%. This paper summarizes the procedures and methodologies developed in Colombia.

In many countries a rapid increase in agricultural productivity is necessary to meet the ever-increasing demand for food. To get more from agriculture, it is necessary to put in more materials and services. Materials include fertilizers, pesticides, irrigation water, machinery, and energy. Services include transport systems, research to improve management practices, promotion, technical training, marketing organizations, and financial credit. The critical input upon which all others depend for full effectiveness is high-quality seed (Thomson 1979).

Rice is an important food in the diet of most Colombians, and it is the country's second most important crop after coffee. Rice production increased from 0.47 million t and a grain yield of 2.0 t/ha in 1961 to 1.9 million t and a grain yield of 4.7 t/ha in 1985. Irrigated areas produced 75% of the total, with an average yield of 5.6 t/ha (Federación Nacional de Arroceros 1985). This tremendous increase in production and productivity was due mainly to the development of high-yielding varieties and good management practices, which were widely adopted by farmers, and to the efficient seed production and distribution of private enterprises and the

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National Rice Growers Association (Federación Nacional de Arroceros [FEDEARROZ]).

In 1965, the Government of Colombia legislated the release of genetic material and basic seed to seed enterprises; seed certification is under the responsibility of the Instituto Colombiano Agropecuario (ICA) (Ministry of Agriculture 1980). This paper summarizes the actual rice seed production system in Colombia.

RICE BREEDING RESEARCH IN COLOMBIA

The five-step process for developing a new variety is simplified in Table 1. The Ministry of Agriculture has delegated to ICA the responsibility for conducting agricultural and cattle research. The ICA, in close collaboration with the Centro Internacional de Agricultura Tropical (CIAT), is developing a great amount of germplasm annually and also receives from CIAT introductions from other sources. ICA functions as a clearinghouse to disseminate information about regional problems toward which national research is oriented.

ICA and FEDEARROZ are in charge of conducting applied research and transferring new technology to farmers.

Information on the identity and genetic stability of varieties is used by breeders, ICA seed certification officers, seed enterprises, and seed law enforcement. One example of this information is included in the description of Oryzica-2 by the rice program of ICA (Table 2).

INITIAL SEED MULTIPLICATION

The plant breeders of the ICA rice program are wholly responsible for the maintenance and production of breeder and basic seed at the experiment stations. Breeder seed is produced every year in small plots. The transplant plant per row

Table 1. Simplified outline of rice breeding research in Colombia.

Generation	Management	Selection
	Step 1 – Obtaining lines (ICA-CIAT)	
Parent selection	Germplasm evaluation in different semesters and experiment stations, gene recombination in 50 annual crosses	Best agronomic entries that show resistance to or tolerance for prevalent diseases, insects, and hoja blanca; short vegetative period; intermediate tillering; good panicle type; high yield; quality grain; and adverse soils tolerance
F_1	Germination in petri dishes for 7 d, then transplanting at 5 plants/pot to maturity	Harvest of desirable plants in triple crossing and backcrossing
F_2	Plots of 100 rows, 12 m long, 5,000 transplanted plants, 20 × 60 cm, modified mass selection	5% of best agronomic plants, 2 panicles of each one, bulk all from same cross

Continued on opposite page

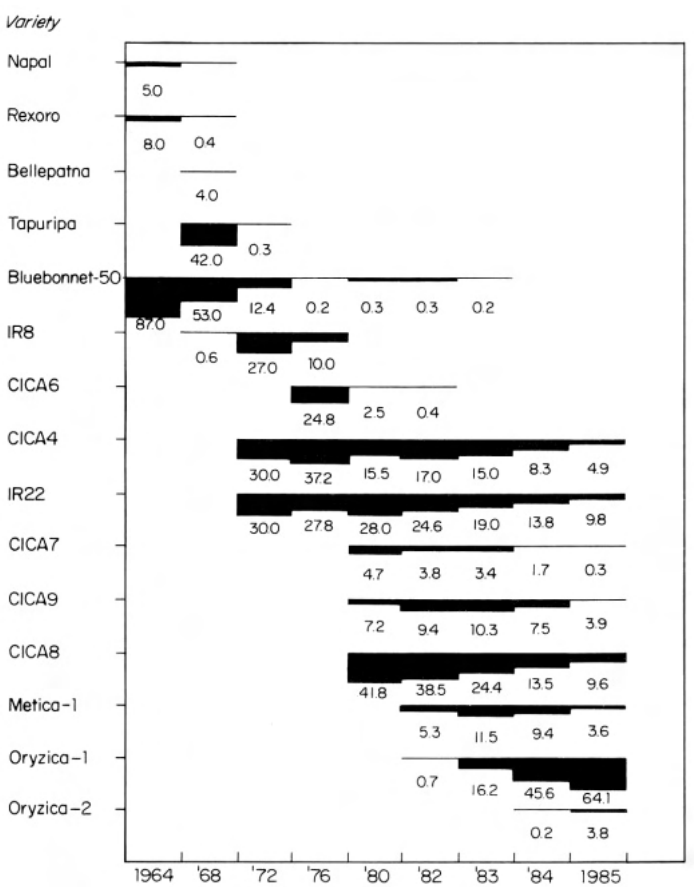
Table 1 continued

Generation	Management	Selection
F_3	Plots of 45 rows, 2.000 transplanted plants, same as F_2	Same as F_2 in each selected family
F_4	Same as F_3, pedigree system	Best 100 agronomic plants of each selected family: plants harvested individually: part of seed tor amylose analysis, white core, and kernel length
F_5	Direct seeded row per plant of 5 m long, best 10 families	Best agronomic rows, 4 plants of each one harvested individually, part of seed for quality as before, bulk rest of plants of row selected for use in observational plots
F_6 observational yield trial	F_5 plants as before, observation lines in plots of 6 rows, 5 m long × 30 cm	Best agronomic F_6 rows that correspond to best agronomic and high-yielding observation lines, bulk harvested for analysis for all quality factors
	Step 2 — Adaptation [ICA-FEDEARROZ)	
Replicated yield trials	Best F_6 lines, 25 lines each trial, 6 rows, plot 5 m long × 30 cm, 3 replications, direct seeded at different stations	Same as observational trial, 10 elite lines for regional trials
Regional trials	Broadcast seeded in farm plots 4 × 5 m, use farming methods recommended for the region, 3 replications, no pesticides	3 best yielding, agronomic, and quality lines; bulk harvest and panicle selection of each line for genetic seed production
	Step 3 — Technology package (ICA-FEDEARROZ)	
Semicommercial trials, interdisciplinary work	Farmer plots of 0.5-1 ha, management practices recommended for the region and replicated plots to obtain technology package	The best yielding, agronomic, and quality line
	Step 4 — Variety review	
Seminar	A group representing research, extension, Ministry of Agriculture, and seed industry reviews the performance record	Determining release of the variety and making recommendations
	Step 5 — Promotion (ICA-FEDEARROZ)	
Field days	Applied and adaptive research in farmers' field being used to get seed of improved variety used; research, promotion, communication, and seed enterprises; personal help; informing, persuading, and teaching farmer	In all generations, commercial varieties are used as checks

Table 2. Description of Oryzica-2 variety by ICA rice program.

Agronomic characteristic[a]	Minimum	Maximum	Mean	Standard deviation	Coefficient of variation
Flowering (d)	98.0	120.0	106.0	7.5	7.1
Height (cm)	38.0	135.0	93.0	13.5	14.6
Leaf length (cm)	27.0	75.0	43.0	7.4	17.2
Leaf width (cm)	0.4	1.8	1.3	0.1	10.7
Flag leaf length (cm)	9.7	56.5	30.0	7.8	26.1
Flag leaf width (cm)	1.0	2.7	1.5	0.2	12.1
Panicle length (cm)	20.0	53.0	27.5	2.8	10.2
Kernel length (cm)	7.0	11.0	9.0	0.7	7.4
Kernel width (cm)	2.0	3.0	2.6	0.5	18.6
Thousand-kernel weight (g)	21.4	25.5	24.2	0.7	3.1
Glume and leaf pubescence, awnless kernel					
Plant semicompact and erect					
Panicle compact and moderately emerged					

[a] 100 observations at each of the 6 experimental stations.



1. Percentage of distribution of cultivated varieties in Colombia, 1964-85.

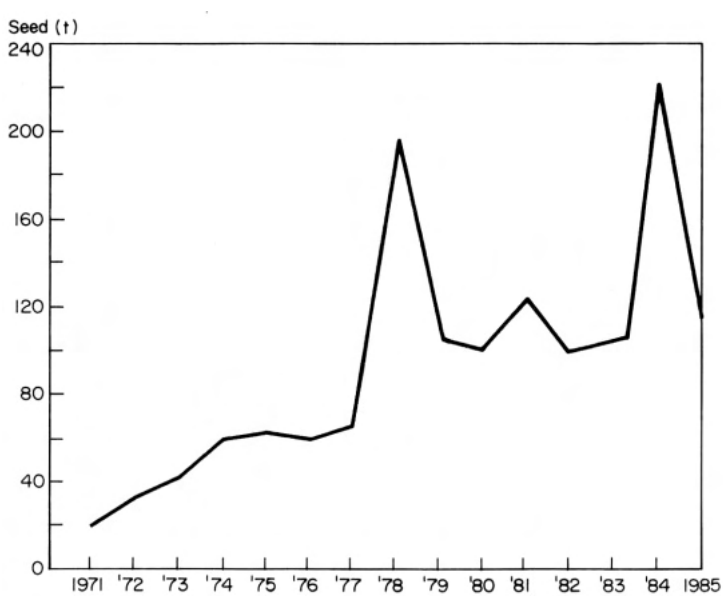
system is used, and seed from selections deemed true-to-type is bulked and used to produce basic seed. The breeder seed is transplanted in 2-4 ha each year. At all stages, off-type plants are eliminated to maintain the variety as tested. Seed lots are rejected if they do not meet quality standards. Seed pure enough to satisfy the seed certification requirements is officially called basic seed and handled through the seed certification system.

Farmers in Colombia are often more willing to change to seed of a new variety than to adopt other technological changes. Figure 1 shows the change of varieties through time. For this reason the basic seed supplies also change from year to year (Fig. 2). The seed of a new variety is multiplied quickly so it can be used soon after it has been developed.

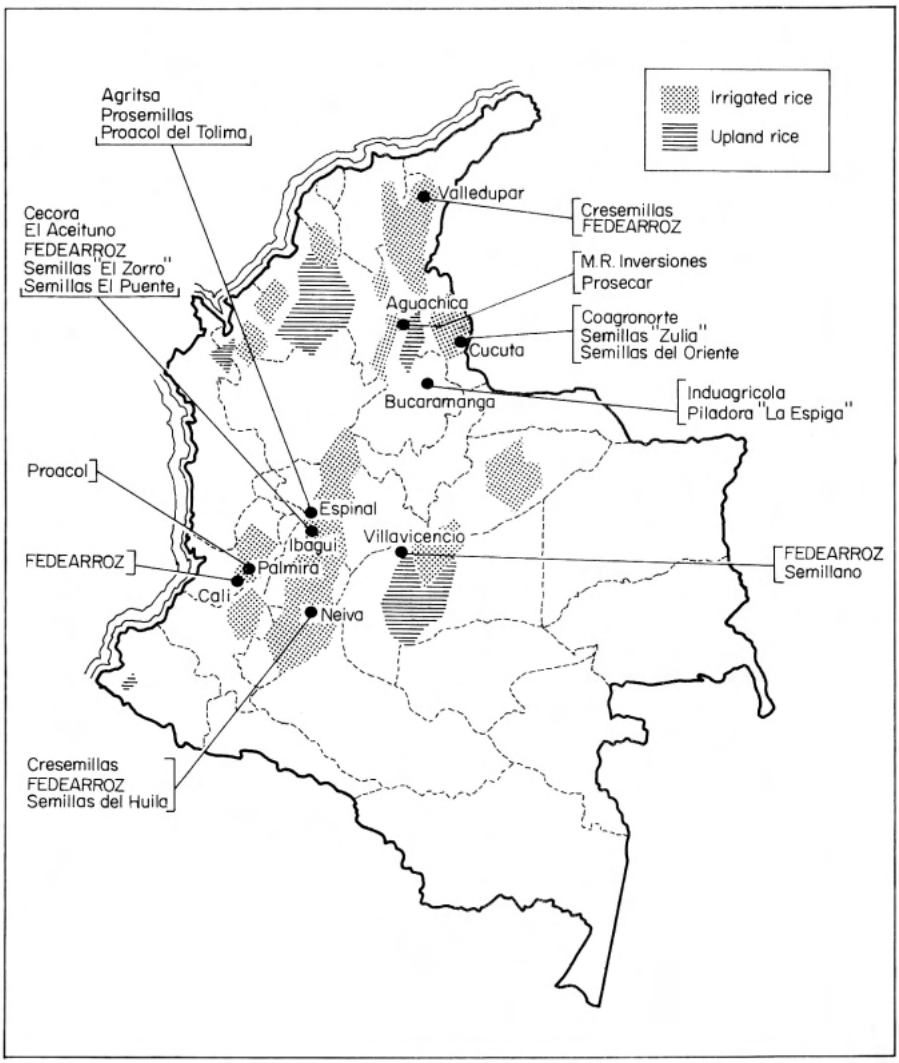
SEED SUPPLY

Eighteen seed enterprises with 24 processing plants produce and market certified rice seed in Colombia (Fig. 3). This includes family operations, partnerships, cooperatives, companies, and corporations. One of the most important seed enterprises is FEDEARROZ, which produces 60% of the certified rice seed. It has 5 processing plants located in the main rice areas and 21 sections to distribute the seed (Fig. 4). The local distributors function as information specialists for the varieties they stock. They are in close contact with their supplier, from whom they receive technical information, literature, and other materials.

The required basic processing needs in each seed enterprise are a receiving hopper, scalper, air-screen cleaner, length separator, gravity separator, seed treater, and bag-sewing machine.



2. Basic seed sold by ICA to seed enterprises in Colombia, 1971-85.

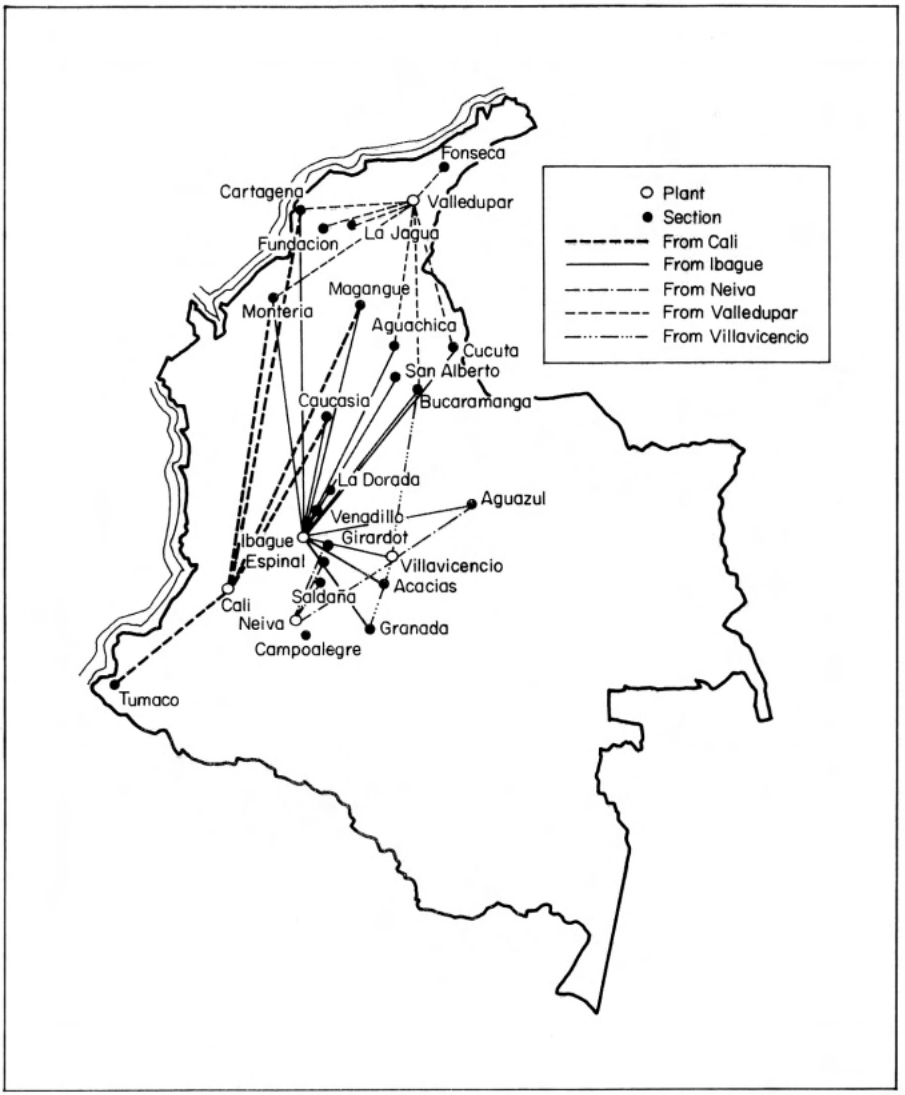


3. Rice seed enterprises and cultivated area in Colombia, 1986.

CERTIFICATION

The seed growers give to the ICA seed certification office a report form that includes information on seed class to multiply, lot area, location, planting date, seed source, and a record of two previous years grown in the lot.

Three field inspections are required to produce certified seed. The first inspection takes place when the seed certification technologists of ICA check the seed growers' field in the first 30 d of the vegetative period. The field should not have been planted to rice in the two previous years, unless it was planted to the same



4. FEDEARROZ seed distribution from production plants in Colombia, 1986.

variety, and both field and variety were approved. The inspector also verifies if the field was planted to certified or registered seed.

Distance to other ricefields is checked; these fields should be far from the certification plot — 20 m when seed is broadcast, 5 m when seed is transplanted or row planted, and 50 or 400 m when the adjacent ricefield is seeded by plane whose flying direction to the certification plot is parallel or perpendicular, respectively.

The second field inspection is made between 50 and 80 d after planting to assess prohibited weeds (*Cuscuta* sp., *Imperata cylindrica, Mucuna pruriens, Rottboellia*

cochinchinensis, Sorghum halepense, S. sudanense, Murdannia nudiflora, and *Stenotaphrum secundatum*), noxious weeds (red rice, *Ipomoea* sp., *Cyperus rotundus, Andropogon bicornis, Cynodon dactylon, Ischaemum rugosum, Macroptilium lathyroides, Echinochloa colona*), common weeds (*Digitaria* sp., *Amaranthus dubius, Ludwigia hyssopifolia, Cyperus esculentus, C. iria, Leptochloa filiformis, Eleusine indica),* off-type plants, other varieties, other crop plants, and diseases present in the field. Recommendations are given to the seed growers to obtain a field that is eligible to produce certified seed.

The third field inspection is made 100 d after planting to verify if the previous recommendations were followed and to make a decision about the field's eligibility for certification. The seed enterprise is responsible for meeting the minimum standards for a certain quality class in the field (Table 3).

Finally, seed produced on the farm requires a series of operations such as drying, cleaning, separation, and grading. The ICA seed certification officer verifies the origin and quantity of seed obtained from the approved seed fields by reviewing documents of the field and plant processing.

QUALITY CONTROL

The processed seed is officially sampled by seed certification technologists. The seed testing laboratory tests the samples before chemical treatment.

Table 3. Standards established in Colombia for certifying rice seed.

Factors	Class of seed		
	Basic	Registered	Certified
Cultivar purity		*Plants/ha*	
Other varieties	0	5	20
Other crops	0	1	2
With diseases transmitted by seed	0	0	0
Prohibited weeds	0	0	0
Noxious weeds	0	2	4
Common weeds		Do not compete significantly with the crop	
Analytical purity		*Percentage*	
Pure seed (min)	99.0	99.0	99.0
Inert matter (max)	1.0	1.0	1.0
Other crop seeds (max)	0.0	traces	traces
Species purity		*Seeds/kg*	
Other varieties (max)	0	4	10
Other species (max)	0	1	3
Prohibited weeds (max)	0	0	0
Noxious weeds (max)	0	1	2
Common weeds (max)	0	1	3
Other determinations		*Percentage*	
Moisture content (max)	14	14	14
Laboratory germination (min)	80	80	80

The materials produced should be grouped in clearly defined and uniform lots to facilitate sampling methodology for quality analysis. The lots have an identification number, and each one has a maximum weight of 20,000 kg; sampling is done in each lot of seed.

The International Seed Testing Association rules that specify recommended methods of sampling, seed lot size, and sampling intensity have been adopted for determinations of quality analysis of the material produced for certified seed. The final quality analysis of the representative sample of each lot should meet the minimum standards for a certain class of seed as established in Table 3.

Fungicides and insecticides are applied to certified seed, and the seed is packed into new bags. Certification labels are put on every bag. The certification label is the document that shows the standards, seed enterprise name, species, variety, class of seed, lot number, weight, active ingredient of the treatment, and the legend "Do not use for food or feed." There are three classes of certified seed labels: white for basic seed, pink for registered seed, and blue for certified seed.

The quality level of a certified seed is officially recognized and controlled. To deserve the farmer's confidence, the certification system is totally independent of seed production and marketing programs. Table 4 shows the percentage of area rejected in order to maintain quality.

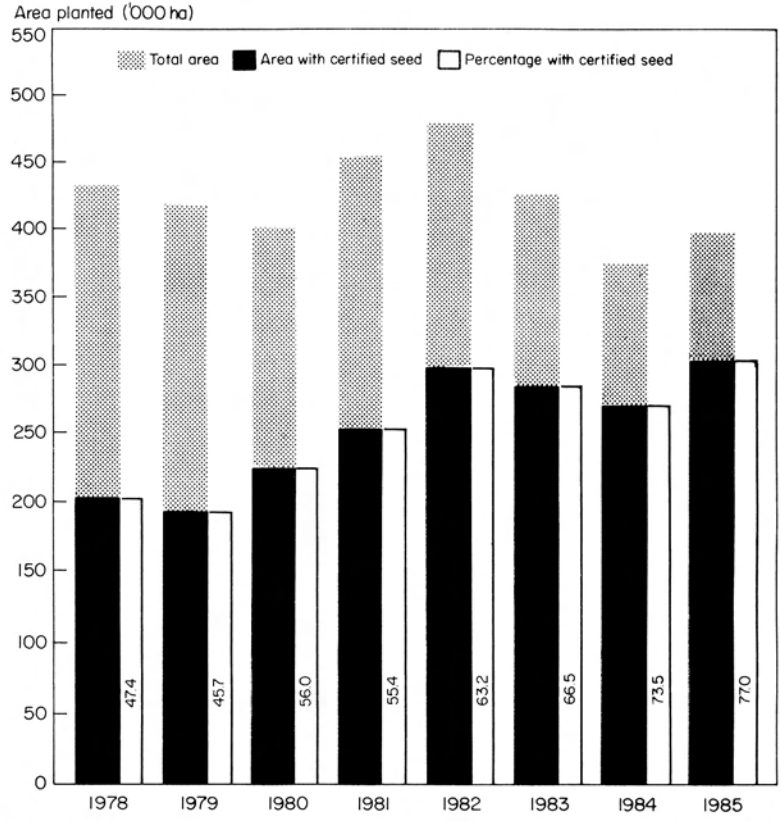
USE OF SEED OF IMPROVED VARIETIES

The country will not benefit from making good seed available if the farmers do not obtain and plant seed of improved varieties. Thus, to facilitate the use of certified seed of improved varieties, it is made available at a fair price, at an appropriate time, at a convenient place, and in the quantities needed. In addition, farmers have access to supplies such as fertilizer, pesticides, and equipment, as well as credit to pay for them. These factors, and the breeding, promotion, and marketing programs, have contributed to the increased use of certified seed of improved varieties (Fig. 5).

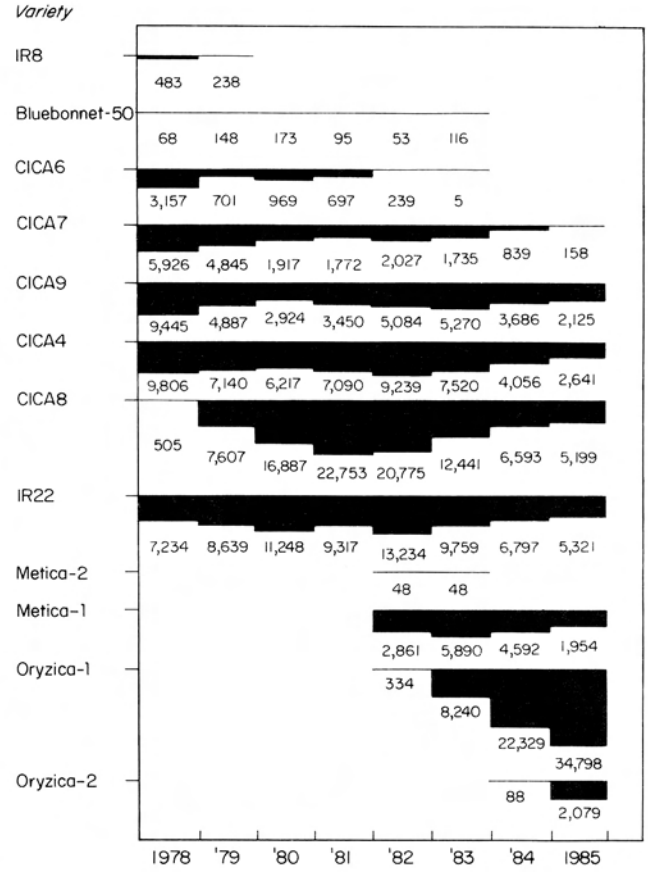
A campaign to introduce seed of a new variety is usually planned to last 3-5 yr. But a new variety makes big news when it is released, and seed adoption spreads over

Table 4. Seed area planted by farmers, area approved, and percentage rejected by ICA to produce certified seed, 1979-85.

