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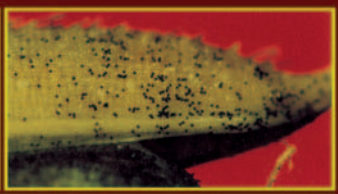
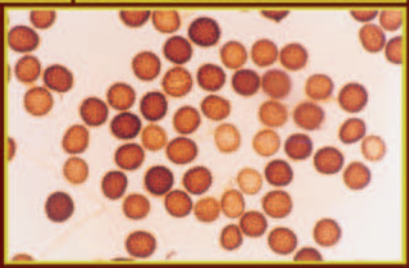
A Handbook of Rice Seedborne Fungi



T.W. Mew
and
P. Gonzales

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A Handbook of Rice Seedborne Fungi

T.W. Mew and P. Gonzales

2002

IRRI Science Publishers, Inc.

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Mailing address: DAPO Box 7777, Metro Manila, Philippines
Phone: (63-2) 845-0563, 844-3351 to 53
Fax: (63-2) 891-1292, 845-0606
Email: irri@cgiar.org
Home page: www.irri.org
Riceweb: www.riceweb.org
Courier address: Suite 1009, Pacific Bank Building
6776 Ayala Avenue, Makati City, Philippines
Tel. (63-2) 891-1236, 891-1174, 891-1258, 891-1303

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P.O. Box 699, Enfield, NH 03748
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COVER DESIGN: Juan Lazaro IV
FIGURES AND ILLUSTRATIONS: Emmanuel Panisales, Grant Leceta, Mylene Viray
LAYOUT AND DESIGN: Grant L. Leceta, Millet Magsino
PRODUCTION MANAGEMENT: Millet Magsino

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Preface

Seed health testing has become an important component of germplasm exchange between international centers and national agricultural research and extension system (NARES) partners. It assures the safe movement of seed, which is a carrier of pathogens, insect pests, and contaminants such as weed seeds.

This handbook focuses on the important seedborne fungi that cause diseases of the foliage, stem, leaf sheath, root, grain, and inflorescence in rice. It provides information on more than 50 species that have been detected in rice seed during routine testing and analysis.

Seed health testing is also a means of quality control that ensures the exchange of high-quality seed among scientists or research centers. For this reason, the Seed Health Unit at IRRI functions as the gatekeeper of safe germplasm movement from and within IRRI, the Philippines, and outside.

IRRI has always given high priority to the safety of germplasm exchange. It has worked closely with the Philippine Plant Quarantine Service to achieve this objective. As the volume of germplasm exchange increased annually, a Seed Health Unit was established in 1982 and a new laboratory was developed and deputized by the Philippine Plant Quarantine to undertake major activities on rice seed health testing for plant quarantine certification. Besides its regular activities on seed health testing of rice germplasm, the unit also offers rice seed health training to NARES partners. To date, more than 100 scientists from rice-growing countries worldwide have received such training.

Rice seed, like seeds of other crops, carries a large number of organisms, such as fungi described in this book, bacteria, and nematodes. These seedborne organisms can be pathogens and saprophytes; many of the bacteria or fungi carried by rice seed are also potential biological control agents against other rice pathogens. Some also function to promote seed germination and seedling vigor.

In quarantine regulations, seedborne pathogens often serve as barriers to seed movement for research and for trade. Misunderstanding arises because of insufficient biological and epidemiological data to guide the development of plant quarantine regulations. Many seed-importing countries need this information to determine whether seed carries the targeted pathogens of "quarantine importance." Yet little is known about the pathogens carried by seed in terms of crop damage and yield losses. Equally important is the transmission of seedborne pathogens in relation to disease establishment in the field and the consequent effects on crop production. Not every pathogen carried by rice seed, for instance, is transmitted to the field when the seed is grown. The rate of transmission varies from one pathogen to another and in the same pathogen when the seed is sown under different conditions for rice growth. These important subjects need further research.

Since the early 1960s, IRRI has conducted rice seed health testing to accomplish seed certification. As a result, the levels of rice seed infection caused by various microorganisms and the detection frequency of a given microorganism from different rice-growing countries are well documented. The information provided on seedborne fungi in this handbook can be used for teaching and as a reference when conducting seed health testing in different laboratories. It should be used with reference to local conditions.

