PART III. Selected Management Practices for Rice Diseases

Section 2. Improving Seed Health

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1. Introduction

There are at least 80 different fungi, 20 viruses and phytoplasmas, 10 bacteria, and 10 nematodes that cause different kinds of rice diseases (Ou 1985). Individually, many of these pathogens cause diseases with defined and noticeable symptoms on certain parts of the rice plant. For instance, 33 distinct diseases have been reported to be caused by fungi alone (Ou 1985). Most of these fungal pathogens are reported to be seedborne (Richardson 1979, 1981). However, especially over in the past 2 to 3 decades, rice crops have been also affected by disease syndromes, which involve more than one pathogen or groups of pathogens. These diseases are difficult to diagnose, establishing their etiology is challenging, and therefore so is their management (Mew 1990. Mew et al 2004).

Seed discoloration, discussed in **Chapter 4 in Part II, Section 1**, is a very good example of such syndromes. To date, at least two groups of pathogens have been shown to be involved in seed discoloration: both pathogenic bacteria and fungi have been isolated from discolored seed (Cottyn et al 2001, Mew and Gonzales 2002, Zeigler and Alvarez 1990). However, the specific role of each pathogen in the induction and development of seed discoloration remains poorly understood and documented. *In vitro* tests have also shown antagonistic interactions between isolates of the different pathogen and non-pathogen groups (Xie et al 2001, Cottyn et al 2009). Isolation from discolored seed collected from the field often yields more than one pathogen from the same pathogen group. For instance, *Fusarium fujikori, Bipolaris oryzae, Sarocladium oryzae, Alternaria padwickii,* and *Phoma* spp. have been isolated from the same seed sample or lot. Among the bacterial pathogens, *Burkholderia glumae* and *Pseudomonas fuscovaginae* are frequently isolated from discolored seed, especially from rainy season rice crops (Mew and Merca 1992, Merca et al 2001, Cottyn et al 2001, Xie et al 2001). These bacteria have also been isolated from discolored leaf sheaths resembling those of sheath rot caused by *Sarocladium oryzae* (see **Part II, Section 1, Chapter 3**).

These findings highlight two research areas related to seed-associated problems. One is seed pathology, which is the study of seedborne pathogens, and the other concerns the management of seed discoloration. Seed health management, a concept more commonly applied to testing for rice seed movement and exchange and rarely mentioned in general plant pathology, can offer a strategy for rice seed discoloration management. We present here measures on improving rice seed health for rice crop production and rice disease management. Most of the examples are based on the work done at International Rice Research Institute in 1980-2000.

2. Improving seed health for disease management

Seeds are biological entities that carry the inherent genetic potential for successful crop production. To realize the production potential of high-yielding varieties, it is important to

use good-quality seed. Contaminated rice seed often result in poor germination and poor seedling vigor and, hence, produce unhealthy crops. Planting seed that carry seedborne inocula of plant pathogens may give rise to more diseases in the crop and reduce either grain yield or quality.

Therefore, it is an important prerequisite to use clean and healthy seed for crop establishment. Certified seed ensure genetic purity and are free from weed seed and undesirable seedborne pathogens. Unfortunately, in most rice-growing countries in South and Southeast Asia, only a small percentage of the total seed provided through government agencies or other private seed suppliers is certified.

In the Philippines, for example, certified seed distribution met only about 15% of the need during the 1980s (Silva et al 1988), although this may have increased in recent years.

In Malaysia, farmers used their own seed for planting to complement the shortage of certified seed (Ali 1996). Instead of purchasing seed from public agencies, most Thai farmers changed their rice varieties every three to five crops or in 3-year intervals due to "red rice" seed contamination (Somsak 2001).

In Vietnam, more than 60% of the farmers changed their rice varieties every year. Only about 30% of the farmers used the same varieties for more than 3 years (Khoa et al 1996, Chien et al 2001). From 20 to 70% of rice farmers chose to use their home-saved seed. The others obtain seed through exchange among themselves or through purchasing from other farmers or relatives.

In Bangladesh, a 1999-2004 survey showed that about 80% of rice farmers used their own saved seed for planting, 3 to 4% exchanged seed with their neighbors, and around 5% purchased seed from other farmers (Hossain et al 2008a,b). It was also observed that, in most countries, standard procedures are not followed to produce quality certified seed.

In Asia, except Japan, Korea, and China, seed exchange among farmers is common, although the situation may have decreased in recent years as farmers' knowledge of seed production and the quality of seed production and supply though public and private agencies is gradually improved too. Without access to adequate seed suppliers, most farmers must use their own saved seed or exchange with other farmers (Diaz et al 1998).

A survey conducted in Nueva Ecija in northern Luzon, the rice bowl of the Philippines, showed that farmers selected fields that appeared to produce high yields, with no off-type and relatively free of weeds, as a seed source for planting during the following season's crop (Fujisaka et al 1993). However, the ability of these farmers to distinguish between healthy and discolored seed seemed inadequate. Harvests from selected fields were then threshed, cleaned, and winnowed. Few farmers used flotation or gravity flotation to remove weeds and unfilled seed. Even with these practices, farmers often used seed contaminated with weed seed and half-filled discolored seed The survey showed that the quality of farmers' saved seed had been deteriorating for the past three decades. The declining productivity of modern rice varieties has been partly attributed to the declining health status of farmer-saved seed for planting (Hossain et al 2008a,b). The deterioration of seed quality is a consequence of the build-up of seedborne pathogens and inoculum in the field. Other factors, including weed seed, deformed seed, partially filled seed, and discolored seed, were also identified for causing the declining productivity of modern varieties (Fujisaka et al 1993). In assessing the importance of seedborne pathogens in crop management, there is a need to consider seed pathology in crop management. Rice seed health improvement is an integral component of rice crop production among smallholder farmers.