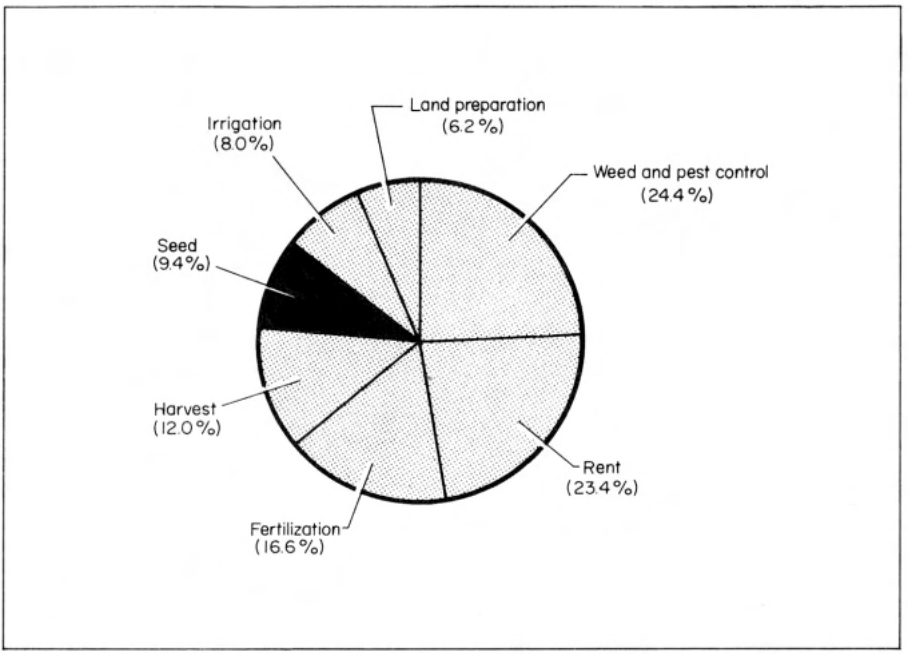
Year	Area (ha)		Rejected (%)
	Planted	Approved	
1979	12,756	11,555	9.4
1980	17,213	14,950	13.1
1981	17,243	13,580	21.2
1982	16,851	13,635	19.1
1983	17,200	13,267	22.9
1984	14,551	9,508	34.7
1985	17,282	14,166	18.0



5. Rice area and percentage cultivated with certified seed in Colombia, 1978-85.



6. Seed (t) certified by ICA and sold by seed industry in Colombia, 1978-85.



7. Percentage of total production cost expended on seed in Colombia, 1986.

several years. Figure 6 shows this situation in Colombia with the varieties used between 1978 and 1985.

The price per kilogram of the different classes of seed is as follows: basic seed, US$0.90; registered seed, $0.46; and certified seed, $0.44. Figure 7 shows the percentage of the total production costs expended on seed. In Colombia, $84/ha or the equivalent of 9.4% of the total production costs is expended on certified seed.

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Hybrid rice seed production in China

MAO CHANG-XIANG

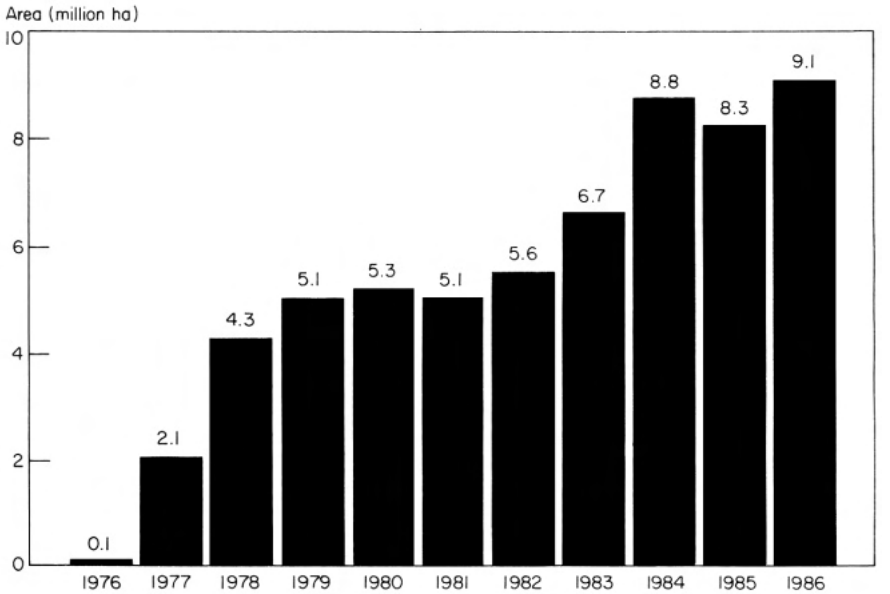
Hybrid rice seed production differs from that of pureline varieties. It involves two steps: multiplication of A-lines and production of F_1 hybrid seed. The system of hybrid seed production in China has three levels. The provincial seed company is in charge of the purification of parental lines and the production of foundation seed. The prefectural seed company is responsible for multiplication of A-line seed. The county seed company organizes the production and sale of most F_1 hybrid seed. The key factors in this process are choice of field, synchronization of heading and flowering of parents, row ratio and row orientation, field management, leaf clipping and gibberellin application, and supplementary pollination. To ensure the quality of hybrid seed, the Ministry of Agriculture, Animal Husbandry, and Fishery has formulated national criteria for crop seed, including hybrid rice. Provincial seed companies have developed the tollowing measures for seed quality control of hybrid rice: purification of parental lines, strict isolation, thorough roguing, field sanitation and quarantine, strict adherence to procedures, purity tests, quarantine certification, and seed treatment.

Research on hybrid rice was begun in China by Yuan Long-Ping and his associates in 1964. The cytoplasmic male sterile (CMS), maintainer, and restorer lines essential to produce F_1 hybrids were successfully developed in 1973, and hybrid seed production techniques were established in 1975. In 1976, hybrid rice was released for commercial production. The hybrid rice area in 1986 was 9.1 million ha, and the cumulative area of hybrid rice was 60.3 million ha from 1976 to 1986 (Fig. 1).

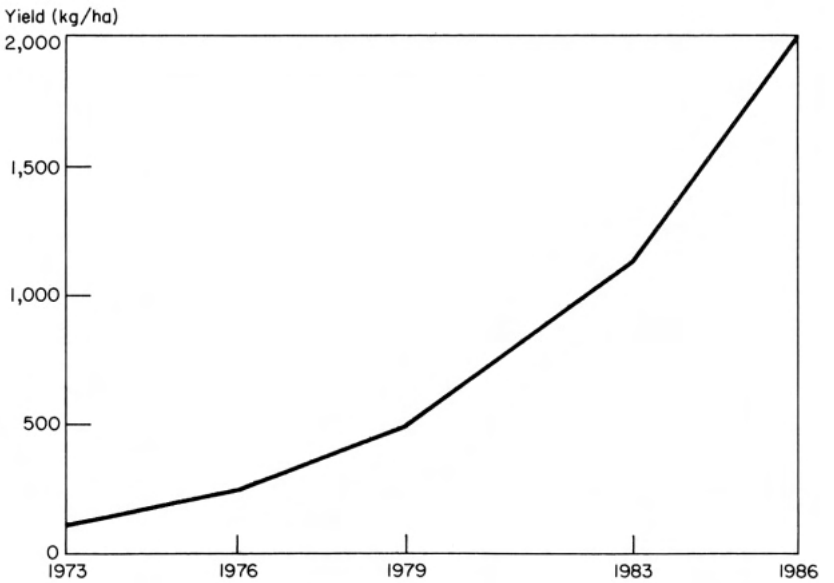
Seed production is a very important link between commercial production and breeding work. Before 1981, the average national yield of hybrid seed was only 0.75 t/ha. In recent years, the average yield of hybrid seed has increased very quickly. The total land for hybrid rice seed production in 1986 was 0.1 million ha, and the average yield was 1.9 t/ha (Fig. 2). Yield was 2.4 t/ha in Sichuang and Zhejiang Provinces, and 2.3 t/ha in Hunan Province, with areas of 15,600, 8,546, and 20,000 ha, respectively. The large increase in hybrid seed yield is attributable to the constant improvement of seed production techniques. The rapid increase in seed

Hunan Hybrid Rice Research Center, Changsha, Hunan, China

yield raised the field area ratio of A-line multiplication to hybrid seed production to commercial production from about 1:30:1,000 in the 1970s to about 1:50:3,000 recently (Fig. 3).



1. Hybrid rice area in China, 1976-86.



2. Average yield of hybrid rice seed produced in China, 1973-86.

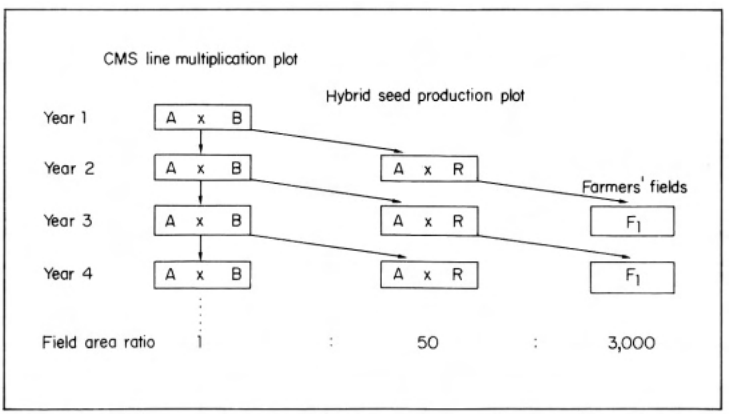
The yield of hybrid rice decreases by about 100 kg/ha when the purity of the hybrid seed decreases by 1% (Yuan 1985). The purification of parental lines and the production of foundation seed are thus very important. But the purity of hybrid seed can be affected by many factors in the seed production process. The local and national criteria for hybrid rice seed and the three parental lines have been established but the quality of hybrid rice seed is sometimes poorer than that demanded by the criteria. The establishment of seed control legislation in recent years has greatly improved the quality of hybrid rice seed.

ORGANIZATION AND SYSTEM OF HYBRID SEED PRODUCTION

The system of hybrid rice seed production in China operates at three levels:

- A seed company at the provincial level is responsible for purifying parental lines and producing foundation seed. In Hunan Province, for example, there are four such foundation seed enterprises supervised by the Hunan Seed Company.
- The prefectural seed company is in charge of multiplying A-line seed. Generally, a state seed farm is responsible for such multiplication and provides A-line seed to the county seed companies for F_1 seed production.
- A seed company at the county level is in charge of hybrid seed production. Generally, one to three suitable locations are selected. The farmers living around the locations are organized in groups to produce hybrid seed according to a contract with the county seed company. The county seed company often sends technicians to train the farmers and check their seed production fields. Most of the skillful seed producers have been so trained.

Before commercial release, a newly developed hybrid should pass a multiple-location yield trial (at least five locations), a regional yield trial (prefectural, provincial, or national level), and a production demonstration, and it should be approved by the Crop Variety Committee. After that, seed production of the new hybrid rice can be begun for commercial use.



3. Interrelationships of the 3 lines in hybrid rice production.

PRINCIPLES OF HYBRID SEED PRODUCTION AND A-LINE MULTIPLICATION

The key factors in obtaining high yields of hybrid seed are:

- *Choice of field.* The chosen fields for hybrid seed production and for A-line multiplication must be properly isolated and possess good fertility, adequate irrigation, and no serious disease or insect problems, especially from pests or diseases forbidden by quarantine regulations.
- *Synchronization of heading and flowering of male and female parents.* Prediction and adjustment of the flowering time of the two parents are very important.
- *Row ratio and row direction.* The principles for determining row ratio and row direction are: 1) to increase the row number of the A-line, 2) to increase the distance between two rows to produce favorable conditions for the growth and normal flowering of the A-line, and 3) to align the row direction with prevailing winds at heading to facilitate cross-pollination.
- *Field management.* Good field management includes: 1) early transplanting and planting a single seedling per hill for the R-line and two seedlings per hill for the A-line; 2) applying fertilizer during the early stages to produce more effective tillers, and less fertilizer and irrigation at later stages; and 3) attention to disease and pest control.
- *Leaf clipping and gibberellin application.* To increase the outcrossing rate, leaf clipping and gibberellin spray are needed.
- *Supplementary pollination.* Rope pulling or pole driving on calm days during anthesis supplements pollination.

The techniques of A-line multiplication are basically similar to those of hybrid seed production.

ENSURING QUALITY OF F_1 HYBRID SEED

To ensure the quality of hybrid seed, the seed companies at different levels have laid down some operating rules for hybrid rice seed production, and the criteria for hybrid rice seed and their parental lines were worked out by the Ministry of Agriculture, Animal Husbandry, and Fishery through the China National Criterion Bureau in 1985 (Table 1). Based on these rules and criteria, the following should be done to ensure the seed quality of hybrids and their parental lines:

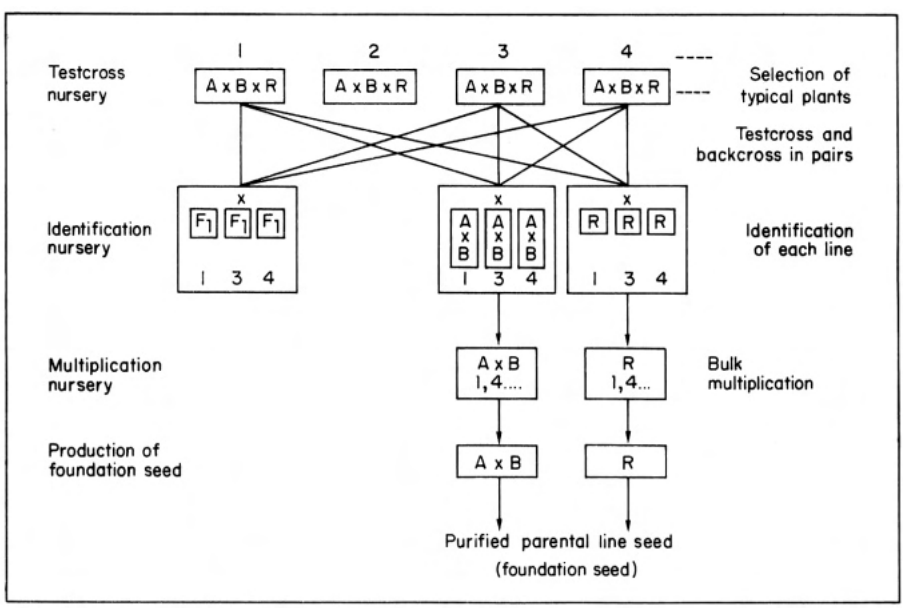
- *Purification of parental lines.* The seed purity of the three parental lines can greatly affect the purity and yield of the F_1 hybrid seed. Different methods are used in China for purifying parental lines; the simplest and most effective utilizes three nurseries and four steps (Fig. 4).
- *Strict isolation.* Space isolation and time isolation are widely used in large-scale hybrid rice seed production. Variety isolation and barrier isolation are used mainly for small-scale production. Space isolation using hills, rivers, and crops other than rice as barriers is commonly used in mountainous and hilly areas. Time isolation is widely used in the plains.
- *Thorough roguing.* The maintainer plants and semisterile plants that appear in the A-line rows and other off-type plants mixed in both the male and

Table 1. Criteria for quality of 3 lines and hybrid seed.

Line	Grade	Purity > (%)	Cleanliness > (%)	Germination > (%)	Moisture < (%)	Weed seeds < (grains/kg)
A-line	Foundation seed	99.9	99.0	90.0	13.0	0
	1st class	99.5	99.0	90.0	13.0	0
	2d class	99.0	97.0	85.0	13.0	5
B-line	Foundation seed	99.9	99.0	96.0	13.0	0
	1st class	99.5	99.0	96.0	13.0	0
	2d class	99.0	97.0	93.0	13.0	5
R-line	Foundation seed	99.8	99.0	96.0	13.0	0
	1st class	99.5	99.0	96.0	13.0	5
	2d class	99.0	97.0	93.0	13.0	5
F_1	1st class	98.0	98.0	93.0	13.0	0
	2d class	96.0	97.0	90.0	13.0	5

female rows should be removed. Seed producers generally do this three or four times between the seedling stage and heading.

- *Field sanitation and quarantine.* To control disease and insect pests, seed production fields that have no serious disease or insect problem, especially those forbidden by quarantine regulations, are selected. Before seeding, parental seeds should be treated with chemicals. During the whole growing period, if pests occur, plant protection measures should be taken at once. Field quarantine certainly should be carried out before harvest, and the quarantine certificate is given to the seed producer by the county plant protection station.



4. The procedure for purifying parental lines.

- *Strict adherence to procedures.* To avoid mechanical admixtures that may occur between parental seed soaking and hybrid seed sale, the seed companies at different levels have worked out rigid operational rules. They send technicians to check quality at key steps. Seed producers use special tools and keep two labels, one inside the seed bag and the other on the bag, with the variety name, producer's name, place of production, etc.
- *Purity tests.* There are four kinds of purity test. In the field purity test, technicians under the county seed company check purity in the seed production field before harvest. The second — the laboratory check — samples seed for purity, cleanliness, germination rate, moisture content, weed seeds, etc. These two purity checks are necessary for all seed producers. The third kind is the nursery test, where seed sampled from each producer's output is planted to check for physiological purity. This test is done only if the purity of the hybrid seed or its parents is suspected. The sampled seeds used for the early cropping season are normally tested on Hainan Island during the winter season; usually about several thousand seeds from each county seed company are tested. Recently the isozyme technique has been used in some institutes to test for physiological purity; it is rapid but has practical shortcomings.
- *Quarantine certification.* If the seed will be sent from one province to another, provincial plant quarantine certification should be done.
- *Seed treatment.* Seed with serious diseases, especially those of quarantine importance, must be destroyed at once. If purity or cleanliness is below standard, the price may be lowered.

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The rice seed production system at the Centro Internacional de Agricultura Tropical

F. CUEVAS-PÉREZ and J. W. GIBBONS

Rice seed production at the Centro Internacional de Agricultura Tropical (ClAT) is intended to speed up the identification and utilization of genotypes that can contribute to removing rice production constraints. With emphasis on irrigated, favoràble upland, and high rainfall savanna upland environments, CIAT's Rice Program evaluates and selects materials at appropriate sites to identify lines that are best adapted to production areas in the region. Seed multiplication, however, is done at the dry-irrigated site in Palmira, Colombia. The genetic material is selected tor multiplication in the F_5-F_7 generations based on disease and insect responses and on grain quality characteristics. Occasionally, commercial varieties are multiplied and distributed by the Field Operations Unit and Seed Unit to support national nce seed production systems. All seed leaving CIAT is protected with fungicides and treated with dry heat at 65 °C tor 6 d to destroy all pathogens. During 1984-86, 2.9 t seed of advanced material and 143 t of seed of commercial varieties were produced and distributed.

The Rice Program at the Centro Internacional de Agricultura Tropical (CIAT) has as its mandate responsibility for assisting the national programs of Latin America and the Caribbean to increase and stabilize rice production and productivity. Depending on the needs of individual countries, this is fulfilled through improvements in crop management, crop protection, plant breeding, and training.

The development and distribution of improved varieties have played a critical role in fulfilling the mandate. Thus, seed distribution is done through the International Rice Testing Program (IRTP) for Latin America, which also includes material from Latin American rice breeding programs and other genetic material from outside the area channeled through the global IRTP network, and by the Field Operations Unit and Seed Unit of CIAT, which support national seed production systems.

This paper describes CIAT's Rice Program seed multiplication and distribution system by presenting the flow of germplasm within the system; indicates methods

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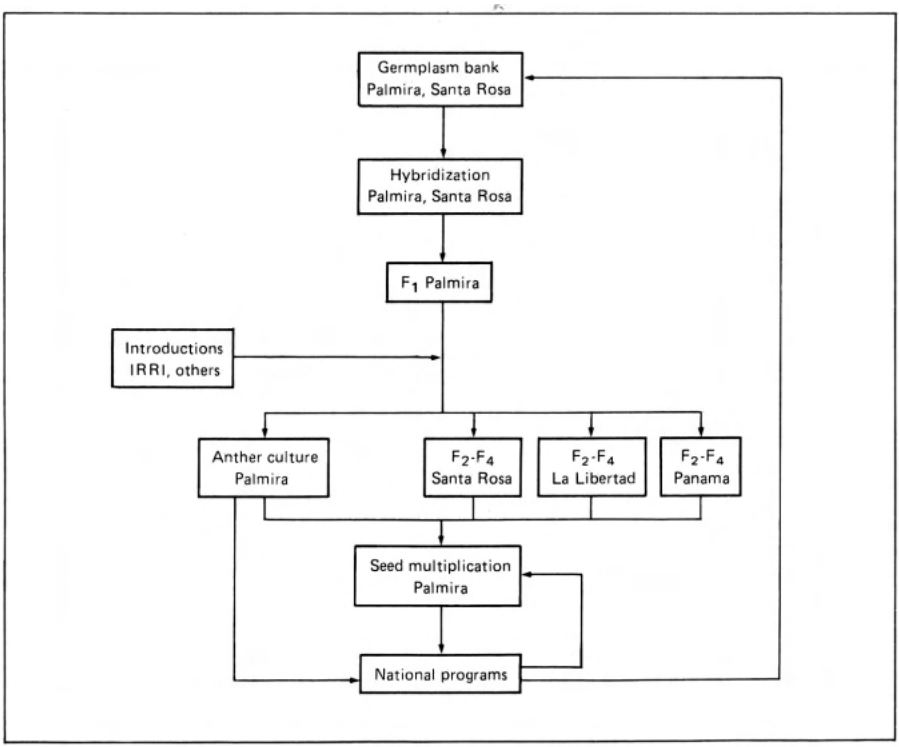
used to ensure seed purity, quality, and health; and summarizes basic rice seed production activities within CIAT.

GERMPLASM FLOW

CIAT's Rice Program concentrates research on the irrigated, favorable upland, and high rainfall savanna (unfavorable) upland rice production systems of Latin America. Further regionalization results in four major target zones: the Southern Cone, Tropical South America, Central America and Mexico, and the Caribbean (Centro Internacional de Agricultura Tropical 1986). Although each region and each production system requires specific traits, some common characteristics include resistance to blast (B1), high milling recovery, high and stable yield, and long, nonsticky grain with low white belly. Resistance to hoja blanca virus (HBV) and tolerance for its vector *Sogatodes oryzicola* (sogata) are required in all regions except the southern temperate areas. Screening methods including "hot spot" evaluations for B1 and other diseases, modified field screening for HBV and sogata, field screening for Fe toxicity and acid soil tolerance, and laboratory evaluation for grain quality and milling recovery have been developed or adapted for evaluation of early generation lines and introduced material. A generalized flow of germplasm is presented in Figure 1.



1. Germplasm flow in the CIAT Rice Program.

Hybridization and F_1 plant selection are carried out at CIAT headquarters in Palmira, Colombia. Crosses programmed for resistance to HBV are screened by semicontrolled inoculation in the F_1. Only resistant F_1 plants are transplanted, and further selection is based on highly heritable traits such as grain shape and fertility. The F_2 seeds thus generated are sent to Santa Rosa, Colombia, and Alanje, Panama, for irrigated and favorable upland environments, or to La Libertad, Colombia, for savanna upland. Selection of individual plants in the F_2 and F_3 generations is based on resistance to B1, relative resistance to other pests and diseases found at these locations, acid soil tolerance (La Libertad), grain quality, lodging resistance, and acceptable plant type.

F_4 progeny from selected F_3 families are screened at "hot spots" in Peru and Panama, and for HBV, sogata, and grain quality in Palmira. Those crosses with Fe-tolerant donors are screened for Fe toxicity tolerance in La Libertad (Table 1). The best lines from the Peru screening are advanced in Peru and enter the Peruvian Regional Testing Network. The Panama Program, which is a cooperative project between the Panama National Program (IDIAP) and CIAT, is specifically oriented toward the needs of Central America; selected lines are directed toward observation trials in Central American countries. The savanna germplasm flow has been described by Sarkarung (1986). At the F_4 stage, appropriate germplasm from all primary selection sites is interchanged.

In addition to the conventional approaches described above, the production of doubled haploid rice plants through the use of anther culture has significantly improved the ability of the program to service the needs of the temperate areas of Latin America and Cuba. The primary constraint to the breeding programs in these areas is the inability to produce more than one cropping cycle per year. The creation of homozygous lines in 7-8 mo would reduce the time required to produce a variety from 15 to only 5 yr, and the potential impact of a successful program would be substantial.

Lines combining excellent grain quality and tolerance for cold temperatures that were derived from crosses passed through anther culture at CIAT, Palmira. are presently being tested by the Chilean Rice Program. Depending on requirements

Table 1. Evaluation sites, characters evaluated, and plant generation of ClAT breeding material.