Introduction

The purpose of seed health testing is to assure the safe movement of seed of different crops, for research or trade. It is premised on the hypothesis that many harmful organisms are carried by and moved together with the seed, and that these organisms have the potential to cause severe damage to crop production and crop seed for international trade once they are introduced. Seed health testing information reveals the organisms carried by the seed and the level of infection, or infestation, that will be introduced to another region or country. The information, although useful, does not indicate the importance of organisms carried by the seed. For most plant diseases, this information is not available. Such information comes from experiments or surveys under field conditions where the seed is grown.

Seed health testing can also be a means of quality control to improve seeding stocks for crop production by farmers. It is also useful for seed certification used by seed growers and public seed suppliers to farmers. Seed health testing is often done in the context of seed movement or trade for phytosanitary certification to meet plant quarantine regulations. The testing information, however, can also be applied to improve farmers' seed stocks for planting for crop management. In developing countries where farmers have to save their own seed for planting, knowledge of seed health can be very important to crop and pest management. It is a service that agricultural extension could provide. Farmers can acquire this knowledge through training. Seed health testing applied to seed certification would establish the standard for quality control. When the seed is put on the market, pest incidence is minimized and productivity of crop varieties is enhanced.

Rice seed, like seeds of other crops, carries many organisms. Among them, fungi, bacteria, and nematodes are the most commonly detected microorganisms. These seedborne organisms can be pathogens and saprophytes. Many of the bacteria or fungi carried by rice seed are potential biological control agents against other rice pathogens. Some of them also promote seed germination and seedling vigor. The ecological relationship between these beneficial microorganisms and the pathogens or between pathogenic forms and nonpathogenic forms on rice seed needs further investigation. Very little research on this subject is published in scientific literature.

Seedborne pathogens often serve as barriers to seed movement. Misunderstanding often arises because of insufficient biological and epidemiological data to guide the development of plant quarantine regulations. In scientific literature, research on seedborne pathogens focuses on developing methods for accurate and reliable detection of pathogens on or in the seed. Many importing countries need seed health information to determine whether the seed carries targeted pathogens important to quarantine. Without epidemiological data on the disease that the pathogen causes, we cannot establish the standard and level of importance of the disease. We know very little about crop damage and yield losses caused by pathogens carried by seed. Equally lacking is information about disease establishment in the field and the effect of seedborne pathogens on crop production. Not every pathogen carried by rice seed, for instance, is transmitted to the field when the seed is grown. Transmission varies from one pathogen to another and the same pathogen may react differently when the seed is sown in different growth conditions. These are important topics for further research. In this publication, we provide information on fungi commonly detected from rice seed during routine seed health testing. We also review briefly the missing links in information on seedborne pathogens and the seed as a source of inoculum for disease development in the field.

Microorganisms carried by seeds can be classified as pathogens, nonpathogens, and nonpathogens with biological control properties. From the viewpoint of plant quarantine regulations, seed-carried microorganisms can be distinguished into either "hazard" or "common organisms" (Kahn and Mathur 1999). "Hazard" organisms involve those pathogens that have never been introduced into an area and can cause serious damage to crop production. Information on the level of damage caused by seedborne pathogens is not always available. The quarantine decision is often conservative to avoid any untoward consequences. Whether serious crop damage or yield losses would occur is a matter of speculation and not necessarily based on experimental results,

which take into account various production situations and ecology. In reality, it is not possible or desirable to obtain seed lots free from any organism (Mew 1997).

From a plant pathologist's point of view, there are missing links in documented information on seedborne pathogens. McGee (1995) pointed out the need for accurate information on seed transmission of some key seedborne pathogens. We need to study the epidemiology of seedborne pathogens in relation to disease development in the field. We need yield loss data to estimate the risk of seedborne pathogens. Furthermore, we need to study the role of seed health testing to improve farmers' pest management and crop production. To know whether common pathogens carried by the seed pose a threat to crop production, we need to understand disease epidemiology. Conventional seed health testing provides adequate information about the frequency of detection from the seed and levels of seed infection. We need to assess whether these pathogens, upon detection, could be transmitted to the field when the seed is sown and if the disease that develops causes damage or injury to effect yield loss. In scientific literature, this information is not readily available or it needs to be confirmed. Very little research has been done in this area. Because of the increasing concern about seedborne pathogens, we need to understand their epidemiology. The initial inoculum is the key to understanding what causes an epidemic in a plant quarantine context. The threshold inoculum carried by a seed lot has to be defined in terms of its effect on transmission and disease establishment. Detection methods and the potential role of nonpathogenic microorganisms, especially those possessing biological control properties, must be studied and taken into account.