3. Defining seed health

Since rice is a self-pollinated crop, at the end of each crop cycle, seed harvested from inbred varieties can be sown for a new crop in the following cycle. This seed will produce a new generation of genetically identical plants and subsequently more identical seed. In tropical Asia, most rice farmers are small landholders. To harvest seed for planting the following season, farmers have traditionally scouted their fields prior to harvest, individually selecting and harvesting the best panicles and keeping them for seed stock. In the old days, seed selection for planting was treated with care. This was also true of harvesting, threshing, cleaning (removing undesirable grains, in form and appearance), drying (exclusively by the sun), and storing. These tasks have been performed mostly by women. Seed were often stored in earthen jars, today more often in jute bags, and then kept in a dry corner of the farmhouse for 6 to 9 months.

Nowadays, farm labor is progressively aging and shrinking as the younger generation moves out of the villages and rice farming to seek opportunities in the cities. Since modern varieties are photoperiod insensitive, flowering can take place even during rainy days (which may favor infection of flower organs) and the plants mature uniformly. For the reasons cited above, today's farmers barely save an adequate amount grain from their one-time harvest for seed stock. An increase in seed discoloration may be associated with these social and technological changes. So, seed health, often ignored, is now an important issue in modern rice production.

Surveys have shown that one of the most common complaints among farmers in South and Southeast Asian rice-growing countries is the decreased productivity of saved seed after only a few cropping seasons (Fujisaka et al 1993, Hossain et al 2008a,b), forcing them to exchange seed with other farmers. The surveys also showed that farmers were forced to save seed that were highly discolored, unfilled, and contaminated with weed seed and other contaminants such as fungal sclerotia (**ISH Table 1**; Diaz et al 1998, Merca et al 2001). Seed health testing of discolored seed showed high frequencies of bacterial (**ISH Table 2**; Cottyn et al 2001) and fungal pathogens (**ISH Table 3**; Mew and Gonzales 2002).

The yield difference between crops grown from farmers' saved seed and foundation seed of the same variety, IR64, during both dry and rainy seasons, was about 1 ton/ha (**ISH Table 4;** Diaz et al 1998). The productivity of newly released rice varieties declined rapidly after 3 to 4 cropping seasons or less. This decline is related to the problems associated with the health status of the farmers' saved seed for planting. The continuous planting of seed harvested from the field crop without adequate seed health management appeared to be the major reason for such a yield decline. Most of the seed was found to be high in discoloration due to seed infection or insect damage, and contaminated with fungal sclerotia and unfilled seed, confirming previous survey findings.

To produce healthy seed, management practices need to begin from the crop before harvest through selection of fields free from weeds, with absence or minimum diseased and insect damage plants; during harvest, through selection of panicles for cutting, and; after harvest, through careful threshing, cleaning, drying and storage prior to sowing for the next crop. The way farmers obtain and save are important determinants of how clean seed are produced in small land-holding rice farmers in tropical Asia.

4. Seed health and seed pathology

The concept of improving seed health for crop production is rooted in seed pathology. The relationship between seed pathology and seed health must be clarified. Seed, like any other plant organ, is attacked by many pathogens. Seedborne pathogens cause seed dis-

ISH Table 1. Difference in seed quality between farmers' saved and original foundation seed of IR64 from Central Luzon, Philippines, 1996-97. Source: Diaz et al (1998).

Locality and seed Items	Quality seed[a]	Farmer seed	Difference[b]	T-value
Guimba, wet season 1996				
Germination with normal seedling (%)	98.8	90.8	8.1	10.99
Lethal seed infection (%)	1.1	5.7	-4.6	-13.74
Mixtures with off-types (%)	0	4.3	-4.3	-6.91
Purity (%)	100	95.6	4.4	6.9
Fully filled seed (%)	90.1	39.6	50.8	34.22
100 seed weigth (g)	2.6	2.4	0.2	10.78
Discoloration of seed (%)	0	23.9	-23.9	-14.27
Gabaldon, rainy season 1997				
Germination with normal seedling (%)	98	90.2	7.8	4.6
Lethal seed infection (%)	1.1	4.8	-3.7	-4.86
Mixtures with off-types (%)	0	3.5	-3.46	8.45
Purity (%)	100	96.6	3.4	8.44
Fully filled seed (%)	89.4	38.0	51.4	37.65
100 seed weight (g)	2.7	2.4	0.3	9.67
Discoloration of seed (%)	0	23.3	-23.3	-14.27

[a] IRRI foundation seed.
[b] All differences are statistically significant at 1% level.

ISH Table 2. Gram-negative and positive bacteria detected from rice seed. Source: Cottyn et al (2001).

FAME group1	Identification	FAME group2	Ideniticattion
	Gram-negative		**Gram-positive**
N 1	*Agrobacterium spp.*	P 1	*Clavibacter michiganense*
N 2	*Sphingomonas paucimobillis*	P 2	*Kocuria kristinae*
	S. capsulate	P 3	*Microbacterium saperdae*
N 3	*Chryseobacterium indologenes*	P 4	*Cellufomonas fravigena*
N 4	*Xanthomonas campestris pv. dieffenbachia*	P 5	*Microbacterum barkeri*
	X. campestris pv. strelitzia		*M. liquefaciens*
N 5	*Stenotrophomonas maltophilia*		*Corynebacterium aquaticum*
N 6	*Acinetobacter baumannii*	P 6	*Corynebacterium aquaticum*
	A. calcoaceticus		*Unidentified*
N 7	*Burkholderia glumae*	P 7	*Bacillus licheniformis*
N 8	*Enterobacter cloacae*	P 8	*B. subtilis group*
	E. sakazakii	P 9	*B. megaterium*
	Kluyvera ascorata	P 10	*B. pumilus*