Site	Characters[a]	Generation
CIAT-Palmira	HBV resistance, grain and plant type, sterility	F_1
	Grain quality, sogata tolerance	F_3, F_4
	HBV resistance	F_4
	"Sun-checking" milling recovery, plant type	F_5
CIAT-Santa Rosa	Leaf blast, neck blast, brown spot, leaf scald, plant type	F_2, F_4
La Libertad	Fe toxicity tolerance	F_4
	Acid tolerance, disease resistance	F_2, F_4
Panama-3 sites	Fungal diseases; adaptation, plant type	F_2, F_5
Peru-Alto Mayo	Leaf blast, eye spot, brown spot	F_4
Peru-Tarapoto	Cercospora, lodging	F_4

[a]HBV = hoja blanca virus.

concerning Bl, Fe toxicity tolerance, and other characteristics, anther culture-derived lines are evaluated in Santa Rosa or La Libertad, or are sent directly to cooperating agencies in the respective production areas. The scope and further uses of this innovative approach are described in detail elsewhere (Pulver 1986).

Introductions from the global IRTP, the International Institute of Tropical Agriculture, or other international sources are screened along with the advanced material in Santa Rosa and Alanje, and evaluated for grain quality characteristics in Palmira. All selected material from the primary selection sites and material from national programs within the region are multiplied in Palmira, where milling recovery is evaluated. Ultimate selection of materials to be included in IRTP Latin American observation trials is made by IRTP and Rice Program scientists.

There is thus much movement of rice seed both within and outside CIAT's host country, Colombia, and the danger of the spread of seedborne pests is of major concern. A memorandum of understanding signed by the Directors General of the Colombia National Program (ICA) and CIAT lists guidelines to be followed by both institutions concerning the import and export of seed. Briefly, the main points of the agreement are: 1) for CIAT to assist ICA in quarantine practices to ensure that seed or vegetative propagules entering Colombia for CIAT are free from exotic dangerous organisms, and 2) for ICA to assist CIAT in the export of germplasm and genetic material by inspecting material in the field and issuing phytosanitary certificates for inspected material. These objectives are partly satisfied by the placement of an ICA quarantine officer at CIAT headquarters.

SEED MULTIPLICATlON

International Rice Testing Program

To improve the genetic purity and uniformity of the germplasm distributed in Latin America, given that most materials are in the F_5 and F_6 generations, only single plants are used for multiplication. Ten to twenty grams of seed per plant are multiplied using the transplanting system, which usually permits the establishment of plots of 8 rows, 5 m long, under 30 × 30 cm single plant transplanting. Fields used for multiplication are planted only one season per year. The rest of the year the land is left idle, and weeds and volunteers are controlled mechanically or chemically.

Some degree of field roguing is usually necessary, because national programs prefer homogeneous lines for observational trials. Few lines are delayed for distribution for reasons of extreme segregation. The ability to select adapted lines and practice purification, multiplication, and yield evaluation under local conditions has many advantages and appeals to most national programs in the region. Most lines originating from the irrigated-favorable upland environment breeding site in Santa Rosa to be multiplied during the first semester (March-August) of 1987 were in the F_5 generation, whereas all those coming from the savanna upland screening site in La Libertad were in the F_6 (Table 2). The latter material is usually less uniform because of the wider crossing involved in their generation compared with germplasm for the irrigated and favorable-upland environments.

Our seed production system takes seed quality and health into consideration by multiplying material under irrigation in Palmira, which has the driest weather

Table 2. Number of lines submitted for multiplication by CIAT's Rice Progam according to generation and evaluation site. CIAT, 1987.

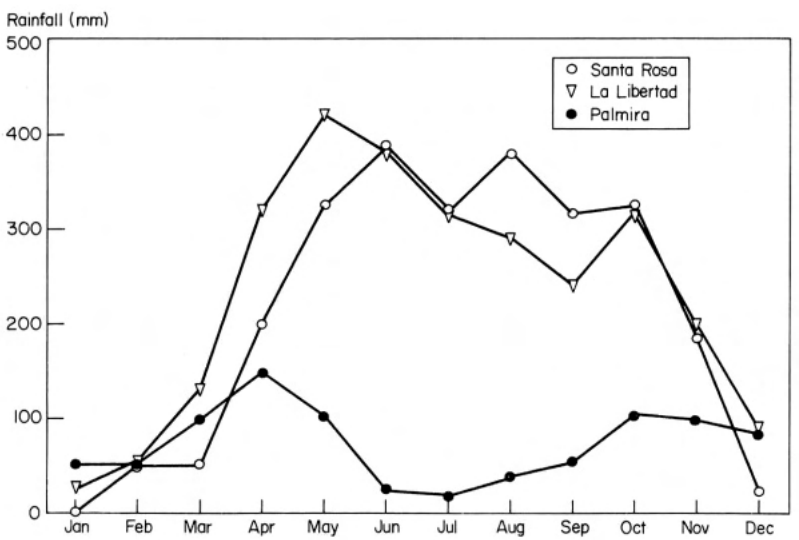
Evaluation site	Generation			
	F_5	F_6	F_7	Total
Santa Rosa	311	170	34	515
La Libertad	–	411	–	411
Total	311	581	34	926

among our test sites within Colombia (Fig. 2). First planting is in October, and harvesting is from early February to early March; second multiplication starts in April and ends in July or August. Additionally, all seeds distributed are treated with a mixture of fungicides (captan plus carboxin), which protects them against fungal pathogens.

The isolation and identification of the seedborne plant pathogenic bacterium *Pseudomonas fuscovaginae* by CIAT rice scientists (Zeigler and Alvarez 1986) has resulted in measures to ensure that this pathogen is eliminated from seed. Fortunately, dry heat treatment of 65 °C for 6 d results in bacteria-free seed. All seed movement within and outside CIAT is now routinely heat-treated before shipment.

Country services

CIAT's Rice Program, Field Operations Unit, and Seed Unit provide occasional seed multiplication services to national rice research programs by producing basic seed to support varietal release and national seed production systems. These services are to facilitate the rapid release and the continuous availability of good-quality seed at the national level.



2. Mean monthly rainfall of 3 rice evaluation sites in Colombia.

During the second semester (September-February) of 1986, our program identified a group of 250 lines resistant to HBV and its vector *S. oryzicola.* Such germplasm could be very useful for Colombia and Ecuador, where HBV caused yield reductions in 1981 and 1985, respectively. Thus, both countries were interested in the rapid release of a resistant variety, which usually requires intensive testing. Because the material was in the F_5 generation and some segregation was still observed, the two national programs decided to conduct preliminary yield trials; they requested CIAT's Rice Program to multiply seed for further yield trials and to begin the purification of those lines identified as having the potential to become varieties after preliminary evaluation. Obviously, some of our multiplication effort would be wasted, because discarded lines would be multiplied; however, enough seed should be available by the time a potential variety is identified, allowing farmers to take rapid advantage of the disease resistance.

The Field Operations Unit of CIAT multiplies basic seed of rice varieties grown in Colombia under the national seed multiplication effort. Seed is multiplied in Palmira under irrigation, using the production system described by Diaz-Duran and Johnson (1979), with the addition of mechanical transplanters. Occasionally the seed goes to other national programs as well, since some Colombian varieties are also grown commercially in other Latin American countries. Such distribution is usually channeled through the Seed Unit of CIAT. In 1984, the amount of basic rice seed sold was 143 t of 6 commercial varieties, serving 4 Latin American countries (Table 3).

SEED HANDLING AND DISTRIBUTION

Rice lines selected for distribution through IRTP-Latin America are harvested and hand-threshed in the field 40-45 d after 50% flowering, which results in grain moisture contents below 18%. Cloth bags are used in all handling processes. Drying is combined with heat treatment to eradicate *P. fuscovaginae* from the seed, reducing grain moisture below 10%.

Table 3. Basic rice seed sold by the Seed Unit of CIAT, 1984-86.

Variety	Quantity (t)	Consignee[a]
CICA4	8.2	ICA, Colombia
CICA7	16.4	ICA, Colombia
CICA8	20.0	Secretariat of Natural Resources, Honduras
IR22	31.5	ICA, Colombia
Oryzica 1	66.1	ICA, Colombia; private enterprise, Brazil
Line 11643[b]	<1	ENASEM, Panama
Total	142.8	

[a]ICA = Colombian Agricultural Institute, ENASEM = National Seed Enterprise.
[b]Variety Oryzica 2 in Colombia. Source: Seed Unit, CIAT.

Table 4. Number of lines and quantity of seed distributed by IRTP-Latin America. 1984-86.

Year	Nurseries		Country requests	
	Lines (no.)	Seed (kg)	Requests (no.)	Seed (kg)
1984	459	1,027	18	131
1985	458	1,292	21	298
1986	315	541	18	115
Total	1,232	2,860	57	544

Seed envelopes are placed in 20-liter plastic drums to prevent the moisture absorption and rat damage that occurred when seed was distributed to national programs in cardboard boxes. Each drum holds 6.5 kg of seed in 7- to 10-g lots packed in coin envelopes. During 1984-85, 1,232 rice lines were distributed in IRTP-Latin America nurseries, with a total weight of 2.86 t, and 0.54 t of seed was sent in response to 57 requests (Table 4). The new system of germplasm distribution established by IRTP-Latin America in 1986, which calls for distribution of observational nurseries only (Centro Internacional de Agricultura Tropical 1986), contributed to a considerable reduction in the amount of seed handled that year.

Our program takes special care to avoid seed mixtures during production by minimizing simultaneous handling of different lines and by carrying out most postharvest practices by hand. So far, despite the large number of lines handled, we have received very few complaints about seed mixing.

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Rice seed production at the International Institute of Tropical Agriculture

T. M. MASAJO, K. ALLURI, and S. L. CLAASSEN

Rice seed multiplication is an integral part of the Rice Research Program at the International Institute of Tropical Agriculture (IITA). Seed is multiplied for multilocational testing for agronomic and on-farm trials, to fill requests from national program scientists, to enter a selection in national and international testing networks, and to provide initial stock for multiplication in national programs. We multiply seed of selected breeding lines, produce breeder seed of promising selections, and multiply in bulk seed of a few selected varieties. The International Rice Testing Program for Africa (IRTP-Africa) multiplies seed of entries nominated for testing in the international nursery program. Accepted procedures followed in rice seed multiplication include the use of fields free from volunteer seed, careful removal of off-types, and raising the crop under good management. Fertilizer application is regulated to avoid lodging. We transplant and harvest seed multiplication plots by hand, but whenever possible, particularly for bulk seed multiplication plots, the operations are mechanized to reduce cost. Germination of stored seed is regularly monitored. In 1985 and 1986, IRTP-Africa multiplied seed of more than 600 entries each year for composing into nurseries, of which there were 6 types. Meanwhile, the breeding program distributed an annual average of 2,300 kg seed of about 270 varieties and lines to 27 countries from 1984 to 1986. Bulk seed dispatches were made mainly for Nigeria. Before being dispatched, the seed was thoroughly cleaned. IITA increased its capacity to multiply seed with the opening of a new rice area in 1986. IITA adheres strictly to the rules and regulations of the Plant Quarantine Service of the Federal Government of Nigeria in importing and exporting seed.

While rice is grown on only about 5 million ha in Africa — representing only about 3.4% of the world rice area — it is the staple cereal in some countries and is quickly becoming a major part of the diet in several others. Importation of rice to Africa has increased sharply because of the growing demand created by population growth, urbanization, and a general dietary shift from traditional foods to rice.

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Rice research at the International Institute of Tropical Agriculture (IITA) has focused on developing better varieties and cultural management practices to increase productivity in Africa's rice-growing countries. We are developing varieties for upland, hydromorphic, and irrigated lowland ecologies. Our breeding strategy is to incorporate into high-yielding, improved plant-type varieties tolerance for or resistance to the major biological and physical constraints that limit rice production in Africa. The bulk of our research work is done at IITA headquarters in Ibadan, where most of the facilities for research on upland, hydromorphic, and irrigated lowland conditions are located.

We evaluate our breeding material at two substations in Nigeria: one at Ikenne, Ogun State, in the transitional zone between forest and savanna; the other at Onne, Rivers State, which represents the high-rainfall zone of Africa. These stations are primarily for research on the upland environment. Screening for Fe toxicity is done by an IITA plant breeder in Liberia in cooperation with the national program in that country and with the West Africa Rice Development Association (WARDA). Testing for low-temperature tolerance is done in Cameroon, and for rice yellow mottle virus in Niger. The International Rice Testing Program for Africa (IRTP-Africa), established in 1985 as a joint program of African national programs, IITA, the International Rice Research Institute (IRRI), and WARDA, operates from IITA.

SEED MULTIPLICATION

Seed multiplication is an integral part of the Rice Research Program at IITA. We multiply seed

- to have larger quantities for multilocational variety trials and for testing for grain quality and tolerance for various stresses,
- to provide seed for agronomic studies and on-farm trials,
- to fill seed requests from scientists in national programs for their evaluations of the material,
- to be able to nominate entries for testing in organized national and international testing networks,
- to provide the basic seed of elite varieties for further multiplication in national programs, and
- for IRTP-Africa, for composing into nurseries for distribution to cooperators in national programs.

Breeding lines

Upland selections harvested in bulk from the pedigree nurseries are grown in irrigated fields the next season for multiplication. Because seeds are drilled and selections are not done strictly on the plant basis under upland ecology, we multiply seed by transplanting one plant per hill in irrigated fields where field conditions are more homogeneous. That provides an opportunity to examine further the uniformity of the lines. Off-type plants are eliminated, and mild negative selection is occasionally practiced. Another advantage of the procedure is that harvests from

irrigated, nonstressed conditions generally result in better quality than harvests from uplands. Seed discoloration is generally minimal. Seeding is in November, with harvest in March and April, in time for May or June seeding in the uplands.

We usually produce 2-3 kg seed of each selection.

In all our seed multiplication, and particularly for the upland materials, we regulate N fertilizer. To avoid lodging, we seldom apply more than 80 kg N/ ha, even with lowland varieties. Removing off-types is difficult or impossible with a lodged crop.

Advanced breeding lines

Selections that have performed well for at least two seasons in advanced variety trials are multiplied to have adequate amounts in stock for the entries to be nominated to national and international trials. We normally grow the selections in plots large enough to yield from 10 to 50 kg seed per entry. Our seed production targets also consider the seed requirements for various agronomic trials at IITA and on-farm research programs.

Breeder seed production

In the production of breeder seed, we follow the general suggested procedure of growing panicle-rows or plant-rows (Briggs and Knowles 1967, Jennings et al 1979, USDA 1973) to ensure uniformity in the selection by eliminating off-types that could result from residual heterozygosity and segregation, or perhaps mechanical mixture. From a field plot planted to 1 variety, we select about 350-400 panicles or plants. Harvested samples are dried and further examined before threshing. Grains are examined for hull color, apiculus color, grain size, shape, length, width, pubescence, and awning — depending on the variety. Selected samples are threshed and kept in separate envelopes.

Fields of uniform fertility and assured water supply, but without volunteer seeds, are selected to build raised nursery beds. We use relatively low seeding densities to raise vigorous seedlings for good stand establishment and minimize gaps due to missing hills when one seedling is transplanted per hill. The seedbed is inspected occasionally for off-type lines, which are eliminated.

In the field, we plant 3 rows that may vary in length from 3 to 6 m, depending on the number of seedlings and the amount of seed needed. Seedlings are transplanted at a spacing of 25 × 20 cm, immediately when possible, at least on the same day they were uprooted. Plots or rows are numbered to facilitate note-taking and accurate discarding. We take notes on the plots at all stages of the crop, paying particular attention to plant height, leaf habit, tillering, time of flowering, and such grain characters as color, size, and shape to identify types not representative of the variety. We do not remove off-type plots before the plants mature, but keep their numbers in the book.

Selected rows (plots) are harvested at maturity or about 30 d from flowering. Plots to be discarded are harvested first, and the field is thoroughly rogued for volunteer plants occasionally found between the rows or hills of selected lines. Harvesting is either by hand or with a combine harvester. We normally produce 200-250 kg seed per variety.

Bulk seed multiplication

We multiply in relatively large quantities a few selected varieties that have been recommended for release for commercial production or have performed well in the nationwide Coordinated Rice Evaluation Trial in Nigeria and are therefore likely to be accepted. Limiting the number of varieties in bulk seed multiplication saves money, hectarage, and seed storage space. When possible, we use breeder seed to plant bulk seed multiplication plots, but occasionally, for lack of breeder seed, we have used other types of seed with acceptable purity. The quantity of a given variety to be produced depends largely on anticipated demand. It has ranged from 300 kg to a few tons. We plan our breeder seed production and bulk multiplication in close consultation with the National Seed Service of Nigeria.

IITA recently developed a new rice area that can be irrigated and drained at will. The underground irrigation system uses water from a reservoir above the fields. The new area enables the Institute to produce larger quantities of seed, carry out more breeding and agronomic trials, and conduct international trials. Ricefields are prepared mechanically with a Kubota 4-wheel drive tractor and rototiller that can prepare 1-2 ha/d.

Bulk seed multiplication plots are transplanted, but when field conditions permit, we practice dry seeding. Birds that feed on seeds and seedlings have limited our success with broadcasting pregerminated seeds. For transplanted crops, we use 3-wk-old seedlings and 25 × 20 cm spacing. Our dry seeding is with an Almaco 6-row grain drill (Almaco Co., Iowa, USA), that can cover 0.5-1.0 ha/d. Spacing between rows is 25 cm, and the seed rate is about 50 kg/ha. Irrigation follows direct seeding, and once flooded, the field is drained for the seeds to germinate. We use herbicides to control weeds, but no insecticide. Bird scarers are employed from 1 wk after flowering until harvest is completed.

Whether transplanted or direct-seeded, rice seed is harvested from the multiplication plots with a Class 25 (Class Combine Co.) compact combine or a Kubota NX 1000 (Kubota Ltd., Japan) rice combine. We can harvest about 0.5 ha/d. After a variety is harvested, the combine is thoroughly cleaned to prevent seed mixture.

IRTP-Africa seed multiplication

IRTP-Africa was established in 1985 to serve the needs of the national programs in Africa. Operating under the global IRTP based at IRRI in the Philippines, its primary objective remains to make world elite germplasm available to scientists in national programs for use directly as varieties or as parents in rice improvement programs.

IRTP-Africa nurseries — based on a 3-tier testing system of preliminary screening, observational trial, and advanced variety trial — are the Preliminary Screening Set (PSS), the Observational Nursery (ON), and the Advanced Trial (AT), with approximately 200, 100, and 20 entries, respectively. IRTP-Africa is now involved only with the upland and lowland environments, but there are plans to expand the testing program to include rainfed rice and nurseries for testing under specific stresses like Fe toxicity, blast, and rice yellow mottle virus — all major constraints to rice production in Africa.

Seeds of nominations to the different nurseries are multiplied under lowland irrigated conditions. The number of entries and approximate seed requirement for each entry in the nurseries are shown in Table 1. Most IRTP-Africa nominations for multiplication are seeded from April to June, to allow sufficient time to process the seed before the nurseries are composed and packaged in January and February the next year. Seed multiplication for IRTP-Africa follows the same procedure discussed earlier in the multiplication of advanced breeding lines. The crop is transplanted at only one seedling per hill. Off-types are rogued at all crop stages, particularly during flowering, when they are most apparent. Harvesting is done manually because plots are too small for a combine harvester.

SEED PROCESSING

Self-cleaning threshers, which are standard equipment in small grain-breeding programs, are indispensable in rice seed production when many varieties are being multiplied in relatively small quantities. A self-cleaning thresher saves time and keeps seed mixtures to a minimum. Panicle and plant selections are threshed in head threshers, and harvests from the multiplication plots on "Vogel Type" plot threshers. Higher capacity, commercial models are more suitable for threshing harvests from larger multiplication plots.

Rice is usually harvested at about 20-23% moisture content, so drying is an important step in seed processing to ensure quality appearance and germinability. Harvested rice not dried on time deteriorates rapidly from accumulated heat and fungus growth. We use laboratory dryers to dry small samples, but we do most of our drying in larger upright dryers (Hotpack Corp., PA, USA).

For bulk seed multiplication plots, seed is dried in rooms where heated air is blown through it. We use a Lister moisture-extraction unit (R. A. Lister Farm Equipment, Dursley, Gloucestershire, U.K.) that uses heat from the air-cooled engine as well as from a diesel fuel heater, in five 4-t drying rooms. We dry about 1 t of rice to 13% moisture content in 12 h in IITA's central drying unit, which is also used for other crops.

Portable self-cleaning blowers with wire screen hoppers are very useful in cleaning small quantities of seed. Two or more passes may be necessary. For large

Table 1. Approximate number of entries and seed requirement for each entry in IRTP-Africa nurseries.

Nursery	Entries (no.)	Seed required (kg/entry)
African Upland Rice Advanced Trial (AURAT)	20	40.0
African Upland Rice Observational Nursery (AURON)	100	5.0
African Upland Rice Preliminary Screening Set (AURPSS)	200	1.0
African Irrigated Rice Advanced Trial (AIRAT)	20	15.0
African Irrigated Rice Observational Nursery (AIRON)	100	1.5
African Irrigated Rice Preliminary Screening Set (AIRPSS)	200	0.6

batches of up to 2 t/d, we use a Clipper M-25 (Blout/Ferrel-Ross, Blufton, Indiana, USA) air-screen cleaner. By selecting appropriate screens and properly adjusting the air blast intake, we easily remove light seed, dirt, chaff, and weed seeds.

SEED STORAGE

The Rice Research Program maintains a storeroom separate from the Genetic Resources Unit (GRU) of IITA. The GRU keeps 24,000 germplasm accessions of several crops (Genetic Resources Unit, IITA 1986), including 9,000 accessions of rice. The Rice Research Program's seed storage facility was built primarily for breeding material. The room is maintained at about 15 °C and the relative humidity at around 60%. F_1 seeds, F_2 populations, and breeding nursery material are kept in the storeroom. Parents used in crosses, breeder seed, seed samples of advanced breeding lines, elite varieties, and IRTP-Africa entries also are kept in the cold storage. The GRU has duplicate samples of the elite and donor varieties in our hybridization program. Bulky materials that cannot be accommodated in the cold storage are stored in 40-kg bags in an ordinary air-conditioned room. We also keep seeds in rooms without air conditioning in 40-kg bags or in covered 200-liter drums. We periodically inventory seed by variety. Germination of all stored seed is regularly monitored.

SEED REQUEST AND DISPATCH

IITA receives requests for seed of improved varieties of rice, cowpea, soybean, maize, and others, and for material of vegetatively propagated crops like cassava and sweet potato. Requests for rice seed have increased rapidly the past 2 yr. We supply seed on request to government agencies and research institutes both in and outside Nigeria. In Nigeria, our host country, we supply seed to the Federal Ministry of Agriculture through the National Seed Service, the Federal Agricultural Coordinating Unit, the National Cereals Research Institute, and the National Accelerated Food Production Program for various agricultural development projects, and to individual farmers. Table 2 records the seed sent by the Rice Research Program from 1984 to 1986. With the opening of new ricefields at IITA, and anticipating that the current restriction on rice imports will increase demand for pure seed of improved varieties in Nigeria, we produced in 1986 about 8 t seed of several varieties for distribution in 1987.

IRTP-Africa, as a medium for the systematic exchange and evaluation of the world's elite germplasm, composes and distributes nurseries for testing by cooperating national programs in the region. Each nursery has a common set of entries. Six types of nurseries were composed in 1985 and 1986. Included in each seed package are directions on how to conduct the trials, and data sheets for recording observations. Upon completion of each trial, cooperators send a duplicate copy of the data to IITA for compilation. Results of IRTP-Africa nurseries are reported each year.

Seed for distribution, whether from the rice breeding program or from IRTP-Africa, is thoroughly examined before being packaged. Grains that are discolored,

Table 2. Dispatch of seeds from the Rice Research Program, IITA, 1984-86.

Year	Varieties and lines (no.)	Countries (no.)	Amount (kg)
1984	197	24	1183
1985	257	34	1480
1986	349	25	4280

smutted, or damaged by insects are removed, as are germinated, partially filled, or empty grains that blowing did not remove. When necessary, seed is washed and redried to remove dust or soil particles. Muddy, badly discolored seeds, seeds with mixtures, and those with low germination percentages are not included. Facilities for chemical treatment, including fumigation and hot-water treatment, are available at IITA. Soon to be installed are a dockage tester for grading seed and removing partially filled and unfilled grains, and an electronic sorting machine to remove discolored grains.

The import and export of seed for planting are governed by the rules and regulation5 of the Plant Quarantine Service, Federal Ministry of Agriculture and Rural Development of the Government of Nigeria. We apply for a permit when we want to import seed. A phytosanitary certificate is needed when sending seed out of Nigeria. Staff of the Plant Quarantine Service visit our seed multiplication plots twice during the growing season to assess seed quality.

DISEASE AND PEST PROBLEMS IN SEED MULTIPLICATION

Foliar and panicle diseases like blast, sheath blight, sheath rot, brown spot, neck rot, and false smut that affect grain filling and development invariably adversely affect seed quality. But glume discoloration is more common, particularly on crops maturing during the rainy season and crops grown on the uplands (IITA 1985). As glume discoloration intensifies, grain weight decreases and endosperm chalkiness increases (Rice Research Program, IITA 1986).