Functions of seed health testing

Seed health testing is done to determine microbial infection or contamination for quarantine purposes (e.g., international seed exchange or movement). It identifies the cause of seed infection that affects the planting value of seed lots for seed certification by seed growers to supply seed to farmers. Seed testing affects policies on seed improvement, seed trade, and plant protection. Neergard (1979) brought out the importance of pathogens carried by seeds and the disease potential assigned to pathogens.

Several routine activities are undertaken during seed health testing. These include dry seed inspection, the standard blotter test for seed infection and contamination, postentry planting for field inspection of undetected plant diseases of seedborne and seed-contaminated pathogens, and certification. In seed multiplication for export, crop inspection prior to seed harvest offers an additional means to link seedborne pathogens and diseases of mother plants. All these activities provide preventive measures to eliminate the introduction of undesirable pathogens into a region or country. Seed health testing offers a powerful tool for documenting microorganisms associated with seeds. Information on microorganisms, however, needs to be associated with a database on yield loss and information on pathogens that cause diseases.

Catalouging pathogens of crops

For rice, seed health testing has been done on more than 500,000 seed lots following International Seed Testing Association (ISTA) rules (1985). A total of more than 80 fungi were detected on rice seeds (Table 1). The detection frequency varied. About 20 species of fungal pathogens were detected from rice seed at any one time. Not all of them cause notable diseases in the field and it was not ascertained whether diseases were all seed-transmitted and, if so, what their transmission efficiency was. The role of a rice seed in a fungus life cycle is not clear.

Pyricularia oryzae, the rice blast pathogen, although considered a very important rice pathogen, has the lowest detection frequency. The level varied according to seed source. Except *Fusarium moniliforme*, the seedborne inoculum of the other pathogens may not serve as an important source of secondary inoculum in the field. The infection level of *P. oryzae* is likely to be higher in temperate or subtropical environments than in tropical environments. The data set provides insights into the occurrence of rice fungal pathogens. The detection frequency and infection level are very high for *Alternaria padwickii* (80–90%) (Fig. 1). In tropical Asia, stackburn, the disease it causes, is hardly observed in the field.

Detection methods

Many detection methods have been developed over the years for various seedborne pathogens. We found the blotter test to be a common but efficient method of detecting seedborne fungal pathogens in rice seed. Following ISTA rules, the method involves plating 400 seeds on some layers of moistened filter paper. Below is a list of the different detection methods used in routine seed health testing. Descriptions of these methods can be found in the references listed (see page 82).

Seed health testing procedures involve techniques such as

- Direct examination of dry seeds
- Examination of germinated seeds
- Examination of organisms removed by washing
- Examination after incubation (both blotter and agar plates)
- Examination of growing plants (for example, the seedling symptom test)
- Embryo count methods
- Molecular and serological techniques

Other methods include a selective medium for specific pathogens. With advances in molecular techniques, emphasis in fungal identification and taxonomy has changed from a morphological approach (for example, spore size and spore shape) to a more functional approach based on aspects of the life cycle, mechanisms of spore production and release, DNA relationships, and physiological attributes. DNA analysis techniques such as the polymerase chain reaction (PCR), and random amplified polymorphic DNA (RAPD) analysis are the most commonly used tools.

These are powerful techniques for detecting and for establishing the relationship between the inocu-

Table 1. Fungi detected on rice seeds, IRRI Seed Health Unit (SHU) data (1983-97).