	Pantoea agglomerans	P 11	*B. cereus*
	P. ananatis	Ungrouped	*Arthrobacter atrocyaneus*
	Pantoea spp.		*Bacillus filicolonicus*
	Salmonella choleraesuis		*B. sphaericus*
N 9	*Pseudomonas spp.*		*Bacillus spp.*
N 10	*Flavimonas oryzihabitans*		*Brevibacillus brevis*
	Pseudomonas aeruginosa		*B. laterosporus*
	Pseudomonas spp.		*Brevibacillus spp.*
Un-grouped	*Burkholderia gladioli*		*Curtobacterium spp.*
	B. multivorans		*Exiguobacterium acetylicum*
	Methylobacterium carotovorum		*Microbacterium arborescens*
	Pectobacterium carotovorum		*Paenibacillus macerans*
	Pseudomonas putida		*Paenibacillus spp.*
	Pseudomonas spp.		*Staphylococcus saprophyticus*
	Sphingomonas paucimobillis		

ISH Table 3. Fungi detected from rice seed; data compiled from IRRI's seed health testing of 1983-1997[a]. Source: Mew and Gonzales (2002).

Species of fungi	Intensity	Species of fungi	Intensity
Alternatia padwickii	+++	*D. longirostrata*	+
Bipolaris oryzae	+++	*D.maydis*	+
Curvularia lunata	+++	*D. rostrata*	+
C. oryzae	+++	*D. sacharri*	+
Fusarium semitectum	+++	*D. sorokiniana*	+
F. moniliforme	+++	*D. turcica*	+
Gerlachia oryzae	+++	*D. tetramera*	+
Phoma spp.	+++	*Fusarium avenaceum*	+
Sarocladium oryzae	+++	*F. decemcellulare*	+
Alternatia longissima	++	*F. equiseti*	+
Aspergillus clavatus	++	*F. fusarioides*	+
A. flavus-oryzae	++	*F. graminearum*	+
A. niger	++	*F. favarum*	+
Cladosporium sp.	++	*F. longipes*	+
Culvularia affinis	++	*F. nivale*	+
C. pallescens	++	*F. solani*	+
Epicoccum purpurascens	++	*F. tumidium*	+

Nakataea sigmoidea	++	*Graphium sp.*	+
Nigrospora oryzae	++	*Humicola sp.*	+
Penicillium sp.	++	*Leptosphaeria sp.*	+
Pinatubo oryzae	++	*L. sacchari*	+
Tilletia barclayana	++	*Magnaporthe oryzae*	+
Pithomyces maydicus	++	*Melanospora zamiae*	+
Rhizopus sp.	++	*Microascus cirrosus*	+
Acremoniella atra	+	*Monodictys levis*	+
Alternaria tenuis	+	*Nectria sp*	+
Annellophragmia sp.	+	*Nigrospora sphaerica*	+
Botrytis cinerea	+	*Papularia sp.*	+
Cephatosporium sp.	+	*Penicillifer fulcer*	+
Cercospora janseana	+	*Periconia sp.*	+
Chaetomium globosum	+	*Pestalotia sp.*	+
Chramyphora sp.	+	*Phaeotrichoconis crotolariae*	+
Colletotrichum sp.	+	*Phyllosticta sp.*	+
Corynespora sp.	+	*P. glumarum*	+
Cunninghamella sp.	+	*Pyrenochaeta sp.*	+
Curvularia cymbopogonis	+	*P. oryzae*	+
C. eragrostidis	+	*Septoria sp.*	+
C. inaequalis	+	*Spegazzinia deightonii*	+
C. intermedia	+	*Stachybotrys sp.*	+
C. ovoidea	+	*Stemphylium sp.*	+
C. stapeliae	+	*Sterigmatobotris macrocarpa*	+
Cylindrocarpon sp.	+	*Tetraphloa aristata*	+
Dartuca sp.	+	*Trichoderma sp.*	+
Diarimedia setulosa	+	*Trichosporiella sp.*	+
Diplodia sp.	+	*Trichotecium sp.*	+
Drechslera cynodontis	+	*Utocladium sp.*	+
D. demotioideu	+	*Verticillium albo-atrum*	+
D. halodes	+		
D. hawaiensis	+		

[a] +++ = frequent; ++ = moderate; + = low.

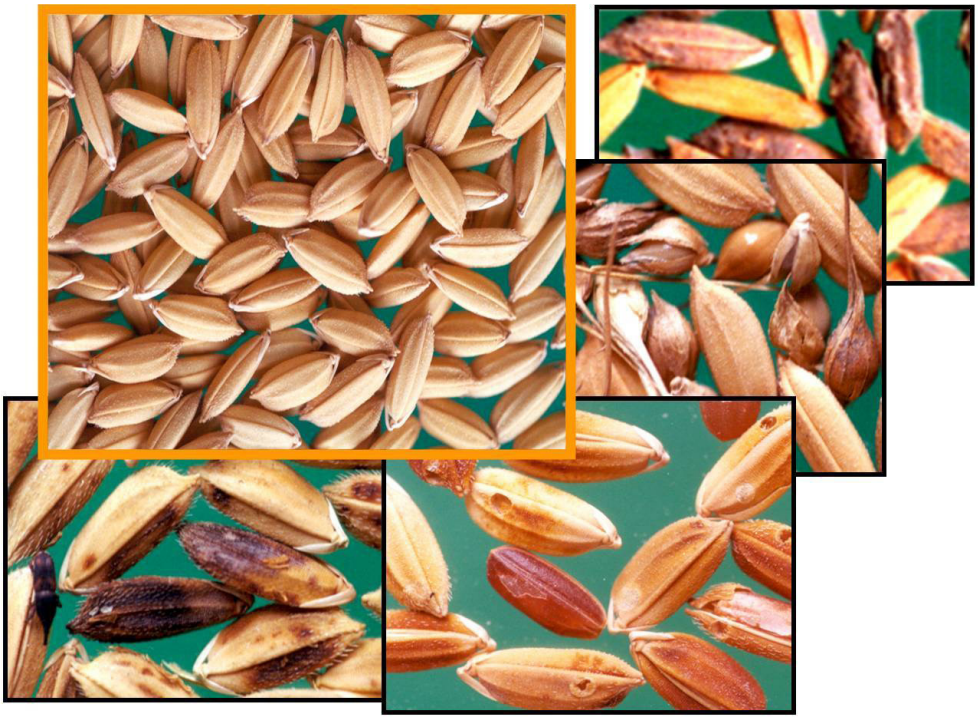
ISH Table 4. Effect of seed quality as planting materials on rice yield,[a] Central Luzon, Philippines, 1996-97. Source: Diaz et al (1998).