The more important grain-sucking insect5 that attack rice during grain development in Nigeria are *Aspavia armigera, Stenocoris southwoodii, Reptortus* sp., *Nezara* sp., and *Mispermus* sp. (Alam 1985). Adults and nymphs damage the developing grain and cause diffused brown spots where they feed. Heavily damaged grains are either empty or only partially filled. The common storage pests are *Silophilus* spp., the rice and maize weevils, and the Angoumois grain moth *Sitotroga cereallela* (Akintayo 1982). We control storage pests by fumigation with phosphine gas.

As in other parts of Africa, weaver birds, particularly the village weaver *Ploceus cucullatus,* are serious pests of rice in Nigeria. At the Institute, it is essential either to assign bird scarers to watch over maturing crops or to cover the fields with fine mesh fishnets to keep the weavers off. Wader birds, including ducks, are also pests of rice at IITA. Some species feed on the germinating seed, but their trampling through newly transplanted fields causes more damage by eliminating hills and creating

empty patches in seed multiplication plots. Missing hills reduce yield, but more important is the difficulty of identifying off-type plants in roguing the irregular stands.

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Rice seed production at the West Africa Rice Development Association

S. A. BOTCHEY

One of the early programs of the West Africa Rice Development Association (WARDA) — the seed program — recognized the role that high-quality seed of improved varieties can play in regional rice production. To ensure effective implementation of the program, WARDA initiated a rice seed production system including varietal improvement, covering germplasm collection and varietal testing; breeder and foundation seed production at the Regional Seed Multiplication Centre in Richard-Toll, Senegal; quality control; and training. Between 1973 and 1983, 350 t of foundation seed were distributed to member countries before the facility was closed. To increase rice production in the region through the use of high-quality seed, more effort is required of WARDA and its member states to remove bottlenecks in the seed production system and thereby contribute effectively to rice seed research and rice seed sector improvement.

The West Africa Rice Development Association (WARDA) is a regional intergovernmental organization comprising 16 countries (Benin, Burkina Faso, Chad, Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, and Togo). It is one of the 13 international agricultural research centers under the Consultative Group on International Agricultural Research (CGIAR) and was set up in 1970 to assist its member states to increase rice production through improved technology. To achieve this objective, WARDA lists the following aims in its constitution:

- promotion of rice production within member countries;
- increase of the quantity of rice production;
- improvement of the quality of rice produced;
- encouragement of the production and use of varieties suited to the conditions of member countries and to existing and prospective demands;
- exploitation, introduction, and extension of rational production methods adapted to the conditions prevailing in member countries; and
- promotion of storage, processing, and marketing of rice both within member countries and externally.

West Africa Rice Development Association, P. O. Box 1019, Monrovia, Liberia.

Rice is cultivated in West Africa under different ecologies and under various sociocultural conditions. Yields are very low because of the use of low-yielding varieties, drought in the uplands and some lowlands, nutrient deficiencies and toxicities, poor crop establishment, diseases, insects, rodents, birds, socioeconomic problems, etc. Yields range from 0.5 to 1.2 t/ha in upland rice, 0.7 to 1.2 t/ha in deepwater and floating rice, 1.3 to 2 t/ha in the inland valley swamps, 1.5 to 2.5 t/ha in the mangrove swamps, and 2 to 3.5 t/ha in irrigated areas. One of the major factors accounting for low yields is the lack of improved seed. Sarfo and Kone (1983) estimated that in 1981 the region utilized about 142,340 t of rice seed for cultivation. Of this, about 80% came from seed of traditional varieties, while 20% was improved seed. Half of the improved seed was cultivated under irrigated conditions, while the majority of traditional seed was used in the uplands.

WARDA has designed research, development, and training programs in germplasm collection and utilization, technology assessment and transfer, manpower training, seed production, technical assistance, and information collection, collation, and dissemination; and it has held numerous meetings, reviews, conferences, seminars, and workshops. Four regional rice research stations were established to undertake programs in basic and applied biological research, constraints analysis, and technology evaluation and transfer under specific ecological rice production systems: at Bouake, Ivory Coast, established in 1983 for the upland ecology; Rokupr, Sierra Leone, established in 1975 for the mangrove swamp rice ecology; St. Louis, Senegal, established in 1976 for the irrigated rice ecology; and Mopti, Mali, established in 1976 for the deepwater and floating rice ecologies. The Mopti Station was closed in March 1986.

One of the programs designed in WARDA's early days was the seed program. In recognition of the important role of high-quality seed of improved varieties in rice production, a Regional Seed Multiplication Centre was established in 1973 in Richard-Toll, Senegal, to produce foundation seed of recommended rice varieties for member countries. With the closure of this facility in 1983 and the new orientation of WARDA, the regional rice research stations assumed its functions.

This paper outlines the various components of the WARDA rice seed production system; highlights some of its activities, achievements, and constraints; and suggests improvements.

RICE SEED PRODUCTION IN WARDA MEMBER COUNTRIES

From 1980 to 1982, WARDA carried out a systematic review and assessment of the rice seed programs in its member countries to identify bottlenecks and recommend improvements (Botchey and Diallo 1982). The review covered all member countries except Chad, which joined the Association in late 1983.

The rice seed programs were at varying levels of development (Table 1), but most were not functioning efficiently. Breeding activities were carried out by only a few countries. All had varietal screening programs, in part because of WARDA coordinated varietal trials — discontinued following the new orientation of

WARDA, which lays much emphasis on the technology-generating activities of its regional rice research stations. Input supplies were inadequate, and field inspection programs were poorly organized. Disease and pest control measures were often neglected. The quality control aspect of seed production was missing in some countries and poorly functioning in others. Seed legislation was almost nonexistent. Distribution and marketing systems were poorly organized in most countries, with no price incentives for seed growers. Some of these deficiencies in the seed programs could be attributed to inadequately trained seed technologists, financial problems, poor organization and management of the programs, and, above all, weak government agricultural policies.

Those countries with fairly well-organized seed programs obtained assistance from donor agencies such as the United States Agency for International Development, German Agency for Technical Cooperation (GTZ), International Fund for Agricultural Development, and Food and Agriculture Organization as well as technical advice and the provision of genetic material and training from WARDA. In 1983, for example, GTZ supported a WARDA seminar on Improved Rice Seed Production in West Africa held in Freetown, Sierra Leone, where proposals were made for the establishment of a Regional Seed Technology Centre and a Regional Seed Commission to coordinate all cereal seed-related activities in West Africa. Work of the Commission—which includes organizations such as the International Institute of Tropical Agriculture (IITA), Economic Community of West African States (ECOWAS), Multinational Programming and Operational Centre (MULPOC), Inter-state Committee for the Control of Drought in the Sahel, and WARDA — started in 1984 but with little success.

Table 1. Rice seed production activities in WARDA member countries (Botchey and Diallo 1982).[a]

Country	Breeding	Varietal screening	Seed quality control	Improved seed production	Legislation
Benin	−	++	−	+	−
Burkina Faso	−	++	++	++	−
Gambia	−	++	++	++	−
Ghana	−	++	++	++	+
Guinea	−	++	−	+	−
Guinea-Bissau	−	++	+	+	−
Ivory Coast	+++	+++	+++	+++	++
Liberia	++	++	−	+	−
Mali	++	++	++	++	−
Mauritania	−	++	+	+	−
Niger	−	++	+	+	−
Nigeria	+++	+++	+++	++	+++
Senegal	++	++	++	++	−
Sierra Leone	+++	+++	++	++	−
Togo	−	++	+	+	−

[a] Chad excluded. +++ = good, ++ = average, + = poor, – = nonexistent.

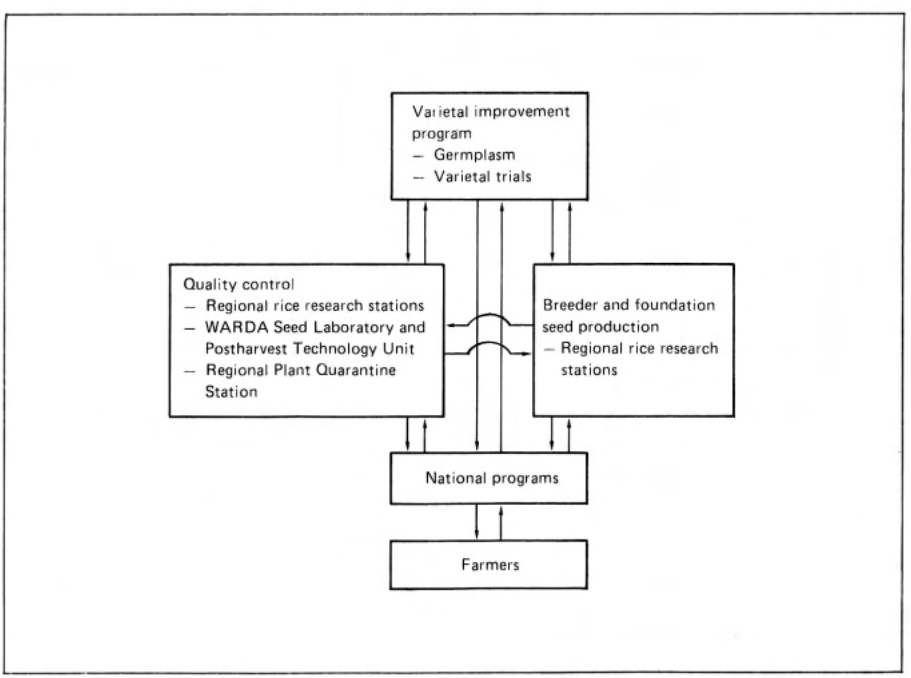
THE WARDA RICE SEED PRODUCTION SYSTEM

The WARDA rice seed production system has several components (Fig. 1), viz:

- the varietal improvement program, which covers germplasm activities and varietal trials;
- breeder and foundation seed production at the regional rice research stations;
- quality control, covering activities of the WARDA Seed Laboratory and the Postharvest Technology Unit in Fendall, Liberia, and the Regional Plant Quarantine Station in Ibadan, Nigeria;
- training in rice seed multiplication, certification, and legislation, including special training at the WARDA Seed Laboratory; and
- reviews and seminars.

Varietal improvement

Germplasm. The main objective of the WARDA germplasm program, which plays a very important role in the seed production system, is to collect rice germplasm from key areas in West Africa, conserve and characterize it, and make the accessions available to any requesting scientist or institution. The program also extends logistic and administrative support to the International Rice Research Institute (IRRI), International Board for Plant Genetic Resources (IBPGR), IITA, Institute for Research in Tropical Agriculture of France (IRAT), etc., when needed for germplasm activities in West Africa.



1. The WARDA rice seed production system flow chart.

The WARDA germplasm program started in 1978 following a collaborative agreement signed by WARDA, IRRI, IITA, and IRAT for germplasm collection in West Africa. The initial activities of the program centered on

- compilation of information from member states on the status of rice germplasm collection in the region;
- maintenance of a working collection at the WARDA Seed Laboratory; and
- receiving samples of collections from IITA and IRAT/Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM).

In 1979, the construction of the germplasm bank in Fendall started, and in 1981, 2 walk-in coolers were installed with a combined volume of 59 m^3. The short-term storage, with temperature of 5-10 °C, is used for working collections and International Rice Testing Program (IRTP) nursery sets for distribution to member states. The medium-term storage has a capacity of more than 12,000 accessions; temperature is maintained at 0-5 °C.

The accessions are routinely monitored, and entries with less than 80% germination rate are rejuvenated at the Seed Nursery Farm in Suakoko, Liberia, established in 1976.

Samples of the germplasm collection are multiplied and evaluated under nontoxic soil conditions each year at the Seed Nursery Farm. The promising entries are made available to West African countries every year through WARDA coordinated varietal trials.

Because Suakoko is a hot spot for screening cultivars against Fe toxicity, routine evaluation of the germplasm entries for Fe tolerance started in 1986.

Some major accomplishments of the germplasm unit follow:

- The WARDA regional rice research stations have carried out collections in Mali, Sierra Leone, and Senegal.
- In 1979, WARDA, with the assistance of the Indian Council of Agricultural Research, carried out expeditions in Mali and Nigeria, resulting in the collection of 666 accessions belonging to 5 species.
- In 1985, WARDA and a team of explorers from the Faculty of Agriculture of Kagoshima University, Japan, collected 23 indigenous cultivars of *Oryza sativa* and *O. glaberrima* in Liberia.
- On a continuing basis, new accessions are collected during WARDA missions and forwarded to WARDA by member states, India, Japan, the Philippines, and France. A good number of accessions have been received from IITA and IRAT.
- Over 6,000 accessions of *O. glaberrima, O. sativa, O. longistaminata, O. barthii,* and *O. stapfii* have been placed in medium-term storage.
- More than 1,500 accessions have been characterized using the IBPGR-IRRI descriptors for rice. The characterization data are computer-stored to facilitate the efficient supply of germplasm with specific characteristics to scientists.

Varietal trials. Before 1984, WARDA's research trials consisted of initial evaluation trials (mass screenings of newly introduced or developed varieties), coordinated varietal trials (essentially yield trials), and plant protection trials carried out at the regional rice research stations and in member countries to identify

valuable genetic material and develop appropriate technology suitable for the different ecosystems.

The initial evaluation trials and coordinated varietal trials were stopped in their original form in 1984 and were replaced in 1985 by three-tier trials, viz., preliminary screening, observational trials, and advanced varietal trials. These trials are conducted as part of the activities of the regional rice research stations, as well as part of IRTP-Africa. Several entries from IRTP have entered into the WARDA testing network (Table 2). From the IRTP nurseries in West Africa, the outstanding entries in the 1982 and 1983 nurseries in the different ecologies are listed in Table 3. The breeding lines and varieties identified in the WARDA coordinated varietal trials (1982-84) that are being used or being considered for production in member countries are listed in Table 4. Most of these lines were from IRTP nurseries.

Breeder seed production

WARDA's breeder seed production started with the establishment of the regional rice research stations. In addition to generating material for WARDA field trials, the stations also produced and supplied breeder seed of proven varieties developed in their respective ecologies to member countries and to the Regional Seed Multiplication Centre for further multiplication. With the closure of the latter facility in 1983, the regional rice research stations strengthened their seed production activities to supply national programs with breeder seed.

The stations endeavor to produce breeder seed by Internationally accepted techniques; emphasis is placed on land selection and preparation, isolation standards, cultural practices, intensive roguing, panicle harvesting, and postharvest operations such as conditioning, drying, processing, and storage. Breeder seed production is carried out strictly by breeders. The area under breeder seed

Table 2. Entries from IRTP nurseries in initial evaluation trials in West Africa, 1980-84 (Seshu 1986).

Year	Ecology	Test entries (no.)	Entries from IRTP (%)
1980	Upland	236	22
	Irrigated	235	61
	Deep flooded	58	50
1981	Upland	174	50
	Irrigated (wet season)	216	85
	Irrigated (dry season)	234	60
1982	Upland	99	17
	Irrigated	251	63
	Coastal saline soils	102	80
1983	Upland	152	51
	Irrigated	260	82
	Deep flooded	88	42
1984	Upland	112	50
	Irrigated	148	72

Table 3. Outstanding entries from IRTP nurseries in West Africa, 1982 and 1983 (Seshu 1986).

Variety or line	Yield range (t/ha)	Height (cm)	Maturity (d)
	Savannah region (irrigated)		
IR2823-339-5-6	5.0-6.5	88	133
IR3273-P339-2-5	4.5-6.0	91	128
IR42	4.2-6.0	111	134
IR54	4.9-5.8	109	125
	Humid region (irrigated)		
IR4422-98-3-6-1	5.0-6.1	107	130
BW298-1	4.2-5.8	120	125
IR2041-178-1	4.1-5.6	120	125
ITA212	4.9-7.0	100	126
IR2373-P335-2-5	4.5-6.0	91	128
BG90-2	4.1-7.0	101	127
BR51-46-2	5.0-6.8	111	134
BR51-118-2	4.2-5.8	107	129
	Deep flooded		
BKN7022-6-1-4	2.1-7.0	160	141
BKN6986-38-1	2.1-5.2	108	144
BKN7022-10-1	3.7-6.0	160	139
	Mangrove swamp (tidal wetland acid sulfate)		
IR2297-125-3-2-2-2	3.8-5.6	150	160
SL22-617	2.9-4.9	149	170
	Cold tolerance		
IR7167-33-2-3	5.1-5.9	99	108
IR2061-522-6-9	4.0-6.0	78	123
B2161C-MR-57-1-3-1	5.0-6.5	105	110
B2983-SR-S7-1-2-1	5.0-6.5	101	128
IR3273-339-2-5	4.0-5.8	78	138

production is relatively small. In the Regional Mangrove Swamp Rice Research Station, 0.5 ha is devoted to the production of breeder seed of varieties WARDA has recommended to national programs.

Foundation seed production

WARDA has identified many varieties as promising, but adoption is often hampered by insufficient foundation seed. The climatic variation within the region and its importance in plant disease development and epidemiology were considered in locating the Regional Seed Multiplication Centre in Richard-Toll, Senegal. Three distinct climatic zones are recognized in the region: 1) areas of short summer rain (<100 cm average annual rainfall) often associated with long periods of hot and dry weather, long sunshine hours, temperatures of 35-44 °C, and relative humidity of 20-75% (Awoderu et al 1983); this area is called the hot equatorial tropical zone and is typical of Northwest Africa; 2) areas with two rainy seasons separated by a short

Table 4. Varieties identified from WARDA coordinated varietal trials that were used or considered for production in member countries, 1982-84 (WARDA 1985). [a]

Country	Lines and varieties			
	Upland	Irrigated and rainfed lowland	Mangrove swamp	Deepwater and floating
Benin	D52-37, IRAT10, Col. 38, C74, IR442-2-58, CR1002, IR937-55-3, IR28, SML AWINI	BG90-2, Col. 38, IR442-2-58, IR3273-P339-2, IR1529-680-3, BW196	–	–
Burkina Faso	IRAT10, IRAT144*, SE302 G, Dourado Precoce, IRAT147	IET1996, IET2885, IR1529-680-3, Vijaya, C74, IET14418, IR1529-680-3		
Gambia	IR442-2-58, SE302 G*, IRAT112, I Kong Pao	I Kong Pao, IR28, BW78, BG90-2, ROK5, IR1529-680-3, IR442-2-58, IR22	ROK5, Phar-Corn-En	ROK5, Phar-Com-En
Ghana	IR442-2-58, IRAT112, Dourado Precoce	IR442-2-58, CICA4, IET2885 IR20, IR2071-586-5-6-3, BG90-2, IR1820-210-2, BR51-118-2	–	–
Guinea	LAC23, ROK16, IRAT109	IR20, IR442-2-58, IET114, IR5	ROK5	BKN6323
Guinea-Bissau	I Kong Pao, IRATl09, IRAT113, IRAT10, SE302 G	BW78, BG90-2 I Kong Pao, IR442-2-58	ROK5	–
Ivory Coast	Dourado Precoce*, IRAT10, IRAT13, IRATl10*, IRAT112, IRAT136	BG90-2, IRAT10*, IR5, Jaya, Bouake 189*, IR1529-680-3	–	–
Liberia	LAC23* IRAT110, IR14	IR5, 2526 (Suakoko 8), improved Mahsuri (Suakoko 10)		

Mali	IRAT10, IR442-2-58, IRAT112	IR442-2-58, IET2885, Sigadis, IR1529-680-3	–	MSP10*, DA29, BKN6323, ADNY 310, DM16, DM17, BKN6985-105-P
Mauritania	–	IR8, TNI, BR51-118-2, I Kong Pao, Thiu Thio Way, BG34-8, IR1561-228-3	–	-
Niger		BR51-118-2, BW196, IR269-26-3-3, NTU770-7-2, IR1529-680-3, IET2885, BG90-2, BW5146-5		T442, FARO 7, BKN6232, FRRS 43/3, Neang-Kiew 5, MALOBADIAN, AA8A, MALIONG, FARO 14
Nigeria	Sel IRAT, 195/1/2/OS6* IRAT136, IRAT13	IR20, BC90-2*, IR1529-680-3 IET2885, ITA123, IR269-26-3*, BR51-46-5, BR51-118-2, Br-49-6	–	FARO 14, BKN6323
Senegal	I Kong Pao*, SE302 G* IRAT110, DJ11-509*	I Kong Pao*, IR8, Jaya, BG90-2, BR51-46-5, IR442-2-58, BR51-118-2, D52-37	ROK5	ROK5
Sierra Leone	ROK16, LAC23*	4414, IET1996, BR51-118-2	R0K5, Djabon	–
Togo	IRAT10, ADNY8, IR441-2-58, IRAT13	IR1529-680-3, IET1444, IR20, IR8, ADNY11, BR151-319-9, BG90-2, IR1416-131-6, IR1442-2-58, IR841	–	–

[a]* = identified in the country.

dry spell and a longer dry season during the northern dry winter, with a mean annual rainfall of 100-150 cm, temperatures of 20-33 °C, and relative humidity 40-85%; this is the savanna zone or the Middle Belt; and 3) the humid southern coastal areas of 1,000-4,000 mm rainfall, 65-95% relative humidity, and 21-32 °C temperature; this is known as the moist forest zone.

Although pests and diseases abound in the region, fungal and bacterial disease incidence is minimal in the Sahel (Senegal, Upper Volta, and Mali), whereas the warm, cloudy conditions of the moist forest zone make it a disease-endemic area. Seed produced during the main season in the moist forest zone is heavily infected with molds and fungi. If dried properly, it can retain an acceptable level of germination for about 1 yr, but it needs presowing treatment. Seed produced in the Sahel, particularly that grown in the off-season, is disease-free and shows excellent germination for 4-5 yr. In most cases it does not require presowing treatment. As an example, LAC23, an upland rice cultivar produced in Gawula Tombe, Liberia, suffered panicle discoloration and disease in the moist upland forest zone but produced clean seed in Richard-Toll, located in the dry Sahel. Production of foundation and breeder seed of introduced and improved varieties was thus carried out during the dry season at the WARDA facility in Richard-Toll. Seed production started with 4 varieties, producing 401 kg of seed from 0.4 ha. By 1980-81, about 28 ha of land had been planted to 9 varieties, yielding a total of 55,221 kg of seed (Table 5). Processing of the seed was carried out by WARDA, while seed certification was done by the Senegal Seed Service Unit. Between 1973 and 1982, more than 350 t of certified foundation rice seed were produced and supplied to member countries (Diouf 1982).

The Regional Seed Multiplication Centre was closed in April 1983 because of:

- *Technical problems.* Poor site selection, salinity, poor drainage, inadequate irrigation water, and bird damage hampered operations.
- *Financial problems.* Lacking the commitment of most member countries to pay for seed collected, the facility could not be self-supporting.
- *Organizational problems.* Member countries did not cooperate in planning their seed requirements in advance. Sometimes large stocks of seed were held at the facility with no request from member countries.

Table 5. Foundation seed yields of rice varieties produced at the Regional Seed Multiplication Centre, Richard-Toll, Senegal, 1980-81 (Diouf 1982).

Variety or line	Area (ha)	Production (kg)	Yield (kg/ha)
D52/37	5.0	14,135	2,827
KSS	0.5	1,158	2,316
IR442-2-58	5.0	11,285	2,257
IR20	2.5	5,407	2,163
IR22	0.5	994	1,988
IR8	2.0	3,488	1,744
I Kong Pao	8.0	12,465	1,558
IR1529-680-3	2.5	3,895	1,558
IR5	2.0	2,394	1,197

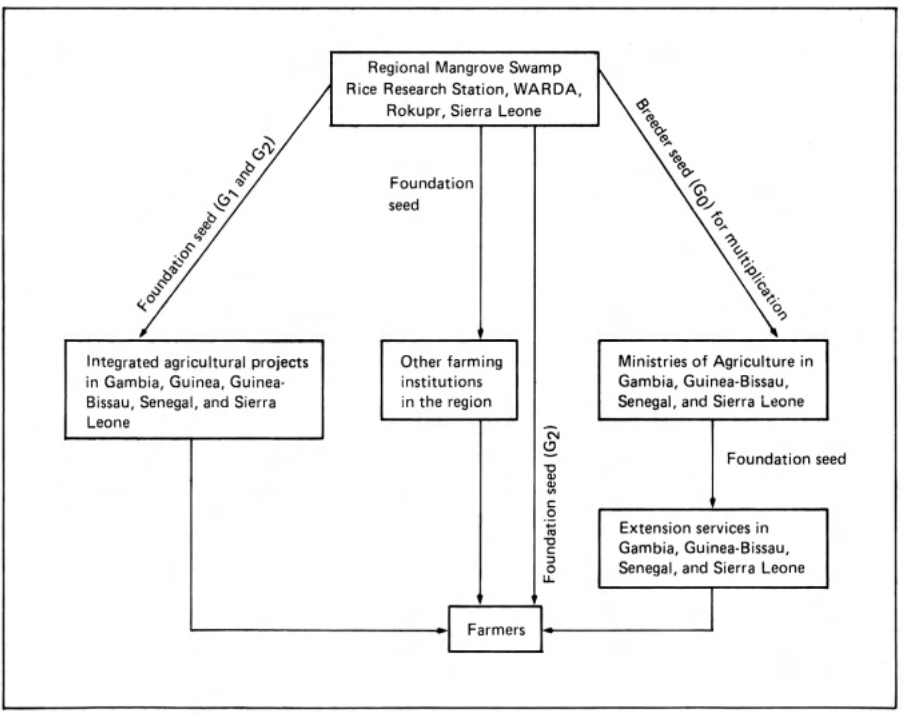
- *Poor communications.* Because of poor communications, some seed consignments were kept for a long time under poor storage conditions at ports of delivery, resulting in viability loss.