Species	Incidence[a]	Species	Incidence
Alternaria padwickii	+++	*D. rostrata*	+
Bipolaris oryzae	+++	*D. sacharri*	+
Curvularia lunata	+++	*D. sorokiniana*	+
C. oryzae	+++	*D. turcica*	+
Fusarium semitectum	+++	*D. tetramera*	+
F. moniliforme	+++	*D. victoriae*	+
Microdochium oryzae	+++	*Fusarium avenaceum*	+
Phoma spp.	+++	*F. decemcellulare*	+
Sarocladium oryzae	+++	*F. equiseti*	+
Alternaria longissima	++	*F. fusarioides*	+
Aspergillus clavatus	++	*F. graminearum*	+
A. flavus-oryzae	++	*F. larvarum*	+
A. niger	++	*F. longipes*	+
Curvularia affinis	++	*F. nivale*	+
C. oryzae	++	*F. solani*	+
Cladosporium sp.	++	*F. tumidum*	+
Epicoccum purpurascens	++	*Gilmaniella humicola*	+
Nakataea sigmoidea	++	*Graphium* sp.	+
Nigrospora oryzae	++	*Leptoshaeria sacchari*	+
Penicillium sp.	++	*Masoniomyces claviformis*	+
Pinatubo oryzae	++	*Melanospora zamiae*	+
Pithomyces maydicus	++	*Memnoniella* sp.	+
Rhizopus sp.	++	*Microascus cirrosus*	+
Tilletia barclayana	++	*Monodictys levis*	+
Ustilaginoidea virens	++	*M. putredinis*	+
Acremoniella atra	+	*Nectria haematococca*	+
Alternaria tenuissima	+	*Nigrospora sphaerica*	+
Annellophragmia sp.	+	*Papularia* sp.	+
Botrytis cinerea	+	*Penicillifer pulcher*	+
Cephalosporium sp.	+	*Periconia* sp.	+
Cercospora janseana	+	*Pestalotia* sp.	+
Chaetomium globosum	+	*Phaeoseptoria* sp.	+
Chramyphora sp.	+	*Phaeotrichoconis crotolariae*	+
Colletotrichum sp.	+	*Phyllosticta* sp.	+
Corynespora sp.	+	*Phyllosticta glumarum*	+
Cunninghamella sp.	+	*Pyrenochaeta oryzae*	+
Curvularia cymbopogonis	+	*Pyricularia grisea*	+
C. eragrostidis	+	*Septogloeum* sp.	+
C. inaequalis		*Septoria* sp.	+
C. intermedia	+	*Sordaria fimicola*	+
C. ovoidea	+	*Spegazzinia deightonii*	+
C. pallescens	+	*Spinulospora pucciniiphila*	+
C. stapeliae	+	*Stemphylium* sp.	+
Cylindrocarpon sp.	+	*Sterigmatobotrys macrocarpa*	+
Darluca sp.	+	*Taeniolina* sp.	+
Diarimella setulosa	+	*Tetraploa aristata*	+
Diplodia sp.	+	*Trichoderma* sp.	+
Drechslera cynodontis	+	*Trichosporiella* sp.	+
D. dematioideum	+	*Trichothecium* sp.	+
D. halodes	+	*Trichosporiella* sp.	+
D. hawaiiensis	+	*Tritirachium* sp.	+
D. longistrata	+	*Ulocladium* sp.	+
D. maydis	+	*Verticillium albo-atrum*	+

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

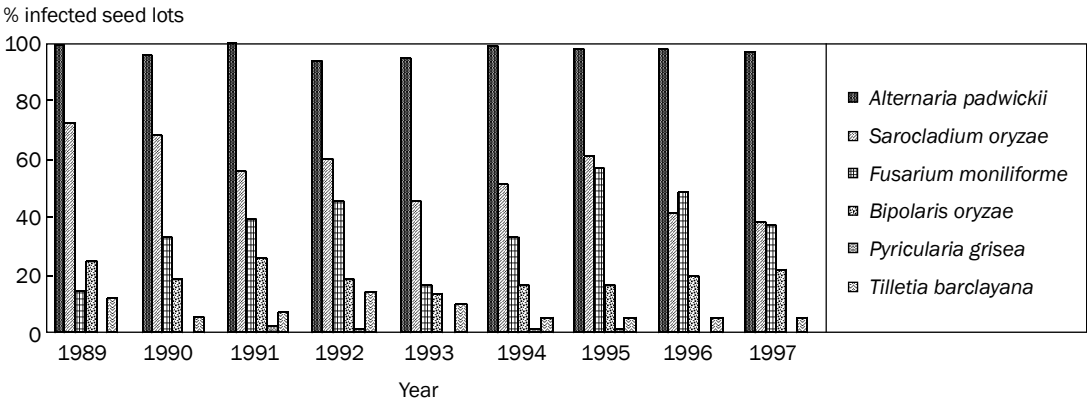

Fig. 1. Detection of common seedborne fungal pathogens of rice from exported seeds at IRRI, 1989-97.

Table 2. Level of fungal pathogens detected from seeds, field observations on seed planted in the field after treatment, disease incidence, and level of fungal infection detected from harvested seeds (24 entries; 1996 dry season).