Locality, Seed Items	Quality seed[b]	Farmer seed	Difference (%)	T-value	P- level
Guimba, rainy season 1996					
Yield[c] (t/ha)	4.3	3.5	22.8	5.91	0.001
Weed infestation (%)	7	27	-20	-2.26	0.031
Pest incidence (%)	27	53	-26	-2.8	0.009
Panicles (no.).	318	286	11	2.68	0.012
100-seed weight at harvest (g)	2.4	2.3	3.9	2.74	0.01
Gabaldon, rainy season 1997					
Yield[c] (t/ha)	5.4	5	8	2.45	0.01
Weed infestation (%)	10	50	-40	-3.89	0.001
Pest incidence (%)	0.5	0.5	0	0	1
Panicles (no.).	267	249	7.3	2.79	0.009
100-seed weight at harvest (g)	2.6	2.6	0	0	0.416

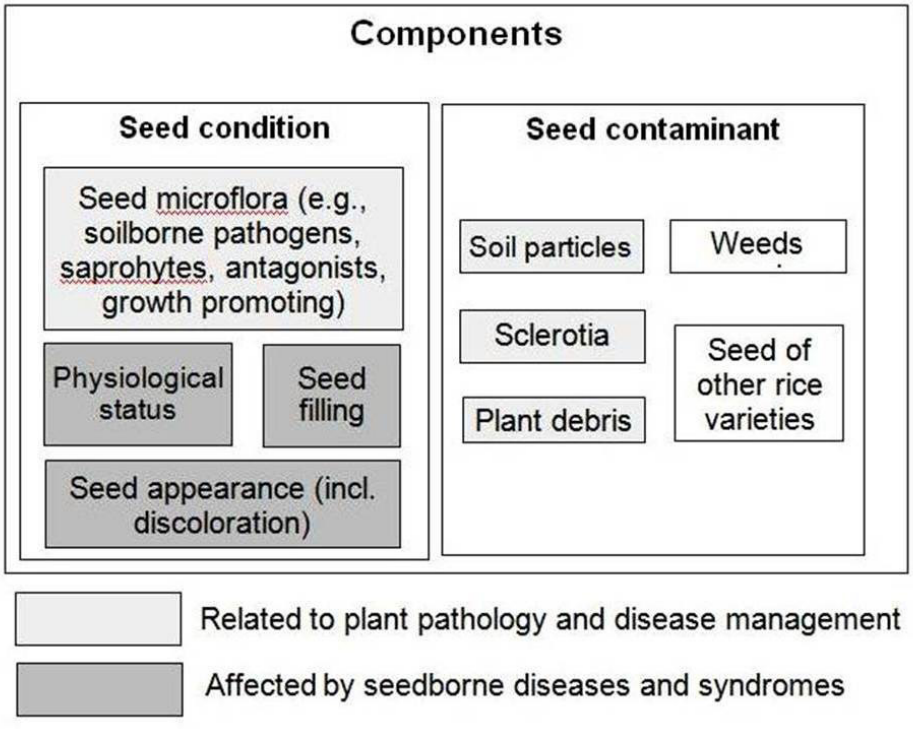
[a] Farmer participated in experiments.
[b] Farmer seed cleaned to obtain 98% quality seed in the laboratory at IRRI.
[c] Yield adjusted at 14% moisture.

eases. They may also infect other parts of the plant. In many cases, seedborne pathogens cause a disease on seed that is less important than the disease they cause on other parts of the host plant. For instance, *Magnaporthe oryzae* infects seed and is also seedborne. However, the seedborne inoculum and the impact of seed infection is far less destructive than its infection on other parts of the rice plant, such as leaf, collar, or node (Mew and Gonzales 2002). In rice, true seed pathogens, i.e., pathogens that cause diseases exclusively on seed are few (for more information, see **Grain diseases, Part II, Section 1, Chapter 4**). Even though rice seed may not be the primary organ of infection, many rice pathogens can be seedborne (Ou 1985). In the literature, the terms seed pathology and seed health are often used interchangeably. Operationally, each has its own definition and boundary of activities. Seed pathology is the science studying seedborne pathogens and the diseases they cause. Seed health, on the other hand, is the health status of the seed in a seedlot such as the farmer-saved seed. Seed health is determined by the health condition of the seed and by the contaminants of the seedlots. (**ISH Figures 1** and **2**). Seed condition refers to seed appearance (e.g., discoloration), physiological state of seed development, and whether or not it is filled. Seed conditions may be caused by the diseases in the field prior to harvest or by pathogens contaminating the seed during harvest. The health condition of the seed is determined by the numbers and types of seedborne pathogens in the seed. Seed contaminants include weed seed, seed of other varieties, inert materials such as plant debris that may also be infested with pathogens and soil particles, and sclerotia of a pathogen. Seed health can affect the productivity and genetic potential of the rice in terms of seed germination, crop growth, and grain yield.

When we discuss seed health issues, disease is always integrated and is often the key component. This is an important consideration in applying seed pathology for seed health improvement in crop production and disease management.



ISH Fig. 1. Seed conditions and contaminants of rice farmers' seed used for planting.



ISH Fig. 2. Components of seed health.