With the closure of the Regional Seed Multiplication Centre and the restructuring and reorientation of WARDA's programs, the regional rice research stations now produce breeder seed (G_0) of high-yielding varieties for distribution to member countries, plus some foundation seed (G_1 and G_2). Figure 2 shows the seed distribution channel of the Regional Mangrove Swamp Rice Research Station in Rokupr, and Table 6 gives the foundation seed production figures of the same station from 1980 to 1986. The distribution system is the same at the other regional rice research stations, i.e., breeder and foundation rice seed is produced by the station and distributed to national programs. Some farmers also collect a few kilograms of foundation seed directly from the stations.

Quality control and analysis

The seed quality control and analysis program covers the activities of the WARDA Seed Laboratory and the Postharvest Technology Unit in Fendall and the Regional Plant Quarantine Station in Ibadan.

WARDA Seed Laboratory activities. The WARDA Seed Laboratory in Fendall, about 28 km from Monrovia, was established in 1976 to undertake seed



2. Breeder and foundation rice seed distribution channels, Regional Mangrove Swamp Rice Research Station, Rokupr, Sierra Leone.

Table 6. Foundation rice seed production at the Regional Mangrove Swamp Rice Research Station, Rokupr, Sierra Leone, 1980-86.

Year	Area (ha)	Production (t)	Countries that received foundation seed
1980	2.0	2.8	Sierra Leone
1981	2.5	3.0	Sierra Leone
1982	2.5	3.5	Sierra Leone
1983	3.5	4.0	Gambia, Guinea, Guinea-Bissau, Sierra Leone
1984	4.0	4.5	Gambia. Guinea, Senegal, Sierra Leone
1985	4.5	6.5	Gambia, Guinea, Guinea-Bissau, Senegal, Sierra Leone
1986	5.0	6.2	Gambia, Guinea, Guinea-Bissau, Senegal, Sierra Leone

quality control activities such as seed viability, purity, and health testing. Seed produced at the Seed Nursery Farm and the regional rice research stations and in some member countries for inclusion in the various WARDA trials is sent to the Seed Laboratory for quality evaluation. Regular viability testing is carried out, however, at the regional rice research stations.

The number of seed packages prepared for the WARDA trials increased from 320 in 1973 to 10,669 in 1983 when the coordinated varietal trials were discontinued. All seed dispatched had hot-water treatment (soaked in water for 20 min at 55 °C, then dried to 14% moisture content or below). The seed is dressed with Aldrex T before packaging. Between 1979 and 1985, 404 nurseries of the global IRTP and IRTP-Africa were distributed through the Seed Laboratory. During the same period, 2,692 rice varieties were supplied to institutions in member states, to other countries, and to IITA, IRRI, and IRAT.

The Seed Laboratory is also used for training participants in the WARDA Rice Seed Multiplication and Certification Course, Rice Seed Production Course, and Postharvest Technology Course. Personnel from member countries — 91 between 1979 and 1984 — are also trained in seed handling practices.

Postharvest Technology Unit activities. Involvement of the Postharvest Technology Unit in WARDA's seed activities started in 1986 when samples of rice varieties grown at the regional rice research stations in Rokupr and St. Louis; at the Seed Nursery Farm in Suakoko; and at an experimental site in Fendall were sent to the Unit, also in Fendall, for quality evaluation and milling. The results show the condition of the grain immediately after opening each package (Table 7). Among the varieties tested for grain and milling quality, Suakoko 8 came out as the best with a total milling recovery of 72.3% and a head rice yield of 65.5%, followed by ITA254 and ITA256; all are extra-long grain varieties. Among the long-grain varieties, WAR27-28-1-3-1, Kuatik Kundur, and IKP gave the best yields (total milling recovery and head rice).

Table 7. Summary of preliminary evaluation test results, WARDA.

Sample source	Purity (%)		Immature kernels (%)		Moisture content (%)	
	Range	Median	Range	Median	Range	Median
Fendall, Liberia	80.3-95.6	89.4	0.3- 3	1.4	11.6-14.8	12
Suakoko, Liberia	87.5-98.3	93.3	0.6-19.3	4.1	11.9-13.8	12
Rokupr, Sierra Leone	94.2-99.6	98.4	0.0- 1.8	0.0	11.4-13.7	12
St. Louis, Senegal	92.9-97.4	95.4	0.9-10.5	4.8	12.4-14.0	13

Regional Plant Quarantine Station activities. For a good varietal research program, WARDA had to import improved, high-yielding genetic material with good resistance to diseases and insects. But such importation activities posed the threat of introducing into the region more virulent strains of existing diseases as well as new diseases. To combat this situation, WARDA affiliated itself with the Inter-African Phytosanitary Council Plant Quarantine Station in Ibadan, Nigeria. Seed imported by WARDA is tested at this station for exotic diseases. Uninfected seed is released to the importers through WARDA. In mild infections, seed is treated either with hot water or chemical and then retested before release.

The WARDA varietal improvement program in the region has benefited immensely from these activities, having had no major disease problem. From 1975 to 1982, a total of 26,929 varieties of WARDA's imported rice seeds were processed by the station. Before 1982, seed multiplied by WARDA within the region for redistribution to member countries was never intercepted for virulent seedborne diseases or pests (Larinde and Diallo 1983). These results also indicate the effectiveness of WARDA's hot-water seed treatment.

Training

Training is a very important aspect of WARDA's seed production system. Apart from special arrangements made by member countries for training their personnel in seed handling practices at the Seed Laboratory in Fendall, WARDA organizes the Rice Seed Multiplication and Certification Course for member countries. Until 1983 the course was organized in a member country, but this was discontinued because of WARDA's financial situation. The course is now held at the WARDA Regional Training Centre in Fendall. The numbers of people trained in various aspects of seed multiplication from 1978 to 1986 are shown in Table 8. In 1986, only participants from the five English-speaking West African countries were invited. Participants in WARDA's 6-mo Rice Production Specialists' Course held annually in Fendall are also given lectures in seed multiplication and certification. These two courses and the Research Assistants' Course have varietal improvement as part of their curricula.

Table 8. People trained in the Rice Seed Multiplication and Certification Course, WARDA, 1978-86.

Country	1978	1980	1982	1983	1986	Total
Benin	1	1	2	–	–	4
Burkina Faso	2	–	2	–	–	4
Gambia	1	2	1	–	2	6
Ghana	3	3	–	–	4	10
Guinea	–	2	2	2	–	6
Guinea-Bissau	2	–	1	–	–	3
Ivory Coast	4	–	2	–	–	6
Liberia	2	2	2	1	2	9
Mali	2	2	3	–	–	7
Mauritania	1	2	–	–	–	3
Niger	2	2	2	–	–	6
Nigeria	2	–	1	–	2	5
Senegal	4	2	1	–	–	7
Sierra Leone	2	3	2	–	2	9
Togo	2	2	2	1	–	7
Tota1	30	23	23	4	12	92

Reviews and seminars

Reviews of the rice seed programs in Togo and Sierra Leone have recently been carried out at their request.

A seminar in Sierra Leone in 1983 on Improved Rice Seed Production in West Africa brought together participants from member countries, international organizations, and agricultural development agencies. The participation of member countries in the seminar was very encouraging, showing the importance they attach to seed production.

COLLABORATION WITH NATIONAL AND INTERNATIONAL INSTITUTIONS

WARDA is unique among the centers supported by the CGIAR in being a regional intergovernmental body set up to assist its member states. To achieve its objectives, member states decided to put their resources together and mandated WARDA to assist them in strengthening their respective national research, development, and training programs. The goal was to develop in national program staff the capacity to collaborate in and direct national programs.

The most important collaboration in the seed sector has been and will continue to be in the varietal improvement program, now part of IRTP-Africa. Also, WARDA and IITA collaborate with the Central Agricultural Research Institute of Liberia in a special program on Fe toxicity varietal improvement.

The Regional Seed Multiplication Centre activities in Richard-Toll offered a good opportunity for collaboration in the seed sector, but the facility had to be closed. Close collaboration with member countries continues in the seed training program, particularly in the Rice Seed Multiplication and Certification Course.

WARDA continues to collaborate with IRRI, IITA, IBPGR, and IRAT/ ORSTOM in germplasm activities, and with IRRI and IITA on IRTP. IRRI supplies rapid generation advance services to WARDA. WARDA has collaborative

research activities on stern borers with the International Centre of Insect Physiology and Ecology.

WARDA established collaborative seed programs with some regional intergovernmental organizations such as MULPOC and ECOWAS, but they have not been effective because of resource constraints.

MAJOR CONSTRAINTS

The ultimate aim of the WARDA seed production system is to produce and supply to member countries their basic needs of high-yielding varieties for further multiplication by national programs. More could be achieved if certain constraints were removed from the system. Some of the major constraints are

- lack of a clear-cut policy on WARDA's responsibilities in satisfying the demands of member states for basic seed and on the role of the member states themselves in the WARDA seed production system;
- insufficient production and supply of seed of high-yielding varieties, particularly for the uplands, which constitute about 60% of the rice area in West Africa; the wide range of environmental differences even within an ecology hampers the development of appropriate technologies;
- very little or no budget for the seed multiplication program;
- inadequate seed production facilities at the regional rice research stations; some stations do not have seed laboratories and depend on the laboratories of the national programs, which themselves have very poor facilities;
- not enough time devoted to seed production activities by the staff, who are saddled with their own programs; in fact, WARDA has no seed technologist; scientists who have seed programs on their schedule devote 30-50% of their time to seed activities (not research);
- inadequate training for junior field staff responsible for seed matters;
- lack of funds to organize the Rice Seed Multiplication and Certification Course regularly; fields for practicals are also required for this course; and
- lack of an efficient communications network in the region.

RECOMMENDATIONS

Considering the important role of high-quality seed in increasing rice production in West Africa, it is necessary that steps be taken to improve the present seed production system.

WARDA has made considerable efforts in improving the rice seed situation of its member countries through the meager and nonguaranteed resources put at its disposal annually for research, development, and training. But yields in farmers' fields have not increased appreciably. Much more could be achieved if the constraints listed above could be removed. To improve the WARDA rice seed production system, the following are necessary:

- Because WARDA's seed program is totally linked with the seed activities of its member countries, those countries should develop policies encouraging the establishment or strengthening of their seed programs (national short-,

medium-, and long-term rice research policies; research, extension, and training links, particularly in seed promotion; models of seed production — private, public, or both; growth strategies for the seed industry; marketing and price policies; etc.). The role of the member countries in satisfying their own seed demands should be defined.

- Attention should be devoted to the introduction of high-yielding rice varieties, particularly for the uplands because of the high priority WARDA's research and development programs give to this ecology.
- Adequate budgetary allocations should be provided for the seed program.
- Adequate facilities should be provided for the seed programs at the regional rice research stations.
- Staff responsible for the seed programs should devote more time to them.
- Field technicians responsible for the seed programs should be trained.
- More technicians and seed technologists from member states must be trained.
- Funds and other facilities should be provided for the Rice Seed Multiplication and Certification Course.
- The seed review program should be continued.
- Seminars and workshops on improved rice seed production in West Africa should be organized to assess the past performance of the seed industry and to offer suggestions for improvement. The first and only seminar on seed since WARDA's establishment was organized in 1983 in Sierra Leone.
- Communications among the regional rice research stations should be improved.
- For an effective regional seed program, WARDA's collaborative links with existing national and international agricultural research and development institutions in seed research and seed sector improvement need to be strengthened.

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Seed vigor in rice

D. V. SESHU,[1] V. KRISHNASAMY,[1] and S. B. SIDDIQUE[2]

Seed vigor is recognized as an important seed quality parameter distinct from germinability. Decline in vigor precedes decline in germinability. Consensus on the definition of vigor was reached during the Eighteenth International Seed Testing Congress. Vigor can be tested by either direct or indirect methods. Preharvest environment, position on the mother plant, specific gravity or weight, seed treatment, aging, pathogens, and genetic constitution are some of the factors influencing vigor. Recent studies at the International Rice Research Institute have identified some superior genotypes tolerant of seed aging and others that have a faster seed germination rate. Dormant seeds showed greater tolerance for aging. Significant yield reductions because of poor vigor were observed. A new index to estimate germination rate has been proposed based on the relative counts at 2 and 7 d after soaking. Future lines of work in relation to rice seed vigor are identified.

One of the potential means of enhancing rice productivity is to ensure the quality of seed for sowing. Seed quality connotes physical and genetic purity, freedom from diseases, and high germinability and vigor. Because of the vulnerability of the seed to adverse weather factors during ripening, harvest, and storage, farmers are often forced to sow poor quality seed, which results in inadequate seedling stand. In recent years, vigor has assumed top priority in seed technology research. An estimated 5% crop loss worth more than $1 billion occurs in the U.S. each year because of low seed vigor (Woodstock 1973). The fullest genetic potential of an improved variety and the benefits of various production inputs and improved farming technologies can be realized only when highly vigorous seed is used for sowing. Production of pure seed in rice is relatively easy because it is self-pollinated. However, the achievement of high vigor warrants scientific management of the seed crop and the adoption of proper techniques for harvesting, processing, treatment, and storage.

Vigor is recognized as an important seed quality factor distinct from germinability. Two seed samples possessing similar germinability may exhibit

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different degrees of vigor. During seed deterioration, reduction in vigor precedes the fall in germinability (Delouche and Caldwell 1960) (Fig. 1).

A definition of seed vigor was formulated during the Eighteenth International Seed Testing Congress (Perry 1978). Since vigor is a concept usually derived from the observation of differences between seed lots, a wide definition based on effect was considered more appropriate than one based on causes. Seed vigor is the sum total of those properties of the seed that determine the potential level of activity and performance of the seed or seed lot during germination and seedling emergence. Seeds that perform well are termed "high-vigor seeds," while those that perform poorly are called "low-vigor seeds."

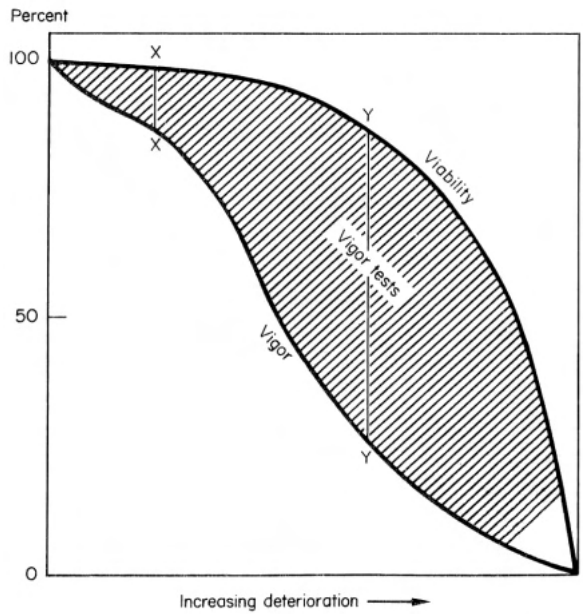
The aspects of performance that may show variations associated with differences in seed vigor include:

- biochemical processes and reactions during germination such as enzyme reactions and respiratory activity,
- rate and uniformity of seed germination and seedling growth,
- rate and uniformity of seedling emergence and growth in the field, and
- emergence ability of seedlings under unfavorable environmental conditions.

The effects of vigor level may persist to influence mature plant growth, crop uniformity, and yield.

TESTING FOR VIGOR

Vigor cannot be quantified because it is a concept, and only specified components can be expressed numerically. The basic principle is that a vigor test must be reproducible and easy to perform, and must correlate with a field performance



1. Relationship of seed viability and vigor during seed deterioration (Delouche and Caldwell 1960).

characteristic such as seedling emergence under environmental stress. There are two principal approaches to measuring vigor, each based on a different concept. Vigor tests may be direct or indirect. Direct tests are those in which an environmental stress is reproduced in the laboratory, and the percentage and rate of seedling emergence are recorded, e.g., the brick grit test, cold test, mannitol or PEG test, NaOH or ethanol test, and accelerated aging test. Indirect tests are those in which other characteristics of the seed that have proved to correlate with an aspect of field performance are measured, eg., respiration rate, topographical tetrazoliun test, conductivity test, seedling growth test.

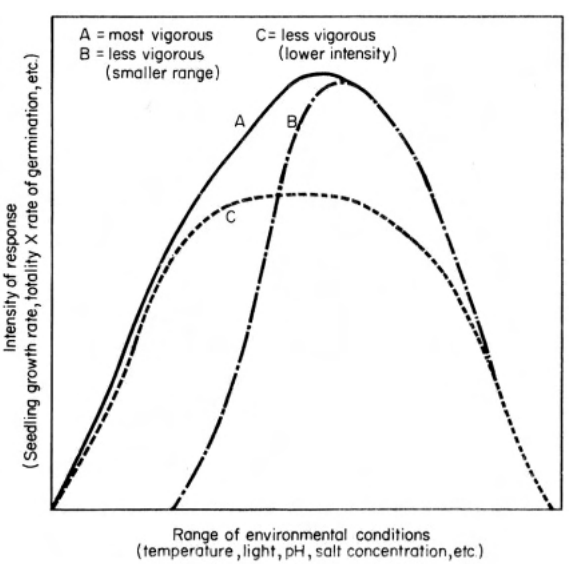
No single test will satisfy all requirements, and a method or a combination of methods should be chosen to suit the crop and the environment in which it will be sown. For instance, the cold test, employed widely in maize (Isley 1950), is next suitable for rice (Mian and Coffey 1971). Recognizing that differences in seed may be important under favorable as well as unfavorable connditions, Woodstock (1969) suggested a two-vectorial mathematical analysis of vigor that includes a speed of germination or rate of seedling growth vector and a range of environmental conditions vector (Fig. 2).

Dormancy breaking techniques should be applied to seed before vigor testing to ensure that the effects of dormancy have disappeared at planting.

FACTORS INDUCING VARIATION IN SEED VIGOR

Many factors induce variations in the level of seed vigor, but the principal known causes are:

- preharvest environment;
- position of seed on the mother plant;
- seed size, weight, or specific gravity;



2. Theoretical curves showing 2-vectorial analyses of seed vigor (Woodstock 1969).

- mechanical integrity;
- deterioration and aging;
- pathogens:
- seed treatment; and
- genetic variability.

Seed dormancy may obscure the vigor potential of a seed lot in a laboratory test, but it should not be regarded as a component of vigor if seedling emergence is unaffected in field sowings.

Preharvest environment

Weather. Fernandes et al (1980) reported varietal differences in rice in degree of germination as affected by sowing date. Seed obtained from plants given short-day treatment germinates more readily than seed from untreated plants, particularly at low temperature (Ota and Takeichi 1966). Seed of the japonica variety Norin 17 ripened at 20 °C day temperature, high light intensity, and low relative humidity (RH) showed maximum germination. A 30 °C day temperature harmed the seed, but low night temperatures increased germinability. In the indica variety IR8, the optimum conditions were a day temperature of 30 or 35 °C combined with high light intensity and low RH (Sato 1973).

Nutrition. Seed longevity, as measured by percentage of germination 270 d after harvest, was greatest in plants that received NPK at 100 kg/ha each in NC220 and 30 kg/ha each in Latisail, Bhasamanik, and Rupsail (Sikder 1965). The crop response to applied N in terms of seed protein and germination potential increased with foliar spraying of gibberellic acid at 10 ppm (Mukherjee and Prabhakar 1980). Seed protein content is enhanced by N application. Similarly, Ca application enhances seed weight (Suseelan et al 1978). However, Maharudrappa et al (1975) found that fertilizers had no effect on the sowing qualities of resulting seed. Costa et al (1983) reported that crude protein content and seed vigor were not affected by the quantity or the type of splitting of N application.

Soil moisture. Soil moisture stress in the late vegetative and reproductive phases results in a decrease in 100-seed weight (De Datta et al 1973, Matsushima 1962). Sharma and Rajat (1979) reported that continuous submergence to 4 cm depth or alternate wetting and drying had no effect on the crude protein content of the seed.

Pest management. Effective management of the seed crop results in highly vigorous seeds. Chemicals, especially systemic ones used to control pests, should be tested for any side effect on seed quality. Street and Richard (1983) showed that the herbicide acifluorfen at 0.1 or 0.3 kg a.i./ha applied to Labelle at the booting, late booting, heading, panicle filling, or dough stages did not affect seed germination or weight. Similarly, 3.6 kg molinate/ha applied 1 d before sowing, 3.6 kg butachlor 1 d after sowing, or 1.6 kg propanil + 3.2 kg thiobencarb 15 d after sowing did not influence seed quality in Blue Belle (Amaral et al 1983).

Stage of harvesting. Harvesting the seed crop at the appropriate stage is important to achieve high seed vigor (Austin 1972). The optimum time for harvesting has been considered to be 30-42 d after heading in the wet season (WS) and 28-34 d after heading in the dry season (DS) (Seetanun and De Datta 1973).

Seed moisture content is an indicator of maturation. Germination percentage and speed of seedling emergence through 10 cm of water was more in seed harvested at less than 20% moisture (Oelke et al 1969). The results of Rajanna and Andrews (1970) indicate that seed dry weight and seedling dry weight provide two consistent and reliable measurements for evaluating rice seed maturation. Irrespective of planting date, seed of Blue Bonnet 50 exhibited maximum germination and dry weight within 25-30 d after anthesis.

Preharvest spraying of desiccants is a technique employed to enhance seed maturation. Eastin (1980) studied the suitability of diquat, glyphosate, paraquat, and $NaClO_3$ and found that none reduced seed germination or seed weight. Foliar spray of 10-20% NaCl at 23-25 d after flowering accelerated seed maturity by 3-5 d and decreased seed moisture by 3.6-4.0% without affecting seed germination (Oommen et al 1979; Ramaiah et al 1974, 1979; Sethuraman et al 1981).

Position of seed

Food reserve accumulation and seed weight may vary with the position of the seed on the panicle and on different tillers. However, seed obtained from the main tiller, primary tiller, secondary tiller, and the whole rice plant gave similar grain yields (Maharudrappa et al 1975, Reddy et al 1976).

Specific gravity and weight

Because the association between vigor and specific gravity is positive (Kobayashi et al 1965, Sasaki 1966), Nagato and Tanada (1957) concluded that the specific gravity of rice seed could be a satisfactory indicator of its quality. Tseng and Lin (1962) suggested that the definition of "pure seed" should exclude physiologically poor, "light" seed. Seed of Bella Patna with higher specific gravity is superior to that with lower specific gravity in germination and subsequent seedling growth rate (Sung and Delouche 1962). Plants from the lightest seed reached the 50% panicle exsertion and anthesis stages about 8-10 d later than those from heavy seed. Grain yield per plot as a percentage of the yield of the control (unsorted) was 68, 87, 104, and 116%, respectively, for 1-1.05, 1.05-1.13, 1.13-1.20, and >1.20 specific gravity classes (Kamil 1975). However, Amaral and Dos (1979) observed that — although seed of higher weight and size had better physiological quality as shown by longevity, germination capacity, and vigor — there was no significant difference in grain yield among the different classes.

Mechanical integrity

Rice seed of low moisture develops fissures when exposed to high RH as occurs in the field (Kunze and Prasad 1978). Fissuring may also occur during drying (Kunze 1979). Dorfman and Rosa (1980) considered 40 °C as the optimum temperature for drying rice seed.

Aging

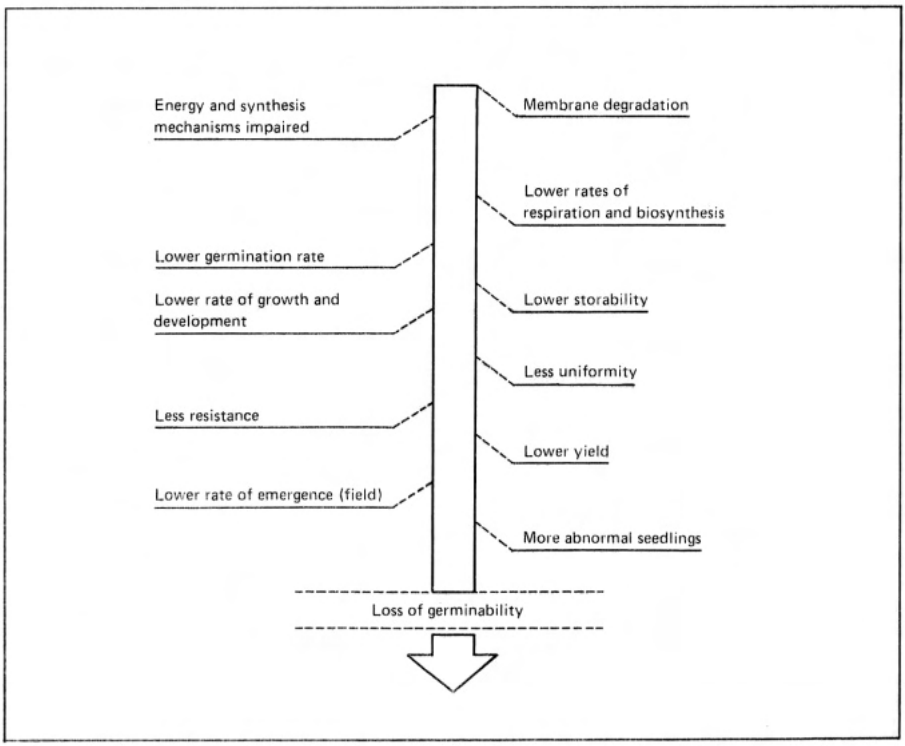
During aging, declines in seed vigor, respiration rate, phosphatase activity, and sugar content accompanied by a complete decline of alpha amylase activity are noticeable. The concentration and the number of amino acids, and the RNA and

DNA contents also show a similar reduction with higher RNAse activity. The protein content declines with high protease activity (Ghosh and Chaudhuri 1984, Mitra et al 1974). Fat acidity increases to 150-220% (Agarwal 1977). Glutamic acid decarboxylase activity decreases (Islam et al 1973). Glucose utilization is poor in aged seed (Banerjee and Ghosh 1978). Delouche and Baskin (1973) provided the probable sequence of changes in seed during deterioration (Fig. 3). Subsequent storability is enhanced by soaking seed that had been stored for 4-6 mo after harvest in water for 6 h and drying it back to the original moisture content (Basu et al 1974).