Fungal pathogen	RSHT[a] at receipt (%)	Disease	Field inspection for disease		%
			Entries infected	RSHT at harvest	
Alternaria padwickii	15.7	Stackburn	0	*A. padwickii*	10.7
Curvularia spp.	5.4	Black kernel	0	*Curvularia* spp.	9.0
Sarocladium oryzae	0.8	Sheath rot	2 (8.3%)	*S. oryzae*	2.7
Gerlachia oryzae	2.7	Leaf scald	2 (8.3%)	*G. oryzae*	0.2
Fusarium moniliforme	0.2	Bakanae	0	*F. moniliforme*	3.8
Bipolaris oryzae	1.7	Brown spot	*0*	*B. oryzae*	0.4
Pyricularia grisea	0	Blast	1 (4.1%)	*P. grisea*	0
Phoma sp.	1.6	Glume blight	0	*Phoma* sp.	4.6
Tilletia barclayana	0.3	Kernel smut	0	*T. barclayana*	0
		Disease-free 19 entries (79%)			

[a]RSHT = routine seed health test. Seed treatment applied: hot water, 52–57 °C for 15 min plus Benlate and Dithane M-45 at 0.1% by seed weight.

lum of seedborne pathogens and diseases in the field.

Postintroduction measures

"Damage control" often refers to actions taken to minimize damage after it has happened. The concept can be applied to seedborne fungal pathogen management by relating it to postquarantine treatment. There is always concern that if a pathogen is unintentionally introduced into a country or region, it may cause potential damage to the crop. The entry of infected seeds when seed lots are brought into a country is unavoidable. However, it is still not clear whether the infected seed being introduced will begin an infection of the crop in the field. It is desirable to limit the probability of infection. Several postquarantine treatments can be applied to control such damage. Many of these postquarantine treatments provide measures to counteract the introduction of undesirable pathogens (Table 2).

Seed health testing is important to assure the safe movement of seed on the one hand and to control the spread of seedborne diseases through seed movement on the other hand.

Seed treatment and seed health testing to eliminate potential pathogens are damage control steps intended to avoid the introduction of key pathogens. Currently available information or control measures in place may not be adequate. Some control measures, such as seed treatment, successfully check the movement of pathogens from the seed.

The missing link

Epidemiology

There is little doubt that many pathogens are seedborne. Questions arise, however, on whether the introduction of seedborne inoculum of these pathogens would lead to the establishment of a disease in the field or whether the field population of a fungal pathogen is derived from the seedborne inoculum.

Pathogens of significance to quarantine suggest the potential of seed transmission. They also relate to the potential damage or yield loss caused by diseases derived from the seedborne inoculum of the pathogen. However, there is very little accurate information about yield loss caused by rice diseases, and diseases derived from seedborne inoculum. Yield loss caused by a pest outbreak or a disease epidemic is important in determining pathogens with quarantine significance. There are very few comprehensive studies or databases on yield losses caused by pests or pathogens in scientific literature. Studies conducted and documented by Savary et al (1996, 1997, 1998, 2000a,b), Savary and Willocquet (1999), and Willocquet et al (1999a,b) are some of the most comprehensive ones on rice diseases. Using both survey and experimental data, they developed pest and pathogen profiles for different rice production situations (PS). Production situations refer to the set of environmental conditions—climatic, technical, social, economic, and biological—under which agricultural production takes place. These were then related to yield losses with individual pests and pathogens, and also pest and pathogen profiles.

Savary et al (1996, 1997, 1998, 1999) believe that by using such a systems approach combined with different statistical analyses, all these factors could be captured by a limited number of variables, such as those that describe patterns of cropping practices, for example, method of crop establishment, amount of chemical fertilizer used, type of weed control, and rice cultivar type (with or without disease resistance). In reality, farmers' practices are, to a large extent, reflections of, or adaptations to, social, physical, and biological environments. Injury profiles refer to the sequence of harmful organisms that may occur during the crop cycle. Many such organisms affect rice. The number of processes by which a pest or pathogen may affect rice, however, is limited to less than 10, and injuries are often associated with one another. On this basis, yield losses caused by individual injuries as well as by injury profiles establish the importance of rice pests and diseases in specific PS at the regional level (Savary et al 2000a,b).