5. Pathogens detected from rice seed

Rice seed health testing and the results it generates can be used as a basis to establish strategies for seed health improvement. The success of modern rice improvement and production is attributed partly to free exchange and movement of rice germplasm, where genetic materials are shared as seed (Swaminathan 1988). This seed exchange has enhanced national and international varietal improvement. Seed exchange and movement may be free, but the quality of seed must be high, and devoid of pathogens. Rice seed health test has shown that rice seed carry many organisms including rice pathogens (as shown in **ISH Table 2** for bacteria and **ISH Table 3** for fungi). For instance, numerous microorganisms have been detected from rice seed coming from a foreign source to IRRI or going to a foreign destination from the IRRI farm or Filipino rice farms. Among the pathogens, fungi, bacteria, and nematodes are the most commonly detected along with some weed seed. The seedborne organisms may be pathogens and saprophytes. Some of the detected bacteria from rice seed, such as *Pseudomonas putida, P. fluorescens, Burkholderia* spp., and fungi such as *Chaetomium globosum*, are also potential biological control agents against other rice pathogens (Mew and Rosales 1991, Xie et al 2001, Cottyn et al 2009). Some microorganisms also show the ability to promote seed germination and seedling vigor while others have deleterious effects on seed germination, even though they are antagonists of other pathogens (Mew and Rosales 1986). The ecological relationships between the beneficial, cultivatable microorganisms (nonpathogenic) and the pathogens on rice seed are not known. Selected seedborne antagonistic bacteria have been used to develop biological control agents against rice fungal diseases (Mew and Rosales 1986, Rosales and Mew 1997, Mew et al 2004). Available information suggests that, in addition to nonpathogenic forms, rice seed carry more than one pathogenic group of bacteria (Cottyn et al 2009).

Two terms are proposed and defined in detecting seedborne pathogens. Detection frequency (DF) is the frequency of seed samples or lots where a pathogen or an organism is detected from rice seed. Infection level (IL) refers to the number or percentage of seed in a seedlot where an organism is detected (for operational purposes, IL is based on 200 seeds per sample or lot tested; Mew and Merca 1992). Operationally or in epidemiological terms, the product of DF and IL is an estimate of the level of inoculum of an individual pathogen or microorganism in a seed sample. Rice is attacked by five groups of pathogens. Except for rice viruses and most nematodes, many of these pathogens are seedborne. Only one nematode, the white-tip nematode, *Aphelenchoides besseyi*, is known to be rice seedborne. However, the role of seedborne inoculum in disease epidemics largely depends on the types of diseases a pathogen may cause, the types of host-pathogen interactions, and the ecosystems where rice is cultivated (*A handbook of rice seedborne fungi*; Mew and Gonzales 2002). Many rice pathogens are also widely distributed throughout the rice-growing countries and seed also carry a large number of other microorganisms that are not only pathogenic to rice but also antagonistic to some rice pathogens. How do we assess the transmission and potential damage on the rice plant or crop that these seedborne pathogens may impose in the presence of nonpathogens or antagonists? The latter was a key consideration in formulating the present strategy on rice disease management. For reference, see **Part III, Section 3, Managing Biological Control Agents.**

At IRRI, routine seed health testing has been carried out since its foundation. More systematic seed health testing commenced in 1982 with the addition of a new facility to the Seed Health Unit (SHU). SHU is capable of testing seed for many rice pathogens and performing other seed health-related activities for phytosanitary certification for movement and exchange of rice seed among different rice-growing countries (Mew 1997). Seed samples are usually drawn from each seed lot following the sampling method

prescribed by the rules of the International Seed Health Testing Association (ISTA 2017). Usually, 200 and 500 seeds per lot for fungi and ***Aphelenchoides besseyi***, respectively, are used during the tests. The blotter and growing-on test methods are used in the laboratory to detect fungi and bacteria, respectively. Throughout the 1980s and from 1990 onwards, on average, 10,000-50,000 and 5,000-10,000 seedlots, respectively, have been tested annually. Research on bacteria associated with rice seed is reported by Cottyn et al (1996a,b), and Cottyn et al (2009). *A handbook of rice seedborne fungi* (Mew and Gonzales 2002) gives comprehensive documentation of all fungi detected in rice seed. These reports provide a synthesis of data on the detection frequency and infection levels of rice seed from various sources.

Seed samples may be infected by more than one pathogen. However, when these samples are sown, most of diseases that the pathogens can potentially cause may not be observed in the field. However, they may still be detected in seed harvested from the subsequent crop (**ISH Table 5**; Mew and Gonzales 2002).

Farmers' seed collected from different fields in the same region show infection of similar groups of fungi. These fungi include *Fusarium fujikori* (an average of 27% of the seed in the samples), *Bipolaris oryzae* (17%), *Alternaria padwickii* (82%), and *Curvuria* spp. (49%). In addition, with less than 5% each are *Sarocladium oryzae, Pinatubo oryzae* (formerly *Verticullium cinabarinum*), *Phoma* spp., and *Microdochium oryzae* (Merca et al 2001). These

ISH Table 5. Levels of fungal pathogens detected from seed before sowing and diseases observed on rice plants after crops established from these seed and subsequent fungal detection from harvested seed. Dry season 1996. Source: Mew and Gonzales (2002).