Factors influencing seed deterioration during storage include seed moisture content, temperature, relative humidity, gases in the environment, the container used for storage, insects, and pathogens.

Pathogens

Germinability and vigor are reduced in discolored seed (Nanda and Chaudhary 1972). Roy (1983) listed 19 fungi associated with discoloration. *Curvularia lunata* (*Cochliobolus 1unatus*) was the most common (37%), followed by *Fusarium* spp. (13%) and *Chaetomium* (6%). Seed germination was delayed after inoculation with conidial suspensions of a virulent isolate of *Rhynchosporium oryzae*, but at 72 h germination was similar to that of noninoculated seed. However, root and shoot



3. Probable sequence of changes in seed during deterioration (Delouche and Baskin 1973).

lengths were markedly reduced in seedlings from inoculated seed (Singh and Gupta 1983). Imolehin (1983) obtained a high negative correlation between seed infestation by *Helminthosporium oryzae* (*Cochliobolus miyabeanus*), *F. moniliforme* (*Gibberella fujikuroi*), *Penicillium* sp., *Curvularia lunata* (*Cochliobolus lunatus*), *Aspergillus* sp., *Rhizopus arrhizus, Geotrichum* sp., and *Alternaria* sp. and seed germination in the laboratory. Seed from plants affected by sheath rot (*Sarocladium oryzae*) exhibited reduced weight and germination (Vidyasekaran et al 1984).

Seed treatment

A recent review by Krishnasamy and Seshu (1987) provides substantial information on rice seed treatment. Hot-water treatment is effective against external and internal seedborne pathogens (Rath et al 1978). However, this treatment may prove deleterious if the temperature and duration are not closely monitored (Ventura and Garrity 1987) (Table 1).

Soaking in solutions containing certain plant nutrients or growth regulators invigorates heed. Increased yields were obtained by soaking in a 10-20% solution of $(NH_4)_2SO_4$, NH_4NO_3, KH_2PO_4, or KNO_3 and in 0.5 and 1% Na_2MoO_4 (Borthakur et al 1973, Mehrotra et al 1967, Singh and Chatterjee 1980). Soaking in 50-100 ppm gibberellic acid increased plant stand establishment under upland conditions at increased sowing depth (Ueyama 1971), reduced soil moisture (Ueyama 1976), and rough soil tilth (Ueyama 1977). Sinha (1969) and Sinha and Ram (1970) reported increased plant dry matter resulting from seed treatment with naphthalene acetic acid or indole acetic acid (IAA) at 75 ppm. Paul and Mishra (1976), however, found no significant effect on seedling growth due to IAA.

Rice seed sown directly in flooded soil often receives inadequate O_2 for germination. Under submerged conditions, coating seed with 40% CaO_2 (by weight) increases germination (Kundu and Biswas 1984), plant density (Brandon et al 1982), and yield (Sen and Gulati 1983).

Geneticvariability

If seed vigor is incorporated into high-yielding varieties, the seed problems of tropical rice-growing farmers will be greatly minimized. Recent studies at IRRI constitute an initial step toward this objective. Varieties were screened for storability through an accelerated aging test and through germination rate.

Accelerated aging. Sixty-four varieties during 1985 DS and 121 varieties during 1985 WS were raised, and the harvested seed was subjected to accelerated aging (43 °C, 100% RH) for 2, 4, and 6 d. The cultivars most tolerant of 6 d of aging in DS and WS are indicated in Table 2 (Siddique 1986). Promising entries included cultivars belonging to all the three subspecies (i.e., Djaub-japonica, Boak-javanica, and several indicas) — some photoperiod sensitive (e.g., ARC11554) and some insensitive (e.g., N22). Also, the best entries included both upland (e.g., OS4, N22) and lowland cultivars. Promising entries from the WS tests included two traditional salt-tolerant cultivars, Pokkali and Nona Bokra. Two of the cultivars, ARC11554 and Utri Rajapan, that performed well in both seasons are resistant to rice tungro virus.

Table 1. Hot-water treatment combinations observed to be safe for application to rice seed (Ventura and Garrity 1987).

Parameters	Hot-water treatments[a]			
	52 °C		57 °C	
	15 min	30 min	15 min	30 min
I. Test conducted immediately after hot-water treatment				
A. Seed presoaked for 3 h				
1. Standard germination test	+	+	+	−
2. Accelerated aging test	+	+	+	−
3. Field seedling emergence	+	+	+	−
4. Field seedling emergence rate	+	+	−	−
5. Field seedling vigor and morphological characters	++	+	+	−
B. Seed not presoaked				
1. Standard germination test	+	+	+	−
2. Accelerated aging test	+	+	+	−
3. Field seedling emergence	+	+	+	−
4. Field seedling emergence rate	+	+	+	−
5. Field seedling vigor and morphological characters	++	+	+	−
II. Test conducted after hot-water treatment and 45 d storage				
A. Seed presoaked for 3 h before hot-water treatment				
1. Standard germination test	+	−	−	−
2. Accelerated aging test	+	+	−	−
3. Field seedling emergence	+	+	−	−
4. Field seedling emergence rate	+	+	−	−
5. Field seedling vigor and morphological characters	++	+	+	−
B. Seed not presoaked				
1. Standard germination test	+	+	+	−
2. Accelerated aging test	+	+	−	−
3. Field seedling emergence	+	+	+	−
4. Field seedling emergence rate	+	+	+	−
5. Field seedling vigor and morphological characters	++	+	+	−

[a] + = statistically significant score reductions not observed (i.e., safe treatment), ++ = scores significantly improved by hot-water treatment, − = scores significantly reduced by hot-water treatment (unsafe).

Cultivars with different degrees of dormancy as determined by germination percentage in the control treatment were compared for their tolerance for aging as indicated by their germination percentage after aging for 6 d (Table 3). A highly significant negative correlation was observed between germination in the control and that in the 6-d aging treatments, indicating that the level of tolerance for accelerated aging is higher when the seeds have a higher degree of dormancy.

Germination rate. A faster germination rate will facilitate early seedling establishment, a clear advantage under direct-sown rice culture. Takahashi (1956,

Table 2. Some varieties identified to have seed tolerant of accelerated aging (43 °C, 100% RH, 6 d) (Siddique 1986).

Variety	Germination (%)	
	Dry season (64 entries)	Wet season (121 entries)
Dharial	10	53
ARC6000	3	55
Habiganj Boro IV	13	41
Taal 2	2	45
ARC11554	6	25
Suweon 287	6	22
Grand mean over all entries	0.9	12.6

Table 3. Mean germination percentage for different classes of germination in the control after accelerated aging (Siddique 1986).[a]

Germination class of control	Frequency of cultivars	Mean germination (%) after aging		
		Control	2d	6d
0-20	38	8.37	89.03	16.13
21-30	27	29.70	89.26	15.37
41-60	22	50.36	89.82	11.64
61-80	19	71.00	89.53	7.63
81-100	15	90.13	91.60	3.80

[a] r value between control germination % and germination % after 6 d aging = -0.98**.

1960) observed varietal differences in rice for germination rate. We evaluated the seeds of 68 varieties harvested from both the field (1985 DS) and the phytotron.

While critically analyzing Maguire's germination rate index, Brown and Mayer (1986) suggested total germination at two separate times (e.g., at the end of the experiment and at some other relevant time such as the 3-d count) to be more informative. To compare varieties, however, it is necessary to have a single index. We propose the following formula to estimate the rate of germination (RG) index in rice varieties.

$$\text{RG index} = \frac{\text{No. of seeds germinated after 48 h (1st count)}}{\text{No. of seeds germinated after 168 h (final count)}} \times 100$$

Seeds were heat-treated at 50 °C for 4 d to eliminate any residual dormancy factor that might interfere with the rate of germination (Urs and Goud 1969), placed over Whatman No. 1 filter paper inside a 9 cm petri dish, wetted with 2.5 ml distilled water, and germinated at 25 °C and >97% RH inside a germinator. Seeds showing radicle growth of 2 mm or more were considered germinated.

The RG index calculated from the proposed formula was compared with the time to 50% germination and the peak value (Czabator 1962), which deal exclusively with the rate distinct from the totality of germination (Woodstock 1973) (Table 4). The rank order of the varieties was similar between the proposed RG index and the time to 50% germination. Peak value, however, showed a discrepancy. The coefficient of variability among the varieties was maximum when the RG index was employed. A further advantage was that the computation of RG index is less cumbersome and requires only two countings.

Eight varieties showed consistently superior performance (Table 5). The association of plant, seed, and seedling characters with germination rate is indicated in Table 6. The protein content of seeds was not associated with germination rate when compared across genotypes, whereas the P and K content of seeds and a-amylase and dehydrogenase activity showed positive correlation. Varieties with high seed vigor showed a high mobility band in the pattern of a-amylase isozyme, which is lacking in those with low seed vigor (Fig. 4). Germination rate and rate of emergence in the soil were positively correlated.

IMPACT OF SEED VIGOR ON CROP PERFORMANCE

An automatic seed analyzer (model ASA610) was used to classify seed of 5 varieties into highly vigorous (5-20 micro amp), moderately vigorous (21-35 micro amp), and marginally vigorous (36-50 micro amp), based on the electrical current passage values of the seed leachates. Seed of each vigor level was raised in the greenhouse and in the field. Observations on yield and its components (Table 7) indicated that high-vigor seed registered a 33.8% increased yield over low-vigor seed in the greenhouse and a 14.1% increased yield in the field (Siddique 1986).

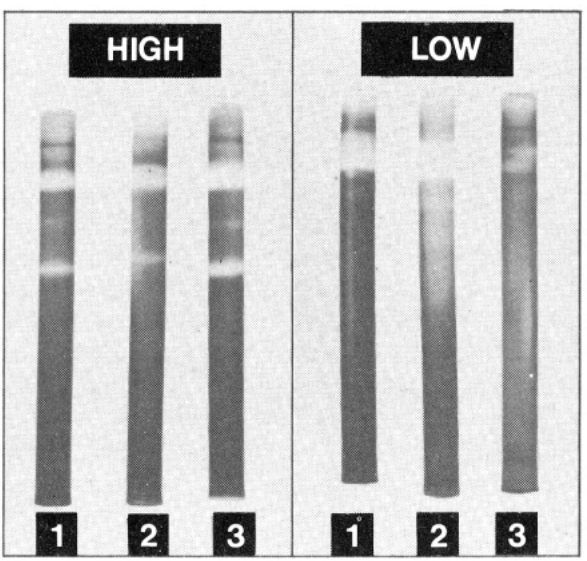
Table 4. Comparison of RG index with time to 50% germination and peak value for 11 rice varieties.

Variety		RG index[a]	Time to 50% germination (h)[b]	Peak value[c]
ADT30	(V1)	52.6	48	1.580
Taichung sen 16	(V2)	17.6	58	0.903
IR50	(V3)	85.0	42	1.770
UPLRi-4	(V4)	40.0	50	1.500
IR25890-82-5-3	(V5)	65.0	45	1.670
IR13429-299-2-1-3	(V6)	16.7	64	1.250
IR25670-15-2-3	(V7)	10.0	66	1.042
Chau-Fon-Thou	(V8)	30.0	51	1.583
Chechon-Chun-Shun	(V9)	5.6	66	1.042
Giza 159	(V10)	0.0	67	0.990
IR21820-154-3-2-2-3	(V11)	20.0	55	1.390
CV		86.0	16.4	22.88

[a]Ranking of varieties (superior to inferior) by KG index: V3 > V5 > V1 > V4 > V8 > V11 > V2 > V6 > V7 > V9 > V10. [b]Rank by time to 50% germination: V3 > V5 > V1 > V4 > V8 > V11 > V2 > V6 > V7 > V9 > V10. [c]Rank by peak value: V3 > V5 > V8 > V1 > V4 > V11 > V6 > V9 > V7 > V10 > V2.

Table 5. Varieties with superior (values exceeding the mean by more than 1 standard deviation) and inferior (values less than the mean by more than 1 standard deviation) performance in germination rate.

Variety	Germination rate (index)	
	Field	Phytotron
Superior		
Laxmi	90.0	76.7
B3981C-PN-165-2-1	93.0	83.3
TNAU (AD) 103	89.7	91.7
IR25924-92-1-3	90.0	80.0
IR50	88.3	85.0
PND160-2-1	98.3	93.3
RNR1429	98.7	95.0
IR31779-19-3-3-2-2	95.0	96.7
Inferior		
Chechon-Chun-Shun	3.5	6.7
Giza 159	10.5	1.7
IRAT140	30.0	5.0
X-3 DJ	24.0	25.0
IR21820-154-3-2-2-3	35.0	20.0
IR21848-65-3-2-2	33.7	13.3
Taichung sen 16	30.5	18.3
IR13429-299-2-1-3	25.0	16.7
IR29692-131-3-3-3	26.5	16.7
Milyang 49	32.4	16.7
IR25670-15-2-3	28.3	10.0
Mean over 68 varieties	62.5	49.9
Range	3.5-98.7	1.7-96.7
SD	25.3	24.3



4. Isozyme pattern of α-amylase in rice varieties with high and low seed vigor. High: 1 = TNAU(AD)103, 2 = IR50, 3 = PND160-2-1. Low: 1 = Giza 159, 2 = IR25670-15-2-3, 3 = IRAT140.

Table 6. Association of rate of germination with plant, seed, and seedling characters in rice varieties.

Character	Range	Mean	SD	with rate of germination[a]
Days to 50% flowering (n=68)	63.3-113.0	90.8	10.3	–0.069ns
Plant height (cm) (n=68)	70.4-126.0	86.8	12.8	–0.098ns
Tillers (no.) (n=68)	8.2- 24.1	15.5	3.7	0.321**
Panicle length (mm) (n=68)	158.6-251.8	211.2	16.1	0.105ns
Seeds/panicle (n=68)	66.2-216.2	112.1	23.7	0.197ns
Sterility (7%) (n=68)	5.0- 29.9	12.0	4.8	0.221ns
Yield/plant (g) (n=68)	16.6- 48.2	32.7	5.8	0.263*
100-seed weight (g) (n=68)	1.942-3.210	2.539	0.279	–0.335**
Seed length (mm) (n=68)	7.4- 10.9	9.17	0.795	–0.080ns
Seed breadth (mm) (n=68)	2.20- 3.50	2.75	0.297	–0.081ns
Seed thickness (mm) (n=68)	1.80- 2.30	2.04	0.092	–0.139ns
Hull thickness (mm) (n=68)	0.07- 0.18	0.114	0.025	0.154ns
Shoot length (mm) (n=68)	79.1-163.1	109.8	17.6	–0.297*
Root length (mm) (n=68)	173.4-283.0	239.2	22.5	0.115ns
Dry weight of 10 seedlings (mg) (n=68)	83-140	109.5	12.7	–0.197ns
Protein (%) (n=32)	1.8- 13.2	10.9	1.292	0.277ns
P (%) (n=32)	0.202-0.414	0.31 3	0.035	0.400*
K (%) (n=32)	0.170-0.335	0.275	0.032	0.438*
a-amylase activity (mg starch digested/h per g fresh weight) (n=32)	6.417-13.187	9.619	1.887	0.627**
Dehydrogenase activity (O. D.) (n=32)	0.04-0.18	0.087	0.039	0.396*
Field emergence rate (%) (n=32)	0-100	57.7	33.9	0.641**

[a] * = significant at P = 0.05, ** = significant at P = 0.01, ns = not significant.

Table 7. Summary of grain yield and ancillary characteristics under 3 levels of vigor averaged over 5 cultivars (Siddique 1986).

Trait	Vigor level [a]				SE	CV (%)	LSD (5%)[b]
	High	Moderate	Low	Mean			
			Greenhouse				
Flowering duration (d)	97.00 b	96.80 b	99.93 a	97.91	0.121	0.83	0.61
Plant height (cm)	125.20 a	120.40 ab	115.73 b	120.44	1.463	8.15	7.40
Panicles/plant	6.87	6.20	6.27	6.44	0.189	19.70	ns
Panicle length (cm)	21.99 a	21.63 a	20.36 b	21.33	0.197	6.18	0.99
Filled grains/panicle	99.93 a	89.20 b	87.00 b	92.04	2.03	14.80	10.27
Sterility (%)	12.81 b	14.93 b	18.05 a	15.26	0.427	18.75	2.16
1,000-grain weight (g)	22.62 a	21.77 b	21.53 b	21.92	0.118	3.60	0.60
Yield per plant (g)	14.57 a	12.05 b	10.89 c	12.51	0.166	8.88	0.84
			Field				
Flowering duration (d)	99.80 b	99.53 b	104.40 a	101.24	0.198	1.31	0.998
Plant height (cm)	118.35	118.46	114.53	117.11	0.940	5.36	ns
Panicles/plant	12.40 a	10.67 b	10.80 b	11.29	0.262	15.57	1.32
Panicle length (cm)	23.90	23.73	23.16	23.60	0.148	4.21	ns
Filled grains/panicle	94.40 a	86.07 b	81.87 b	87.44	1.391	10.67	7.03
Sterility (%)	20.83 b	24.81 a	24.29 a	23.31	0.454	13.07	2.30
1,000-grain weight (g)	23.03	23.41	22.78	23.07	0.147	4.26	ns
Yield per plant (g)	21.92 a	20.19 b	18.82 c	20.31	0.244	8.05	1.23

[a] Means in a row followed by the same letter are not significantly different at the 5% level by DMRT. [b] ns = not significant.

RESEARCH NEEDS

The following research objectives will result in greater insight into rice seed vigor and thus help to maintain vigor at a higher level in improved varieties.

- Study the inheritance of seed vigor.
- Improve seed production techniques in relation to mother crop management, harvesting, processing, seed treatment, and storage to maximize the seed vigor of a given variety.
- Identify the biochemical factors associated with vigor.
- Associate the vigor level of seed with crop performance in interaction with varieties, season, soil fertility, and rice culture.
- Identify a suitable vigor test.
- Develop effective seed invigoration techniques.

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Seed quality control

P. COOLBEAR and M.J. HILL

Many seed development programs are short of high-quality seed of suitable varieties. Efficient and impartial seed quality control is an essential prerequisite, not only for alleviating such shortages, but also for attracting and retaining the confidence of local farmers. This paper reviews some of the current issues in the area of seed regulation, with particular reference to technological developments in postharvest cultivar verification, detection of mechanical damage, and the assessment of seed vigor. Advances in the detection of polymorphism at the biochemical level are a particularly exciting potential solution to the current problems of varietal testing. Unfortunately, the difficulties in developing such techniques from useful research tools to standard seed testing procedures may be greater than generally appreciated. Although development and standardization of new methods in certain areas are undoubtedly necessary, in many developing agricultural economies there is much scope for improved application of existing techniques. Instigation and maintenance of efficient seed rregulation programs depend on adequate legislative and financial support. Within this framework, the need for sufficient trained personnel and efficient extension programs oriented to the requirements of local farmers and growers is of paramount importance.

Seed quality control concerns quantifying the extent of seed care prior to sowing. At their simplest level, quality control systems should be able to screen against poor or misrepresented seed lots. At their most sophisticated, quality control techniques should — in theory at least — provide a means of predicting seed performance in the field or of diagnosis when things go wrong in the seed production or distribution network.

This paper presents a broad overview of the current status of quality control for seed. We do not discuss in any detail the methodology of well-established procedures such as field inspection or seed germination testing, for which practical manuals are readily available (International Seed Testing Association 1985, Mehta et al 1972). Rather, we wish to highlight areas where we feel major advances in technology have been, or need to be, made. Also, we wish to address the questions of why such

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apparent sophistication in the technology of quality control is often not matched in practice, and why supposedly "improved" seed is often of such disappointingly low quality when it reaches the farmer (Hill 1981, Schoorel 1977).

DIMENSIONS OF SEED QUALITY CONTROL

High seed quality relies on

- good production practice, especially careful maintenance of its genetic purity, and the maximization of genetic potential during the growth and development of the seed crop;
- appropriate harvesting and processing technology, including careful timing of harvest, and correct methods of harvesting, threshing, cleaning, and, if necessary, drying; and
- good storage and distribution systems.

Ideally, therefore, good seed quality control should aim to monitor the seed effectively at all these stages. There is an often repeated argument that seed testing technology is lagging several years behind breeding and (perhaps) production technology. In the course of this review, we wish to tackle this issue and ask whether the technology for seed quality control limits its effective implementation.

The answer is not straightforward, because there are many dimensions to this rather vague concept of seed quality (Thomson 1979). Essentially, though, its components fall into three categories:

- accurate description,
- hygiene, and
- viability and potential performance.

The aspects of each category are summarized in Table 1, each of these presenting its own special set of problems for anyone attempting to quantify the quality of a particular batch of seed.

Procedures for assessing many of the parameters (either directly or indirectly) after the seed is harvested are detailed in the *International rules for seed testing* of the International Seed Testing Association (ISTA) (1985). The standard laboratory methods prescribed in these rules are technically relatively simple but require a good

Table 1. The components of seed quality.

Description	Species identification Cultivar purity Percentage of foreign or inert material in sample Average seed weight
Hygiene	Contamination of sample with noxious weed seeds Microfloral contamination (from both field and storage fungi) Bacterial and viral infection Infestation by insects and mites
Viability and potential performance	Capacity of propagules to produce normal seedlings Expected field emergence and uniformity Seedling vigor Potential storability

deal of experience to be carried out effectively. One of the greatest lessons of this experience is the need for careful and continuous attention to detail, especially with the all-important sampling protocols.

Other procedures such as those for cultivar verification and seed vigor testing are much grayer areas. There is a technology gap here, and, although extensive research is being done, not much thought has been given to the routine application of these new techniques in seed testing laboratories. It is these areas (with the exception of seed hygiene) that we wish to consider in the next section.

AREAS OF TECHNOLOGICAL DEVELOPMENT IN SEED QUALITY CONTROL

Cultivar verification techniques

With the intensive efforts being made in local varietal selection and specialized breeding programs for economically important crops throughout the world, there has been a massive increase in new and often closely related varieties. Accordingly, increasing attention must be paid to the verification of cultivars at the postharvest regulatory level (Ditmer 1978). This is proving to be one of the most difficult areas of seed quality control, particularly because of the lack of standardization of even simple methods (Andersson 1986, Kelly 1975). These difficulties reflect the inadequacy of present techniques for processing large numbers of samples rapidly and accurately. The range of possible techniques is outlined in Table 2. This is not intended as a comprehensive list, but is presented as an indication of the methods available. No one method is likely to be sufficient for reliable differentiation among cultivars, and the multiple testing approach (e.g., Ednie et a1 1978) is clearly best. Inevitably, problems arise in the choice and ordering of test combinations, deciding what confirmatory tests are needed, and interpreting results. As Andersson (1975) points out, the related biometrical problems of varietal verification are particularly difficult.

Presently, many of the more complicated tests are done diagnostically when complaints arise, rather than as routine presowing screening procedures (Ednie et a1 1978). However, as the number of specialized varieties for different economic species continues to increase, the capacity for presowing regulation becomes ever more important, not only to prevent errors or malpractice during distribution and marketing, but because, in many circumstances, this is potentially a more cost-effective means of monitoring seed multiplication than field inspection (e.g., Chuan and Yen 1986).