Fungal pathogens (disease)	Detection level (%)[a]	Corresponding diseases found in the field	
		Entries (no.)	Detection at harvest[b] (%)
Alternaria padwickii (stackburn)	15.7	0	10.7
Culvaria spp. (black kernel)	5.4	0	9
Sarocladium oryzae (sheath rot)	0.8	2 (8.3%)	2.7
Gerlachia oryzae (leaf scald)	2.7	2 (8.3%)	0.2
Fusarium moniliforme (bakanae)	0.2	0	3.8
Bipolaris oryzae (brown spot)	1.7	0	0.4
Magnaporthe oryzae (blast)	0	1 (4.1%)	0
Phoma spp. (glume blight)	1.6	0	4.6
Tilletia barclayana (kernel smut)	0.3	0	0

[a] Detection level used the standard method described in the text before treatment.
[b] Detection level from rice seed harvested from the rice plants grown in the field.

data further suggest that the distribution of seedborne fungi is influenced by both the environment and rice variety. Assessment of farmer-exchanged seed also revealed a high percentage of infection by *F. fujikori, A. padwickii, Biporaris oryzae, Sarocladium oryzae, Pinatubo oryzae, Phoma* spp., and *Curvuria* spp. Bacteria pathogenic to rice such as *Burkholderia glumae* and *Pseudomonas fuscovaginae* are commonly detected in discolored seed. Many pathogenic and nonpathogenic bacteria, with some exhibiting antagonistic effects to fungi such as *M. oryzae, Rhizoctonia solani*, and *S. oryzae*, were also detected in rice seed from different tropical regions (Mew and Rosales 1991, Xie et al 2001, Cottyn et al 2009).

The literature often reports that a single pathogen from a seed sample provides the inoculum and causes infection on a crop derived from seed, suggesting a close relationship between seed inoculum and crop infection. In blackleg of crucifer caused by *Phoma lingum* or *Leptosphaeria maculans* (Gabrielson 1983), the detected seedborne inoculum was closely related to the disease produced in the field where the seed were planted. Another classic example from Heald (1921) suggests that the spore load of wheat seed is highly correlated to the percentage of smut appearing in the field. In these two examples and many others (for references, see McGee 1995), there was no indication if other microorganisms were detected from the same seed or seed samples. In the case of loose smut caused by *Ustilago segetum* var. *tritici*., the fungus remains inside the host during most of its existence and a relatively constant relationship occurs between infected seed and infected plants derived from these seed (Rennie and Seaton 1975, Hewett 1979). Loose smut is a good example of a monocyclic disease in which the initial pathogen inoculum determines the outcome of the disease in the field. For polycyclic epidemics involving seedborne inoculum, the correlation between levels of disease incidence in the field and level of seedborne inoculum may be low. This is because secondary infections will occur and their magnitude will depend on environmental conditions.

In the case of *Pseudomonas syringae* pv**.** *phaseolicola*, which causes halo blight disease of legumes (Taylor et al 1979, Webster et al 1983), rapid spread of the pathogen under suitable weather conditions results in severe epidemics even at low levels of seed infection (Walker and Patel 1964). For instance, seed infestation levels of 0.02% (Webster et al 1983) or 0.05% (Trigalet and Bidaud 1978) resulted in severe halo blight in Wisconsin USA and France, respectively. Various factors affect the detection and transmission of seedborne pathogens, including resistance of the varieties, environmental conditions such as moisture, temperature and relative humidity, inoculum location, type of inoculum, and cultural practices during seed harvest (Agarwal and Sinclair 1988).

Many studies on seedborne inoculum and disease development in the field were based on artificial inoculation of a target pathogen on seed. While infection and transmission based on artificial inoculation can provide useful information on potential damage caused by individual seedborne pathogens, it may not correspond to the actual field situation. In routine seed health testing over the past 30 years, covering more than 1 million rice seedlots, it was seldom encountered where rice seed in a sample carried only one organism or a particular pathogen. Microorganisms other than the causal pathogen were also found in rice seed collected from plants in diseased fields. The presence of the pathogen in the seed samples (as indicated by detection frequency and the infection levels of the seed in the samples) can be quantified, but transmission of the pathogen in the field and its interactions with other microorganisms including other pathogens are unclear. The effects of various microorganisms (whether pathogens, nonpathogens, or antagonistic against pathogens) present in seed on the infectivity of a specific pathogen are not known.

6. Principles applied to improving seed health

There has been research on rice fungal and bacterial pathogens involved in seed and leaf sheath discoloration or "dirty panicle" (Cottyn et al 1996a,b). It has helped to conceptualize an approach to improve rice seed health, i.e., the quality of seed used by farmers for planting, crop production, and disease management. Dirty panicle is associated with different groups of microorganisms and is more severe in the wet season. Knowledge of the health status of seed can also help farmers to decide if they should obtain seed from private or public seed agencies. Seed health testing is a means of quality control to help farmers minimize disease problems in the field (Mew and Hossain 2008).

The use of quality seed for planting can potentially reduce the number of pathogens and the amount of seedborne inoculum that may be introduced in the field. It therefore corresponds to the inoculum reduction of, not just one pathogen, but of several or all microorganisms carried by the rice seed. Reduction in inoculum is an important principle in disease management (Fry 1982). Seed exchange among farmers may introduce to the field new pathogens or virulent races. Seed health management provides a means to prevent such introductions, thus, an exclusion of a pathogen that is not commonly encountered in the field. Seed health improvement targets disease management at a field level micro-scale.

Seed health management, conversely, corresponds to a holistic approach to manage seedborne pathogens, which allows a reduction of seed discoloration and of the incidence of seedborne diseases such as bakanae. Considering that rice seed can serve as an efficient vehicle for the dissemination of pathogens, quality seed can be used to prevent or minimize the spread of seedborne pathogens. The initial inoculum of seedborne pathogens can be defined as the amount of seed infection that will cause the diseases related to the inoculum of all pathogens introduced to the field. As such, this primary inoculum, x_0 (sensu Van der Planck 1963), may be expressed by DF x IL = $\boldsymbol{x_0}$.

It seems that the concept of improving the health of seed used for planting has been practiced by rice farmers for several centuries, even though the underlying principle may not have been well understood. Using high-quality seed for planting has been a general practice of traditional rice farming. In the past three to four decades, this practice has been gradually neglected by aging farmers who use modern rice varieties. When rice seed health is improved, yield increases from 5 to 20% depending on the initial quality of the seed (more details below). Rice farmers appear to understand the concept of seed health as indicated by their practices. It is also readily accepted by extension specialists and policymakers. Seed health management is a holistic approach to minimize potential damage caused by seedborne pathogens responsible for seed discoloration that can be integrated into farmers' routine seed health practices, such as winnowing, seed soaking, and flotation, to achieve sustainable productivity using modern rice varieties. More importantly, the approach also closes the technology efficiency gap in rice production of resource-poor farmers through seed health and grain quality management (Hossain et al 2008a,b).

7. Case study in the Philippines

This case study conducted in the Philippines demonstrates the process. Similar studies have also been conducted in Bangladesh and Vietnam. Although rice crop production environments differ among these countries, productivity decline due to poor quality seed are similar (Mew and Cottyn 2001). Although the scale and approach differed, the results of the studies in Bangladesh and Vietnam were similar to those in the Philippines. Improvement of farmers' seed health management resulted in yield gains of from 5 to 20% depending on the level of seed quality used. Perhaps it is not surprising that similar types

of seedborne pathogens are also found in these countries. Because of the low productivity of the seed farmers used, higher seeding rates were also used. With the improvement of the health status of the seed for planting, not only was yield gain attained but seeding rate was also reduced to the recommended rate for irrigated transplanting or direct seeded rice.

7.1. Seed health status

Since the 1970s, Filipino farmers have experienced a rice malady known as "dirty panicle" during the rainy season. They attribute it to "not productive" seed. The grain yield of the new modern rice varieties also declined when seed from the previous harvest were continuously used for planting. This prompted farmers to frequently exchange seed among themselves. The genetic potential of the modern varieties cannot be attained if the health status of the seed for planting is not good. The deterioration in seed quality after a few cropping seasons has both biological and socioeconomic implications. Rice crop growth is highly vulnerable to pest and pathogen attack at the flowering and crop-ripening stages, affecting grain filling and seed quality. Because of farm labor shortages and intensive rice production systems, few of today's farmers practice seed selection and care that was done by traditional rice farmers of the past.

Studies were conducted to (1) determine the quality of seed used by farmers for planting, (2) identify factors contributing to reduced quality of farmers' saved seed, and (3) determine the effect of rice seed health on grain yield.

A 1-kg rice seed sample was collected from each of at least 30 farmers per village. There were three villages each in the major rice-growing regions of Iloilo, Nueva Ecija, Laguna, Cavite, and Quezon. Seed samples from both the rainy- and dry-season crops were taken from farmers' processed seed stock and taken to IRRI's SHU laboratory for quality analysis on seed condition, detection of fungi and bacteria, and presence of weed seed and other contaminants (**ISH Figures 3-7**). Throughout, IR64 foundation seed from IRRI were used to compare with farmers' own IR64 seed. IR64 was the most popular variety in the country during the 1993-95 study period.

ISH Fig. 3. Farmer seed health practices in tropical Asia: seed sorting.

ISH Fig. 4. Farmer seed health practices in tropical Asia: blotter seeding.

ISH Fig. 5. Farmer seed health practices in tropical Asia: incubation chamber.

ISH Fig. 6. Farmer seed health practices in tropical Asia: growing-on test.

ISH Fig. 7. Farmer seed health practices in tropical Asia: nematode extraction using modified Baerman funnel set-up.

The blotter method was used to detect seedborne fungi. A 200-seed subsample was taken from the 500-gram seed sample by placing 20 seed each on a sterile Petri dish lined with moist blotter paper. The seeded plates were incubated for 5 days (max. 7 days) at 21°C under near ultra violet light (NUV) for 12 hr, followed by 12 hr of darkness. For detection of bacteria and nematodes (*A. besseyi*), the growing-on test method and the modified Baerman funnel set-up, respectively, were employed (**Figures 6** and **7**).

Analysis was done on the quality and health of farmer-grown IR64 seed from Nueva Ecija, a province of intensive rice production. The seed was found to be of lower quality as indicated by lower purity, best seed as compared to reference IR64 seed, and seedling vigor and higher numbers of discolored seed, weed seed, and other contaminants when compared to high-quality seed of IRRI's IR64. In addition, the quality of the seed harvested from the high-quality seed plots was lower after just one cropping season, as indicated by a reduction in amount of best seed and increased amounts of discolored seed, rice mixture, and weed seed. This suggests that the farmers' seed health management was lacking.

Increasing rice yield was possible through the use of high-quality seed that had both high physical purity and germination rate. Across all three planting seasons, the yield obtained from planting high-quality IR64 seed was 7-12%, significantly higher than farmer-saved IR64 seed (**ISH Table 4**). In Guimba, where yield levels were low, grain yields using high-quality IR64 seed were 12.1 and 10.9% higher than farmers' planting of their own saved IR64 seed during the 1996 rainy season and 1997 dry season, respectively, and 7.3% higher in the 1997 rainy season in Muñoz, a site with high yield levels. Variables related to quality seed, such as 100-grain weight, fewer discolored seed, unfilled seed, weed seed, crop stand establishment, and seed mixtures, were the determinants of yield advantage. The yield differences were significant and common in Guimba, Muñoz, and other sites. The seed quality and crop stand variables explained the 39 to 70% variation in yield between high-quality and farmer-saved IR64 seed. Weed and disease incidences in the field were also significant determinants of the yield difference although the disease effects were inconsistent, which may be related to the resistance of the variety to some diseases at the site.

Rice seed in different regions of the Philippines seemed to carry similar fungal pathogens, which were also detected in high-quality IR64 seed, although the detection frequencies and infection levels were lower than those of farmer-saved seed. *Alternaria*

padwickii, Sarocladium oryzae, Microdochium oryzae, Bipolaris oryzae, and ***Fusarium moniliforme*** were the common fungi detected in the seed. However, except for ***F. moniliforme***, seed is not the primary target organ of these fungal pathogens**.** Other common fungi detected included ***Phoma*** spp. and ***Curvularia*** spp., which are also known to be involved in seed discoloration. Detection frequencies and infection levels were significantly higher in the rainy season than in the dry season. The pathogens detected in rice seed were similar at all sites over the 3-year period.