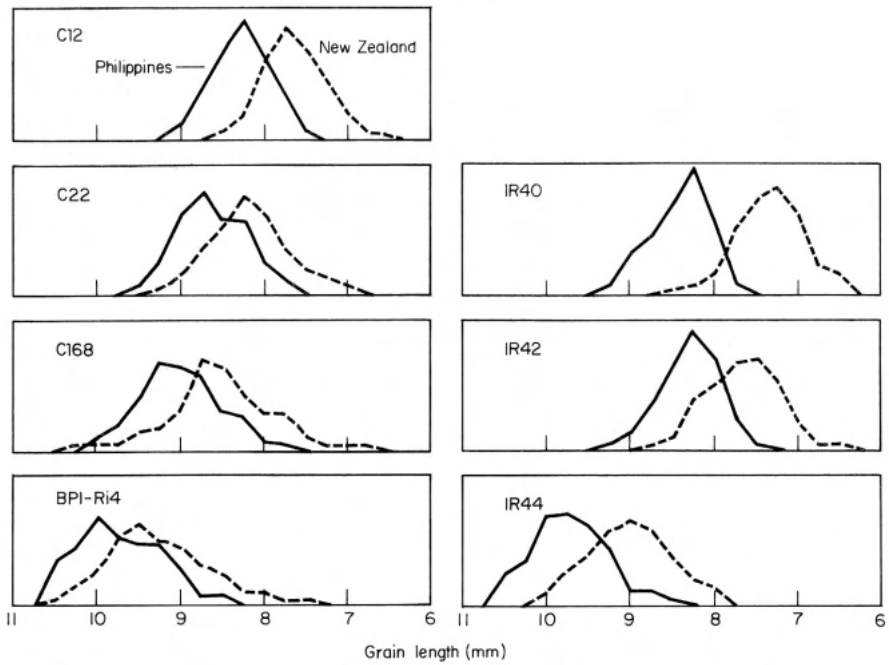
Recent postgraduate research work at the Seed Technology Centre by Quero (1980) highlighted some of the problems of applying even the simplest verification techniques. He investigated the possibility of differentiating rice grains on the basis of grain length, one of the techniques advocated by Rosta (1975). Figure 1 shows the frequency distributions of grain length measured on samples of several rice varieties in the Philippines and on a subsequent generation of each cultivar produced in New Zealand. Seeds produced at the Seed Technology Centre were in all cases significantly smaller than those of the same variety produced in the Philippines, but the relative changes were not always the same. For example, the grain length of IR40 was more severely affected by a change in production environment than that of any

of the others. Similarly, another easily measured statistic, 1,000-grain weight, revealed several changes in varietal ranking with change in the location of production (Table 3). Clearly, great care must be taken to compensate for genetic and phenotypic heterogeneity when selecting material as references for putative varieties. Sample size is also an important consideration. These problems have not always been fully considered in research on varietal testing methods.

Table 2. Examples of the range of methods available for postharvest cultivar verification. [a]

Morphological	
Shape or size (geometry or weight)	of whole or parts of seeds (13, 19)
Seed coat characteristics	e.g., scanning electron microscopy of some *Brassica* spp. (14)
Seedling morphology	e.g., lettuce to third leaf stage (2), tiller angle in rice (18), hypocotyl length in soybean (16)
Pubescence of seedlings	e.g., presence/absence in clover (20), color and angle in soybean (16)
Pigmentation	e.g., rice grains (19); soybean hilum (16); aleurone color in barley (7), rice (18), or soybean seedlings (16)
Physiological	
Germination vigor	e.g., median germination time in rice (19)
Swelling capacity	e.g., of rice grains in water at 80 °C (19)
Response to phytohormones	e.g., growth rate of wheat cultivars in response to gibberellic acid (8)
Sensitivity to herbicides	e.g., metribuzin effects on soybean (16)
Phenol test	e.g., for wheat (8, 21) or rice (12) grains
Fluorescence	e.g., Kentucky bluegrass seeds (9)
Seed coat peroxidase activity	e.g., soybean (16)
Pathological	
Resistance to fungal infection	e.g., anthracnose for clover (20) or bean (15) seedlings
Resistance to bacterial, viral, or insect infection	e.g., rice screening programs (18)
Resistance to parasites	e.g., nematodes in clover (15)
Chemical composition	
Electrophoresis of	
general seed storage proteins	e.g., for ryegrass mixtures (10), wheat (4,6), barley (4, 6), and wild oats (5)
isoenzymes in seeds	e.g., for esterases in F_1 rice hybrids (3)
leaf isoenzymes	e.g., for esterases in ryegrass (17), various isoenzymes in pea (11)
Gas-liquid chromatography	e.g., for fatty acids in rapeseed (8)
Thin layer chromatography	e.g., for phenolics on soybean (8)
DNA restriction fragment hybridization techniques	e.g., for barley hordein genes (1)

[a]Examples from: 1. Bunce et al (1986); 2. Burgoon (1984); 3. Chuan and Yen (1986); 4, 5. Cooke and Draper (1986a,b); 6. Draper (1986); 7. Dhesi et al (1975); 8. Ednie et al (1978); 9. Elekes (1975); 10. Ferguson and Grabe (1984); 11. Greneche and Blanchard (1986); 12. Jensen and Legaspi (1979); 13. Kelly (1975); 14. Mulligan (1977); 15. Olsson (1974); 16. Payne (1978); 17. Payne and Koszykowski (1984); 18. Quero (1980); 19. Rosta (1975); 20. Schoen and Payne (1984); 21. Steen et al (1986).



1. Frequency distributions of individual grain lengths of rice varieties grown in the Philippines and New Zealand. Details about cultivars used are given in Table 3. Redrawn from Quero (1980).

Table 3. Changes in 1,000-grain seed weight (g) of rice cultivars[a] grown in the Philippines and New Zealand. Values are means of 8 replications. Source: Quero 1980.

Variety	Seed production location[b]	
	Philippines	New Zealand
C12	17.892 a	16.535 a
IR42	19.059 b	17.245 b
IR36	19.798 c	17.684 c
IR40	20.160 c	18.511 d
C168	21.831 d	20.609 f
C4-63G	23.084 e	21.564 g
C22	23.193 ef	20.082 e
C4-137G	23.699 fg	20.829 f
BPI-Ri4	23.960 g	24.195 i
IR44	25.687 h	23.620 h

[a]Rice varieties used in this study were supplied by the Bureau of Plant Industry of the Philippines. The IR varieties, developed by IRRI, have a common parent (C494-13), while the C varieties were bred at the University of the Philippines at Los Baños and have a common parent, BPI-76. BPI-Ri4 was developed at the Maligaya Rice Research and Training Center. All are lowland varieties except C22. C4-63G and C4-137G are sister lines, as are IR36 and IR42. [b]Means within a column followed by the same letter are not significantly different at the 1% level by Duncan's New Multiple Range Test. LSD (P = 0.01) for comparing means within rows = 0.924.

If these problems can be resolved, however, there is considerable scope for automated image analysis techniques, if only in removing much of the routine separation effort from the seed analyst's work. Westerlind (1986) outlined the use of computer-based scanning systems for seed testing laboratories in Sweden. The use of such instruments for preliminary sorting of large samples is highly promising.

Undoubtedly the most exciting prospect in cultivar verification technology is the use of "fingerprinting" techniques based on either protein electrophoresis or DNA restriction fragment hybridization. The ISTA Variety Committee working group on biochemical tests for cultivar identification has developed a reference method for analyzing wheat and barley storage proteins by polyacrylamide gel electrophoresis (Draper 1986), recently proven in a series of interlaboratory tests (Cooke and Draper 1986a). The banding patterns of the seed storage proteins separated on the basis of their molecular weights are characteristic of the cultivar and independent of environmental effects during seed production. This is a first step in formulating electrophoretic identification procedures for a wide variety of species.

For a properly equipped seed physiology laboratory, the methods are relatively quick and simple, but not necessarily as sensitive as might at first appear. Banding patterns are often complex, in many cases necessitating densitometric interpretation. Several authors have found that variations occur within seeds in a single varietal line (Ferguson and Grabe 1984, Payne and Koszykowski 1984, both working on ryegrass). In assessing bulk samples of perennial ryegrass, Ferguson and Grabe detected annual ryegrass contamination at levels of only 10% or higher. Electrophoretic analysis should be carried out on large numbers of replications of single seeds (Draper 1986 recommends 100 or more) to assess variation within an identified pure varietal line used for reference purposes. Careful assessments of varietal purity in test samples may require much higher replication levels.

One approach to simplifying the interpretation of electropherograms is to develop the gels of proteins extracted from seeds of seedlings with substrates giving color reactions to only one group of enzymes. Identification based on esterase isoenzyme differences seems to be the most promising approach (Payne and Koszykowski 1984 for ryegrass, Chuan and Yen 1986 for rice). Other enzyme groups may show either no variation among cultivars (e.g., glutamate dehydrogenase) or variation within cultivars or stages of seedling development (e.g., peroxidases) (Payne and Koszykowski 1986). Greneche and Blanchard (1986) suggest that initial varietal verification of peas can be achieved by electrophoretic analysis of the combined polymorphism of 8 groups of enzymes extracted from 7-d-old seedlings; of 60 varieties tested, 27 were capable of unequivocal identification, and a further 24 were each identified as 1 of 2 alternatives. They also claim that less than 4% impurities can be detected with greater than 95% confidence. Whether the capacity to carry out their techniques is available in more than a few seed testing laboratories is open to question. There is no doubt, however, that electrophoretic techniques have great potential for application to specific problems such as the detection of noxious weeds, e.g., screening for various species of wild oats (Cooke and Draper 1986b) or identification of varieties prone to physiological disorders, such as cotyledonal cracking in beans (Hashim and Campbell 1984).

A more fundamental approach to the problem of varietal purity is to look at the DNA of the plants themselves. This is a feasible proposition, because when DNA is extracted from plants and digested into specific fragments by restriction endonucleases, considerable differences exist among the fragments produced, depending on the exact base sequence of DNA in the genome of each plant. These restriction fragments can be separated by electrophoresis and then specifically detected by hybridization to radioactive mRNA or cDSA. Recently Bunce et al (1986) demonstrated the potential of this methodology for cultivar identification of barley using ^{32}P-labeled cDNAs coding for hordein proteins to hybridize with restriction fragments obtained from DNA extracts from different cultivars. They suggest this may be an even more powerful analytical tool than two-dimensional electrophoresis of hordein proteins. At present, however, it remains an extremely sophisticated and time-consuming technique.

Detecting processing damage

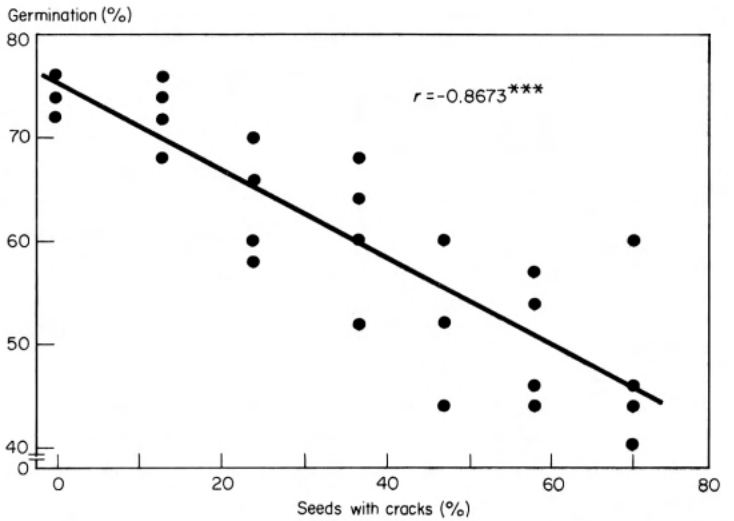
Often too little attention is paid to the harvesting and processing techniques used on seed to be retained for sowing. This is, of course, one of the crucial areas affecting seed quality, and many potentially high-vigor seed crops can be seriously impaired at this stage even in highly mechanized production systems.

Escasinas (1986) has demonstrated how seed quality control techniques may be used diagnostically to pinpoint problem areas in mechanical processing of maize seed, which was found to deteriorate rapidly during storage although it had good initial germination. X-ray radiography of seed proved a useful technique in assessing the extent of stress cracking incurred during too rapid seed drying. There was a significant ($p<0.001$) negative correlation between stress cracking detected by X-rays and seed germination after 12 mo of storage (Fig. 2). X-ray determination of cracking proved a far more reliable indicator of damage than visual assessment; it was also found that crack position was critically important for the storage potential of the seed (Table 4).

Predicting seed performance in the field and in storage

The third component of seed quality (Table 1) is seed viability and potential performance. Methods for assessing seed germination are well established and standardized (International Seed Testing Association 1985), but many seeds that pass laboratory tests for germination do not perform well in the field (e.g., Escasinas 1986, Stormonth 1978). Seed testing associations have discussed the problem of assessing seed vigor (and even what seed vigor means) for decades (Association of Official Seed Analysts 1983).

"Seed vigor" has become an umbrella term for a multitude of diverse aspects of seed condition and physiology (Perry 1980), but Ellis and Roberts (1980) have made a strong case for regarding low seed vigor as the result of seed deterioration processes that proceed in a uniform manner through all aspects of seed behavior. Potentially, any seed may be of high vigor within the limitations of its genotype, but loss of that potential may begin to occur at any point of development from fertilization onward. Thus, Ellis and Roberts suggest that there is a continuity between losses of various



2. Relationship between proportion of artificially dried maize seed with X-ray visualized cracking and germination capacity after 12 mo storage at 20 °C, ambient relative humidity, and 12% initial moisture content. Source: Escasinas (1986).

aspects of seed quality and, ultimately, loss of seed viability. On the basis of demonstrated correlations between common measures of seed vigor (such as mean germination rate and conductivity) and viability, they suggest that seed quality in terms of expected field performance can be quantified by a seed lot's survival under a standardized artificial aging test, preferably using controlled deterioration methods such as those described by Matthews (1980).

While Ellis and Roberts (1981) have ably demonstrated that seed survival in storage can be accurately predicted by these techniques, it is debatable whether all aspects of seedling vigor can be measured by a single storage-stress test. In no case in their 1980 paper do Ellis and Roberts test their idea by correlating the results of different vigor tests on different seed samples. All correlations presented are essentially between different measurements of seed vigor loss during storage. Therefore their arguments are somewhat circular.

From the physiologist's point of view, too, it is difficult to envisage how factors within the seed that limit performance under environmental stress or determine rates

Table 4. Position of stress cracks identified by X-ray and germinability of artificially dried maize seed after 12 mo storage at 20 °C, ambient relative humidity, initial moisture content 12% (after Escasinas 1986).

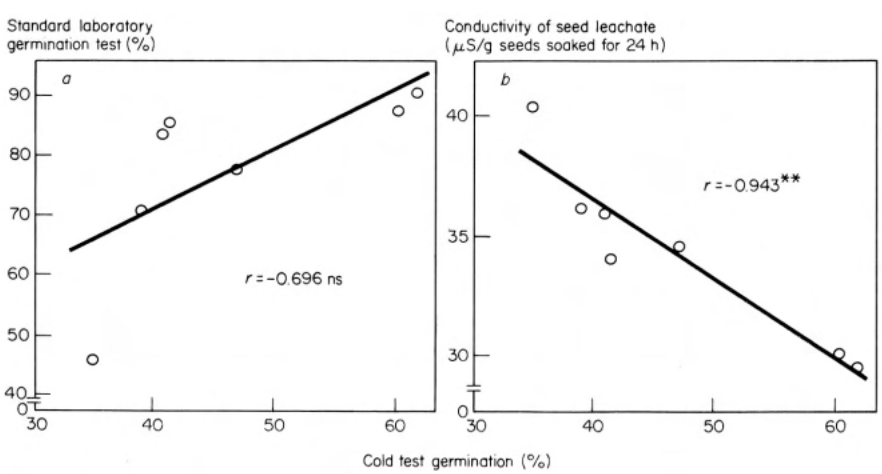
Cracking	Normal seedlings (%)
No cracks	73.3
Cracks confined to endosperm area	69.3
Cracks along the side of the embryo	45.3
Cracks along the embryo itself	42.7
LSD (0.05) =	7.5

of germination at the subcellular level will always deteriorate at the same rate as losses of seed viability during storage. Our work with artificially aged tomato seed, for instance, suggests that germination rate is a much more manipulable parameter of seed behavior than loss of seed viability (Francis and Coolbear 1986). Similarly, in a preliminary study, Aguinaldo (1986) found no significant correlation between the viability of aged soybean seed and its performance under cold stress (Fig. 3a). Interestingly, conductivity measurements of seed leachate are well correlated with the cold stress performance of this seed (Fig. 3b).

Although controlled deterioration testing must thus be used with caution, it does seem to be potentially the most useful method of assessing seed quality. Its big advantage is that it is a relatively simple technique, requiring little special expertise and no major capital equipment above that which should already be available in a seed testing laboratory. Conductivity testing, now standard practice for estimating field emergence in pea (Scott and Close 1976), may have considerable potential for use with the above technique, although potentially confounding factors such as seed weight-surface area ratios should be considered (Mugnisjah and Nakamura 1986).

THE NEED FOR ADEQUATE APPLICATION OF EXISTING TECHNIQUES

So far, we have highlighted some aspects of seed quality control that we feel are among the major areas of technological concern and will continue to require attention before effective regulation can be imposed. Of these, cultivar verification is clearly the most pressing and difficult problem, and solutions on the horizon currently seem to be dependent on sophisticated technology that is likely to be beyond the present scope of most seed testing laboratories.



3. Correlations between a) results of the standard laboratory germination test, and b) conductivity of seed leachate with germination in the ISTA cold test (Fiala 1981) of soybean seed previously subjected to rapid aging treatments (0, 3, 6, or 8 wk at either 30 °C, 80% RH or 20 °C, 60% RH). Source: Aguinaldo (1986).

Nevertheless, many of the basic techniques of seed certification and germination testing are relatively straightforward, with well-established and standardized procedures. Despite this, although many developing agricultural economies have new or specialized cultivars available, the supply of reliable quality improved seed is often a limiting factor (Hill 1984), and an efficient seed quality control scheme is an essential component of the necessary seed multiplication program (e.g., Douglas 1980, Mohd. Lassim and Chin 1980). So, too, is an appropriate extension program designed to motivate and maintain the confidence of farmers (Hill 1977, Maalouf et a1 1975).

In many regions of the developing world, seed quality control schemes have been established but have lost impetus (Hill 1981). Such lack of progress is not necessarily due to lack of available technology, but may often occur through a failure to apply existing procedures properly in the right circumstances or through culpable inefficiency in detecting malpractice. Schoorel (1977) quotes several incidents that resulted in a loss of confidence by the very farmers whom the programs were designed to help.

While continued improvements in the technologies of regulation will unquestionably make the task of quality control easier, failures in this area often stem from the lack of personnel adequately trained in the application of existing techniques or the lack of a fully independent, properly equipped, impartial control agency with adequate legal authority. Although there are sufficient market incentives for countries such as New Zealand to maintain voluntary certification systems, it is presently difficult to see how such voluntary systems can be maintained efficiently in developing agricultural economies. Mohd. Lassim and Chin (1980) emphasize the importance of a Seed Act in the maintenance and development of a seed program. Walker (1980) echoes these sentiments, pointing out that governments must be prepared to underpin such legislation with adequate financial support. This support must be channeled in two directions: first, to provide for adequate training, facilities, salaries, and status to enable employees of regulating bodies to carry out their tasks efficiently and impartially; and second, to develop and maintain the necessary extension package for farmers, including guaranteed prices for quality seed.

Ultimately, the success or failure of a new variety depends on its acceptance by local farmers. Often the criteria on which they make their decisions are unclear, but experience has repeatedly shown that high seed quality is one of the most important factors contributing to the acceptance of improved cultivars over home-saved seed. It would be a tragedy if a great deal of the effort put into plant breeding and its ancillary sciences continued to be wasted because of inadequate seed quality control.

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Seed processing, storage conditions, and seed viability

T. T. CHANG

The availability of viable rice seed of high quality requires a systems approach to harvesting, processing, drying, packaging, storing, and monitoring seed germinability. Seed viability can be efficiently extended by cold and dry storage in airtight containers. Improved measures and alternative choices are presented to help seed workers perform their jobs effectively and at low cost. Basic principles of seed storage are discussed so that appropriate equipment and procedures may be chosen by a broad range of rice workers: conservationists, biological researchers, breeders, and seed technologists.

Rice seed exhibits orthodox (or nonrecalcitrant) storage behavior and is amenable to extended viability periods under cold and dry storage. It is similar to other major cereals. Rice seed is generally stored in the hulled condition, known as grain. (See Chang and Bardenas 1964 for a morphological description of the rice grain.) The silica-rich hull (consisting of lemma, palea, and sterile lemmas) helps the caryopsis (brown rice) by deterring granary insect penetration and gaseous exchange. However, the hull adds to the grain's hygroscopic properties.

About 70% of the world's rice is produced and consumed in the humid areas of the tropics and subtropics. The viability of rice seed stored in open-air conditions in the humid tropics seldom exceeds 2 yr. Therefore, seed storage for extended longevity calls for a combination of processes and conditions that will provide maximum efficiency and economy. This paper discusses the processes and conditions that have demonstrated their efficacy in the operations of the International Rice Germplasm Center (IRGC) at the International Rice Research Institute (IRRI).

REQUISITES FOR MAXIMIZING SEED LONGEVITY

Rice workers need to consider both biological and physical factors in harvesting, selecting, and preparing seed for storage to maximize the longevity of the stored seed at minimal cost. Human factors also affect the security of seed stocks.

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Biological factors

Biological factors refer to seed health and maturity and to intrinsic factors in the seed.

Physiological maturity. The most satisfactory stage of seed development is obtained from seeds harvested as soon as they have reached physiological maturity, even if their moisture content may be as high as 30% when they enter this stage. Maximum dry weight is a general criterion for physiological maturity, although it is not always easy to determine (Harrington 1972). Generally, better quality seed is obtained from a slightly advanced harvest than from a delayed harvest. Damage from lodging or alternate wetting and scalding may also be reduced by an earlier harvest.

State of seed health. Seed for preservation or further propagation should be harvested from plants that are free from disease infection, insect infestation, exposure to alternate wetting and sun scalding, and stresses due to water deficit, water excess, or mineral deficiencies in the field. The seed should also be as free as possible from microbial infection and insect infestation.

Freedom from mechanical injury. A single harvest operation will include premature, mature, and overmature seeds. More than one harvest operation may be needed for a crop with an extended maturation period to minimize harvest injury. Mechanical injury during threshing may be reduced by using a lower cylinder speed, coating the beater bars with rubber tips, and threshing when seeds are within an appropriate moisture content range (Harrington 1972).

Grain dormancy. Dormancy generally helps prolong longevity. A rice crop planted in the wet season has stronger grain dormancy than one grown in the dry season (Chang and Yen 1969).

Interspecific and intervarietal variations. Crop species vary greatly in their seed longevity (Barton 1961, Harrington 1972). In rice, marked variation was found among varieties of different geographic origins (Chang and Tolentino 1983, International Rice Research Institute 1981).

Physical factors

Temperature, moisture, and other factors affect seed viability at different phases.

Temperature. As a rule of thumb, for each 5 °C-increase in seed temperature, the life-span of the seed is halved. This rule applies between 1 and 50 °C. The adverse effect of high temperature extends from physiological maturity to harvest, during transport and drying, and from open-shelf storage to cold storage inside hermetic containers (Chang 1983, Harrington 1972).

Moisture. The rice seed is hygroscopic, and seed moisture content will reach equilibrium with the ambient relative humidity (RH) and temperature. The relationship among temperature, RH, and seed moisture content is usually expressed in a sigmoid curve called an isotherm. Different crops have slightly different isotherms (Harrington 1972).

As another rule of thumb, for every 2% increase in seed moisture content, the life of the seed is halved. This rule applies to a range between 5 and 14% (Harrington 1972, Roberts 1979).

Temperature-moisture interaction. The two rules based on temperature and moisture apply independently. For example, seed with 10% moisture stored at 20 °C will survive as long as seed with 8% moisture stored at 30 °C (Harrington 1972).

Other factors. High O_2 content tends to hasten viability loss, especially in seed with high moisture content. High CO_2 or N_2 content or a vacuum may retard deterioration. Seed exposed to ultraviolet light will deteriorate faster. Radiation can damage seed in storage (Harrington 1970). Virus infection of the mother plant leads to a lower initial viability and a faster drop in germinability than that of seed taken from protected plants before storage (International Rice Research Institute 1986).

Human factors

Managing a large seed production and storage program requires vigilance, continuity of personnel, and administrative support. Political instability adds to the vulnerability of stored seedstocks, as do natural disasters such as earthquakes and floods (Chang 1985).

OPERATIONS TO MAXIMIZE SEED LONGEVITY

A number of conditions and treatments add to seed longevity.

Two-step drying process

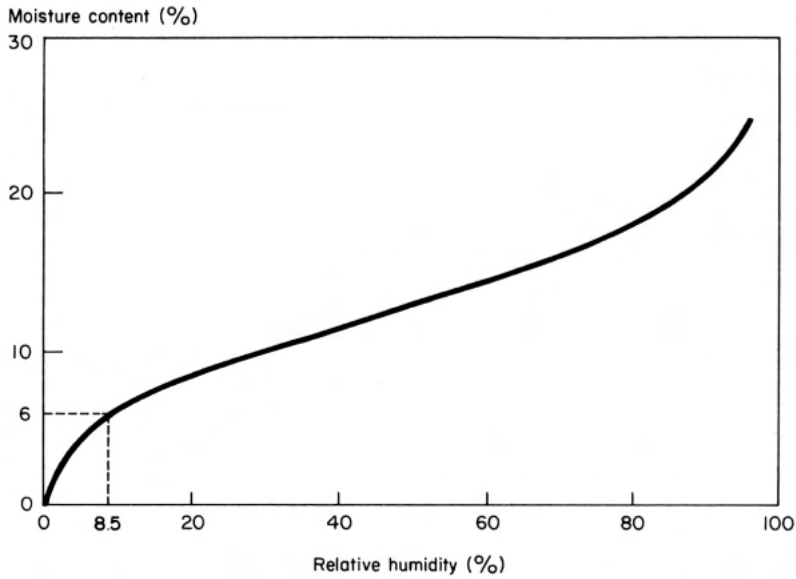
For freshly harvested seed with moisture content exceeding 18%, most commercial dryers using forced ventilation of heated air will be effective, provided the flowing air does not exceed 40 °C. Sun drying may cause radiation damage. It also requires frequent turning of the seeds in a pile. Heated seed should be cooled in a dry atmosphere and quickly packaged to minimize moisture reabsorption. Seed moisture content will generally come down to about 12%.

Moisture loss begins with the diffusion of moisture from the inner parts of the seed toward the seed surface. Moisture evaporates from the seed surface to the atmosphere around the seed and is then removed from there. This process is called desorption. Each of the steps requires a difference in moisture content (vapor pressure) between adjoining layers.

Moisture loss from the seed requires that the RH of the air surrounding the seed be lower than the equilibrium moisture content (Me) of the seed. The term moisture content ratio (MCR) is often used to indicate the relative power of a seed drying environment. MCR is expressed as the ratio of the difference between the moisture content M after H hours of drying (this can be the desired M at the end of drying) and the equilibrium moisture content Me to the difference between the original (initial) moisture content Mo and the Me:

$$MCR = \frac{M - Me}{Mo - Me}$$

To have efficient seed drying, Me should be substantially lower than the intended M at the end of the drying process (Cromarty 1984, Ellis 1986). The desorption curve for rice is shown in Figure 1.



1. The desorption curve of rice grains.

More precise control of drying conditions is needed to further reduce seed moisture content to 5-10%. The common methods are: 1) heating seed (not above 45 °C) in a dehumidified atmosphere, 2) mixing seed with a desiccant (silica gel or LiCl) and keeping the bulk in an airtight container until the desired moisture content is reached, and 3) keeping seed in porous materials (paper or cloth bags) in a very dry room. A quick freeze-dry technique has been proposed by Woodstock and coworkers (U.S. Agricultural Research Senice 1986) but is still experimental.

In the first 2 decades of IRRI, we dried seed to about 8.5% moisture content by pouring liberal amounts of activated silica gel into an airtight glass jar containing seed packages in paper envelopes. The silica gel was replaced with a fresh activated lot after 2 wk. Now we dry seed in an oven at 38 °C with incoming air dehumidified and chilled to 8% RH and 30 °C, following the lower portion of the desorption curve. It is a safe method to lower seed moisture content (6%) within 20 h (Chang 1986).

Seed cleaning, inspection, and selection

Seeds for storage should first be cleaned to remove chaff, weed seeds, soil, other inert particles, and poorly developed spikelets. Mechanical cleaning generally consists of winnowing and sorting seeds of proper size by means of sieves.

The next step is to visually inspect the seeds and remove offtypes, discolored seeds, diseased seeds, and smut balls. Seeds produced on plants infected with virus tend to show rusty spots on the hulls, although such seeds are not known to transmit the virus. In the operations of the IRGC, we visually inspect each seed lot and select only the healthy and true-to-type seeds for the second stage — drying and packaging

in aluminum cans. Electronic seed sorters are now available for use on a small number of cultivars with high volume.

Fumigation

Granary insects that have infested the ripening seed must be eliminated before storage. The common fumigants are carbon tetrachloride (the weakest), ethylene dichloride, and methyl bromide (the strongest), or a combination of two. Extra caution should be taken in using methyl bromide with respect to dose, seed moisture content, and human safety. We have recently used phosphine gas in tablet form, which is easier to handle than other gaseous fumigants.

Fumigation is more effective when the seed moisture content is above 10%. The storerooms should also be free from granary insects. At IRRI, we maintain insect-free storerooms by allowing only fumigated seeds to be admitted and by maintaining tight doors and insectproof air inlets.

Seed treatment for controlling microbial deterioration

Adequate drying and cold-and-dry storage should control the majority of microbes that cause seed deterioration. Applying fungicides or hot-water treatment before storage may affect viability if the seed will be stored for an extended period. It is more advisable to treat the seed just before planting or shipment. On the other hand. commercial seed to be held in short-term storage is treated before packaging.

Seed containers

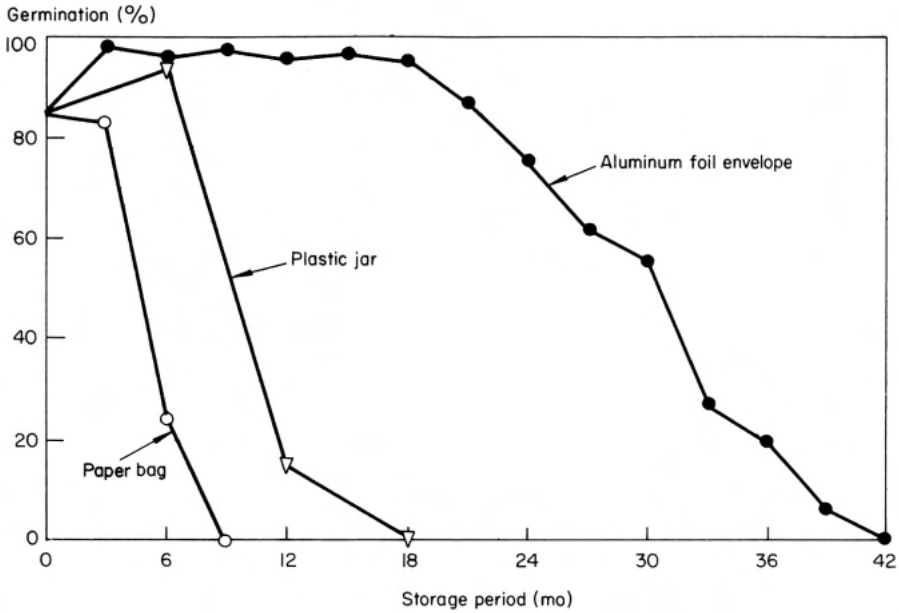
An airtight (hermetic) seed container will maintain the seed moisture content despite changes in the surrounding atmosphere. The choice of hermetic containers is restricted to metal (nonrusting or rusting types) and glass. Both metal and glass containers need reliable gaskets to keep them airtight. A glass ampule sealed by a gas torch is also effective (Mao 1987, Yndgaard 1983). However, the use of hermetic containers is restricted to small and valuable seedstocks because of the relatively high cost. At IRRI, we seal seed of 6% moisture content in aluminum cans under partial vacuum only for medium- and long-term storage.

For commercial seedstocks of large quantities or high volume, plastic materials may be used. High-quality sacks of about 50 kg capacity may be made of a fused layer consisting of polyethylene-nylon-polyethylene. Heavy-duty polyethylene bags lining polypropylene sacks may also serve commercial purposes. Such sacks can be sealed by a sewing machine. Small seed lots may be heat-sealed in polyethylene-aluminum foil-cellophane envelopes. Plastic jars can also be used for short-term storage. In general, all kinds of plastics tend to warp or develop microfissures with age. They deteriorate very rapidly under hot and humid conditions (Fig. 2).

Monitoring seed viability is necessary for all types of storage systems. Hermetic containers, especially the gaskets, also deteriorate with age.

Storeroom conditions

The key words for optimum storeroom conditions are *cold* and *dry*. It is a costly operation to keep such storerooms in subtropical and tropical areas. The expected



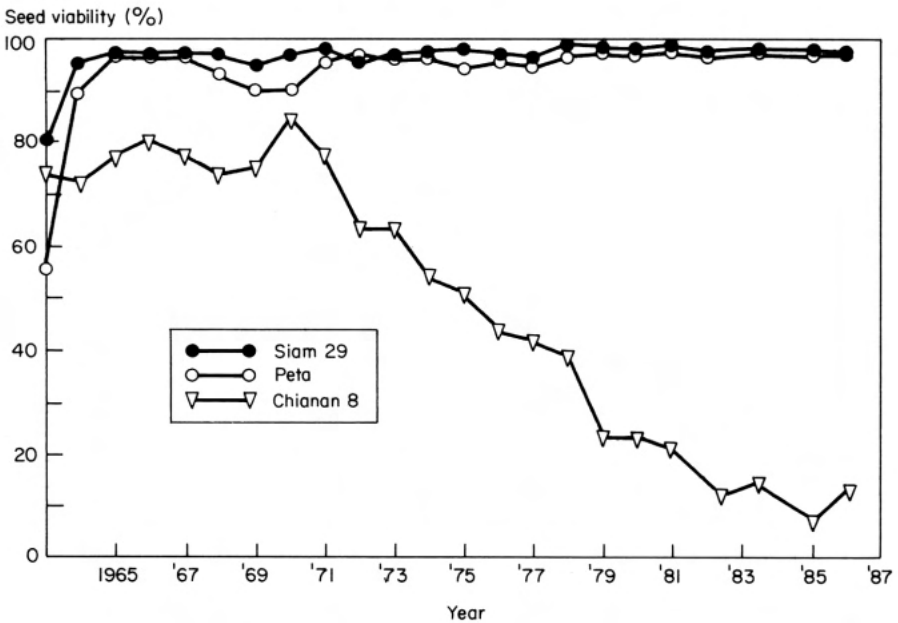
2. Germination percentage of seeds at 12% initial moisture content kept in 3 packaging materials in a damp room (24-32 °C, 80-100% RH).

longevity of the seed to be stored will determine the type of storeroom conditions needed, expressed primarily as temperature and RH. Other factors are the insulation of the room and the flow of air inside the room (continuous or intermittent).

Roberts and Roberts (1972) have furnished nomographs that predict seed longevity under given temperature and RH ranges. However, the reliability of the prediction equation has not been tested over a sufficiently long period. For practical purposes, maintaining a room at 20 °C and 6% RH will provide a life expectancy of 3 yr or slightly longer for seed initially dried to 12% moisture content. A room kept at 20 °C and 50% RH will provide more than 5 yr of longevity, but a dehumidifying device is needed to attain 50% RH in the humid tropics. Seeds placed in porous containers will come to equilibrium at 10% moisture content in such a room. When the seeds are dried to 8.5% moisture content and kept at 2 °C, the longevity will exceed 20 yr (Fig. 3). We have no experimental data beyond our 23-yr experiment, which is the longest monitoring effort on seed viability.

The storage rooms of the IRGC, their temperature and RH levels, and the projected seed longevity are summarized in Table 1.

Modern refrigeration equipment and efficient insulation materials have significantly lowered construction and maintenance costs. Discussions about the choice of equipment and comparative costs may be found in Chang (1983, 1987), Cromarty et al (1982), and International Board for Plant Genetic Resources (1976). For security, backup equipment and an emergency generator are needed in most tropical areas.



3. Seed viability pattern of 3 rice varieties stored in the medium-term room of IRRI (2 °C, 50% RH, 8.5% moisture content), 1963-86.

Table 1. Storage conditions in 3 storerooms of the IRGC and projected seed life-spans.

Room designation	Temperature[a] (°C)	RH (%)	Seed moisture content	Seed containers	Expected longevity (yr)
Short-term	19± 1	50	10[b]	Paper bags	5-7
Medium-term	2± 1	40	6	Aluminum cans	20-40
Long-term	-10 ± 1	37	6	Aluminum cans	> 50

[a]The International Board for Plant Germplasm Resources has recommended 1-10°C for medium-term storage and -18 to -20 °C for long-term, but not above -10 °C. [b]Initial moisture content was 12% but dropped to 10% after 2 mo storage.

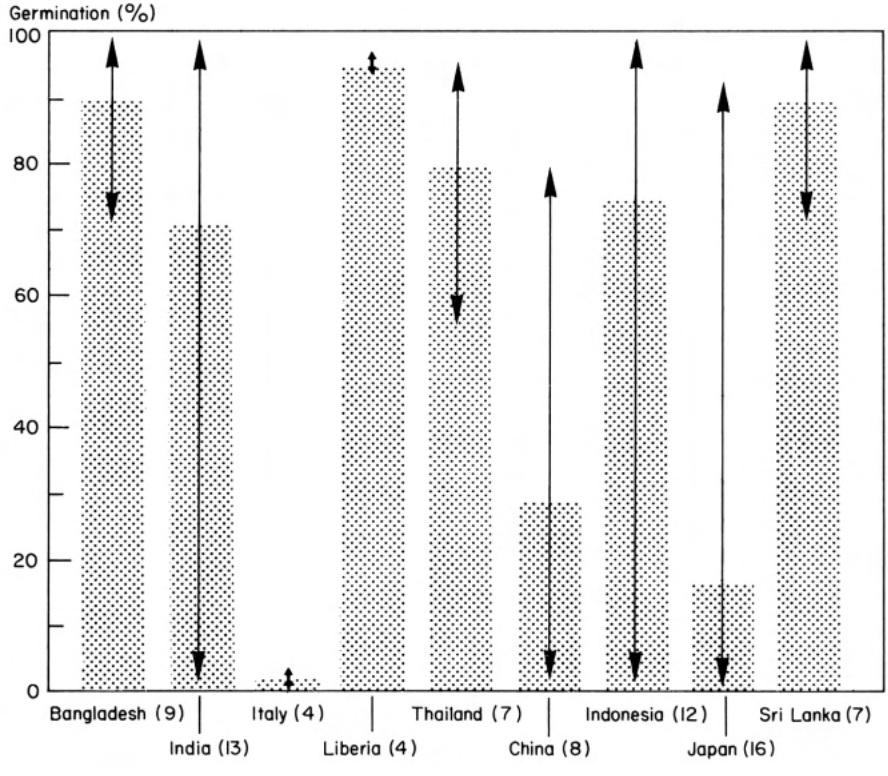
For small laboratories, household refrigerators and freezers can be used to store seed in small containers (Roberts 1983).

Overall effect on seed longevity

The relationship between Me of rice seed at different RH levels within a temperature range of 25-30 °C in an ordinary room is shown in Table 2 (Justice and Bass 1978). Such estimates of seed moisture content can be used to predict seed longevity at different temperatures as given in the short-term survival curves of Roberts (1961, p. 24).

Table 2. Relationship between equilibrium moisture content (Me) of rice seed at various RH and in 25-30 °C range (Justice and Bass 1978).

	RH level									
	15	30	45	60	70	75	80	85	90	100
Me (%)	5.9	8.6	10.7	12.8	13.5	14.6	15.0	16.5	18.4	- -



4. Viability patterns of 3½-yr-old seed samples of different national origin stored in IRRI's short-term room (19 °C, 50% RH) tested during 1979 wet season. The rectangle represents mean viability; the line with arrows indicates the range of variation. The number in parentheses after a country name shows the number of samples tested.

SEED VIABILITY DURING AND AFTER STORAGE

It is impossible to prevent seed viability from declining over time, even under the best storage conditions. Periodic monitoring of viability is absolutely necessary to plan rejuvenation (regeneration) schedules before viability is entirely lost. Rice varieties are now known to differ markedly in their longevity patterns: the glutinous varieties and low-amylose varieties from temperate regions usually have shorter life-spans

than tropical varieties. The strongly dormant varieties of very humid countries have survived the longest in our studies (Chang and Tolentino 1983) (Fig. 4).

Seed earlier stored under cold and dry conditions should not be left for long in an open-air room before use, because adsorption will occur and quickly lower the viability. On the other hand, low-moisture-content seed should not be soaked immediately after removal from cold storage. It should be allowed to reach equilibrium with ambient temperature and RH before wetting.

Seed vigor, expressed during germination, and seedling emergence will naturally show some decline in proportion to the storage period. The embryos will be somewhat shrivelled. On the other hand, we have not seen an increase in mutation frequency after extended storage.

When should workers rejuvenate stored seed? An 80% mark has been suggested by Roberts (1960), but most rice workers consider that rather impractical. I suggest a 50% threshold.

CONCLUDING REMARKS

It is obvious from the preceding discussions that recent advances in refrigeration engineering, seed physiology, and chemical products have given seed handlers a wide variety of facilities, equipment, processing methods, and seed containers to choose from to suit their needs and financial capabilities. Seed viability can be markedly extended beyond what was possible 2-3 decades ago, and at lower cost. By stretching seed longevity, frequent seed rejuvenation and its associated disadvantages (Chang 1980) can be minimized, as can seed production costs. On the other hand, rice workers in the humid tropics must not forget that the perennial enemy of seed viability persists: the combination of high temperature and high humidity that is prevalent most of the time, if not year-round. These are the two main forces to consider when choosing a storage system.

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Recommendations

Group I
Seed health testing

- Give priority to the most economically important seedborne pests and pathogens.
- Strictly follow the International Seed Testing Association (ISTA) rules on sampling for seed health tests as long as the size of a seed lot allows.
- Follow alternative sampling procedures for purity analysis of consignments of fewer than 2,500 seeds. Adjust the sample size to the minimum number of seeds required to detect a certain infection level, taking into account the necessary confidence limits.
- Into training programs on seed health testing, incorporate training in sampling according to lSTA rules.
- Organize comparative tests on seedborne fungi of rice. The coordinating center might be the International Rice Research Institute (IRRI), the Danish Government Institute of Seed Pathology for Developing Countries, the Centro Internacional de Agricultura Tropical (CIAT), or ASEAN Plant Quarantine Centre and Training Institute.
- Establish a working group to develop and standardize detection methods for *Pseudomonas* spp. and *Xanthomonas* spp. The coordinator can be R. S. Zeigler of CIAT. The cooperators can be M. Goto (Japan), T. W. Mew (IRRI), N. Schaad (USA), Yuanbo Di (China), and Chang Zie-Yong (China). This working group should operate under the umbrella of the ISTA Plant Disease Committee (PDC).
- Establish a working group covering the development of appropriate detection methods for seedborne nematodes. C. S. Huang from Brazil will be invited to be the coordinator. T. W. Mew of IRRI and R. Caubel of ISTA-PDC will participate.
- Organize training in South and Central America, Africa, the Middle East, and Asia on either a country basis or on a regional scale. In countries with an established seed health testing system, one center (e.g., the Indian Council of Agricultural Research) may coordinate such training. For training on the international level, the following organizations have been suggested: the Danish Government Institute of Seed Pathology for Developing Countries, IRRI, and ISTA-PDC.

Group II

Research on seed pathology and pests

- For bacterial blight caused by *Xanthomonas campestris* pv. *oryzae,* which is of significant quarantine importance and is spreading, determine the conditions under which the pathogen is seed-transmitted. Researchers and organizations interested are T. W. Mew, D. N. Srivastava, S. Wakimoto, and the Central Rice Research Institute (CRRI), India.
- For glume blight caused by *Pseudomonas glumae,* which has caused serious losses in southern Japan and Korea, determine the geographic distribution and yield losses in tropical areas.
- For bacterial brown sheath rot caused by *Pseudomonas fuscovaginae* — which is reported to be seedborne, is considered important in Latin America, and has been observed in Japan — determine its economic importance and geographic distribution. Researchers and organizations interested are R. Rasolofo (Madagascar), T. W. Mew, and R. S. Zeigler.
- For sheath rot caused by *Sarocladium oryzae,* which is seedborne and seed-transmitted, determine its economic importance and ascertain the importance of seedborne inoculum. Researchers interested are J. M. Bonman, R. S. Zeigler, M. Goto, V. T. John, and L. P. Kauraw.
- For glume blight caused by *Phoma sorghina,* which has assumed serious proportions in Brazil since the 1979-80 epidemic, investigate epidemiology and effective eradicant seed treatments. A.S. Prabhu of CRRI is interested.
- For false smut caused by *Ustilaginoidea virens,* which is of importance in India and West Africa, determine the importance of seedborne inoculum in disease occurrence and severity. A.S. Prabhu is interested.
- For leaf scald caused by *Gerlachia oryzae,* which is a serious seedborne disease in several areas, determine the importance of seedborne inoculum. A.S. Prabhu and J.M. Bonman are interested.
- For the seedborne white tip nematode (*Aphelenchoides besseyi*), determine its economic importance in different rice types and varieties under different environmental conditions, and investigate the interaction between nematode attack and seedborne fungi (e.g., *Sarocladium oryzae*). Researchers and organizations interested are J. Bridge; the University of the Philippines at Los Baños (UPLB); the National Bureau of Plant Genetic Resources (NBPGR), India; and CRRI.
- For the ufra nematode (*Ditylenchus angustus*), determine its means of survival and whether it is seedborne or not. Researchers and organizations interested are J. Bridge, UPLB, NBPGR, and CRRI.
- For storage insects that are of quarantine importance (*Trogoderma granarium* and *Prostephanus truncatus*), determine the effectiveness and safety of control procedures on different geographical strains and develop alternative controls as necessary. Researchers interested are W. K. Peng, B. Morallo-Rejesus, and S. del Rosario.

- For healthy rice seed, as sensitive, accurate methods of detecting pathogens in rice seed lots are developed, develop a measurement of the importance of this inoculum. A finite percentage of seed can be infected and not lead to disease resulting in economic loss. This will be affected by the biology of the pathogen, the susceptibility of the variety, the environment, and agronomic practices where the crop is grown. Seed lots with infection percentages below this tolerance level can be considered healthy for disease management purposes. In addition, quarantine regulations based on seed health tests establish tolerance levels based on required sample size and unavoidable sampling errors. Tolerance levels should be established by national programs through research and should be based on the average conditions where the crop is grown. Effective, nonphytotoxic seed treatments need to be developed to reduce infection to acceptable levels where seed lots are determined to have infection percentages above established tolerances.

Group III
Plant quarantine regulations and procedures

- Allow phytosanitary certificates to be issued only by authorized officials of national plant protection or plant quarantine services.
- List and update pests that should be excluded from the exchange of germplasm materials. Each country should monitor its pest status regularly and provide the information on request.
- Provide with all consignments of seeds originating from IRRI a statement relating to their general health status. This document should accompany the Phytosanitary Certificate. The methodology for detection should be based on generally accepted principles.
- IRRI should develop sensitive techniques for detecting and identifying bacteria (e.g., *X. campestris* pv. *oryzae*) and other obscure organisms.
- Ensure that incoming consignments follow the guidelines of Article 6 of the International Plant Protection Convention. National governments should be responsible.
- Ensure that plant quarantine inspectors responsible for inspecting incoming consignments are properly trained in all phases of plant quarantine. IRRI should liaise with regional plant quarantine or national plant protection services to provide training in the movement of rice germplasm.
- Because of the likely possibility of some organisms (golden snails [*Pomaceae* spp.], rice water weevil, etc.) becoming dangerous pests in the rice ecosystem, reassess the entry status of such organisms. Plant quarantine officials should liaise closely with the national agencies concerned.
- IRRI should continue providing national plant protection services with publications relating to rice pests.

- In the event of an economic pest of unknown etiology being reported from an exporting country, postpone introduction of rice germplasm from that country until more information is available on the causal organism.
- Encourage all collectors and distributors of rice germplasm to follow these recommendations.

Group IV
Seed technology

- Refine crop management techniques to maximize seed yield and quality in rice varieties as well as hybrids.
- Prepare a *Rice seed production manual* in the manner of the *Crop production manual.*
- Provide a thorough varietal description of new varieties to facilitate roguing, and make available advance information on characters that may deviate from the original descriptions because of environmental factors.
- Develop reliable and quick laboratory methods for cultivar identification.
- Develop seed processing protocols to accompany the release of new varieties.
- Identify botanical pesticides of nontoxic chemicals to treat seed so that it can be diverted for consumption or for other purposes if not used for sowing.
- Exploit varietal differences in seed vigor to incorporate this character in high-yielding varieties; do genetic studies on tolerance for adverse storage environments, including the identification of traits associated with the tolerance.
- Further evaluate packaging materials and procedures to determine the most cost-effective methods and materials.
- National programs should produce breeder seed of recommended varieties emanating from international institutes and other national programs along with that developed locally.
- National programs should conduct drill-box surveys to assess the quality of seed currently used by farmers; demonstrate the superiority of high-quality seed (certified seed) in farmers' fields; and develop information and promotional strategies to promote the wider use of certified seed.
- Establish guidelines based on experience for use by countries in rationalizing the rate of replenishment of rice seed, e.g., on how much of the total seed needs to be supplied each year.
- Create awareness among prospective seed production agencies in countries outside China of the newly emerging hybrid rice technology.
- Identify and develop chemical, physiological, and physical treatments for enhancing seed performance, e.g., rate of emergence, resistance to seedbed stresses, and late-season chemical treatment to improve seed luster.
- Determine and quantify the influence of physiological traits, quality, and healthiness of seed planted on emergence, growth, and yield of the crop.
- Improve methods for assessing seed quality.

- Do research on both conventional and nonconventional storage techniques, including on-farm storage.
- Identify large-scale quick-drying methods.
- Develop strategies to control red rice where it is a problem.
- Do research on the efficacy of growth regulators to promote outcrossing and seed set in hybrid rice, including an economic evaluation.
- National programs should emphasize training of technical personnel involved in the seed sector.
- International agricultural research centers (IARCs) should contribute to seed research related to rice.
- IARCs should strengthen technical collaboration with national seed programs; assist in developing clear goals, strategies, and policies; assist in the horizontal transfer of seed technology; and stimulate the development of basic seed units, seed multipliers, and seed marketing groups in cooperation with seed trainees and national program leaders.
- IARCs should facilitate the communication process by building up the technical database required within each region.
- IARCs should pursue training activities and conferences to meet a range of needs to improve the seed sector, with emphasis on training trainors, problem-solving skills, and preparing training materials.

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