7.2. Scaling-up rice seed health

To scale-up the technology for improving rice seed health, a collaborative project was initiated in 2001 between IRRI and the Infanta Integrated Community Development Assistance (ICDAI), a nongovernment organization (NGO) based at Infanta, Quezon, Philippines,.

This project demonstrated that farmers can obtain a 10% increase or more in grain yield, reduce pesticides (including herbicides) use, and reduce seeding rate by planting quality seed. By the end of the project, ICDAI had become a hub for seed health training agents in this part of the country. Infanta farmers have become known to produce high-quality seed of the modern rice varieties.

In practical crop management, the role of seed health in farmers' crop production and disease management must be understood. To achieve this objective, it is necessary to: (1) determine current practices and knowledge of farmers, (2) assess the extent of problems associated with farmers' seed quality for planting, (3) assess the benefits of seed health improvement, (4) characterize the seed quality management chain and intervention opportunities, (5) identify pathogens associated with seed health for crop production, and (6) develop methods to up-scale research findings.

The activities of the project conducted with the Infanta rice farmers are outlined below.

Step 1. The training was organized to include 42 farmers (21 each male and female) together with IRRI and ICDAI staff. Farmers were each asked to bring 2 kilograms of their own seed to the training activity.

Step 2. A 100-gram seedlot from each of the 2-kg farmers' seed was sampled to evaluate the seed health status.

Step 3. IRRI social scientists interviewed the farmers on their seed health management, practices, and perceptions using structured questionnaires. Data on their seed source, criteria for varietal choice, and methods and conditions of storage of seed destine for planting were also documented.

Step 4. The 42 farmers were then grouped according to their seed management practices such as winnowing, flotation, physical sorting, or any combination of various practices.

Step 5. The farmers were taught seed health improvement practices such as identifying seed that is good, discolored, weed, deformed, and unfilled. Farmers also practiced manual seed sorting.

Step 6. Seed germination test was conducted. Test seed were initially soaked in water for 24 hr. Each farmer sowed two trays with 150 grams of seed, one where the seed were treated following the farmers' seed management practice and the other with seed treated using the trainers' method. Planted trays were covered with fishnet for protection, left outdoors, and watered regularly.

Step 7. A farmer-participatory appraisal of the seedlings was organized 10 days after sowing. Individual and group evaluations of the seedlings, based on seedling height, color, uniformity, and overall seedling stand, were conducted by partici-

pating farmers. The researchers shared their experiences on identifying healthy and diseased seedlings and general observations with farmers.

Step 8. Field experiments were conducted. Different seedlings were transplanted to respective farmers' own fields superimposed with farmers' standard planting procedures. The plots were managed by the respective farmers until maturity. Yield was determined after harvest.

Step 9. During the course of the field experiment, field visits were organized according to the rice crop growth stages. In the monitoring visit, diseases, insects, weeds, and rice crop growth were recorded and evaluated.

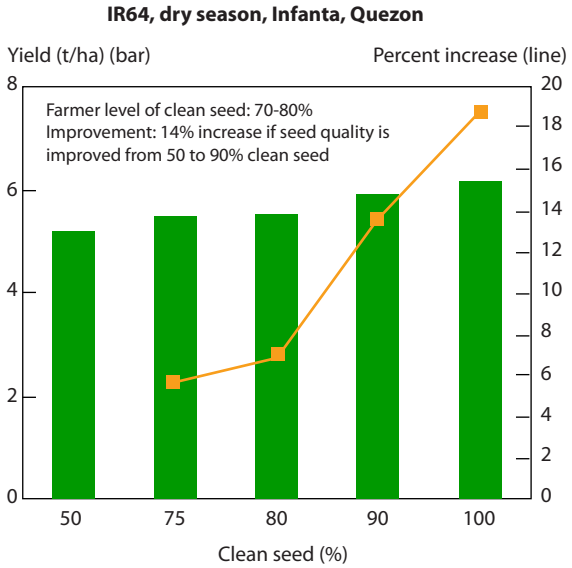
Step 10. During harvest, the farmers were trained to select healthy panicles and how to store the seed destined for planting in the next crop season.

In the farmers' participatory experiments, farmers' seed for planting were assessed together with seed management practices and seed storage practices. The yield gain by improving farmers' saved seed for planting ranged from 10 to 15% (**ISH Figure 8**). The disease incidence was reduced when farmers' own seed management was improved. This project illustrates a way to scale-up the technology of seed health improvement for rice disease management and rice crop production. It is now practiced in Bangladesh, Philippines, Thailand, Vietnam, and elsewhere.

8. Conclusions and perspectives

The concept of rice seed health management can be applied to increase yield and reduce significantly disease intensity, particularly of the panicle. The approach highlighted in this section is, and should remain useful, in areas where access to good quality seed is difficult **how it may be done**. This approach can be applied by the farmers with no costs entailed, apart from the time needed to select the panicles, sort the seed, and store under dry, cool conditions.

Alternate methods to improve rice seed health can be considered and could prove to be useful in the future. These methods include biocontrol agents, which could be coated on seed and provide protection against pathogens infecting during the early stages of



ISH Fig. 8. Yield gain using clean seed of different degrees for planting as a means to improve seed productivity.

crop establishment (For reference, see **Part III, Section 3, Managing Biological Control Agents** and Gnanamanickam 2002). Fungicide coating could also provide an efficient protection for seed against fungal pathogens infecting both seed and seedlings (Scher 1999). Finally, purchasing certified seed allows farmers to benefit from good-quality material and furthermore enables them to use rice varieties recently released with improved traits. This last option requires efficient channels to be developed to produce good-quality seed at low cost and at a large scale.

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