The database identified sheath blight caused by *Rhizoctonia solani* AG1 and brown spot caused by *Bipolaris oryzae* as the two most important diseases in rice in Asia, each responsible for 6% yield loss, whereas blast caused by *Pyricularia grisea* and bacterial blight caused by *Xanthomonas oryzae* pv. *oryzae* account for 1–3% and 0.1% yield losses, respectively. However, most rice cultivars planted by Asian farmers are resistant to these two diseases. If cultivars possess no resistance to these two diseases, yield losses are likely to be higher than current estimates. Other diseases, such as sheath rot, stem rot, and those known as sheath rot complex and grain discoloration (Cottyn et al 1996a,b), are responsible for rice yield losses ranging from 0.1% to 0.5%. All other diseases alone or in combination would not cause more than 0.5–1% yield losses based on estimates. Projected yield losses cause by various rice diseases under different production situations are given in Table 3.

In seed health testing, detection frequency means the number of pathogens detected in a seed lot. Infection frequency refers to the number of seeds (based on 400 seeds tested) within a seed lot which are infected (Mew and Merca 1992) and is equivalent to the inoculum level. In the epidemiological sense, no information is available to correlate detection frequency and infection frequency to seed transmission and disease establishment in the field. Still, there are other questions related to seedborne pathogens that must be answered. In rice, in which most fungal pathogens can be seedborne, and for which current farmer cultural practices have done little to improve quality (a result of farm labor shortage and short turnaround time), what is introduced to the field with seeds when the rice crop is planted? In seed production fields, it is necessary to practice disease management to produce disease-free seed?

Table 3. Pathogen profiles closely associated with rice production situations (PS) and potential yield losses caused by rice diseases (adapted and modified from Savary et al 1998, Savary and Willocquet 1999).

	PS1	PS2	PS3	PS4	PS5	PS6	Yield loss (%)
Actual yield (t ha^{-1})	4.8	4.6	3.5	6.7	3.8	3.9	
Disease							
Blast[a]			L	L	M	M	1–3
Bacterial blight	L	L		L	L	L	0.2
Bakanae				VL			0.0
Brown spot	L	L	VH		H	H	6.6
Sheath blight	VH	VH	M	VH	H	H	6.4
Sheath rot complex	M	M	H	M			0.5
Grain discoloration	M	M	H	M			0.1
Characteristics of environments							
Mineral fertilizer	m	l	l	h	m	h	
Fallow period	l	l	m	s	m	s	
Drought stress	l	l	h	l	h	m	
Water stress	l	l	l	h	h	h	
Crop establishment	tr	tr	tr	ds	ds	ds	
Herbicide use	m	l	l	m	l	l	
Insecticide use	m	m	m	m	m	m	
Fungicide use	l	l	l	h	h	h	
Previous crop	rice	rice	w/b	w/b	rice	rice	

[a]In the surveys, rice varieties possessing resistance to blast and bacterial blight diseases. For characteristics of environments, m = moderate, h = high, l = low, tr = transplanted rice, ds = direct-seeded rice, s = short, w/b = wheat or barley. For diseases and grain discoloration, L = low, M = medium, H = high, VH = very high.

Disease and infection cycles

Figure 2 shows how seedborne inoculum reinfects the seed during the development of a disease epidemic: seedborne inoculum → disease establishment → disease development in the field (infection cycle) → crop damage or yield loss (effect of seedborne inoculum) → reinfection of infestation of seed (potential dissemination to other fields, regions, or countries).

There is voluminous information on seedborne pathogens of various crops derived from routine seed health testing for either certification or issuance of phytosanitary certificates. Information on transmission of the pathogen from the infected or infested seed to disease development in the field is scarce. Various factors that affect the infection cycle are weather conditions, cropping practices, resistance or susceptibility of the variety, virulence of the pathogen, and amount of incoculum produced for secondary spread and efficiency of the inoculum.

It is often assumed that, for a pathogen to be seedborne, it must be seed-transmitted. McGee (1995) indicated that in only very few seedborne pathogens is the transmission clearly established.

When conditions in the nursery bed and the ecosystem where rice is grown re taken into account, there is inadequate documentation on plant quarantine to guide decision making. It is not known under what specific conditions seedborne pathogens are transmitted to the crop at the seedling stage. Blast caused by *P. oryzae* and bakanae caused by *F. moniliforme*, are two of the better known diseases (Ou 1985). Once a disease is established in a crop, its intensity will depend on factors that influence the infection cycle. Climatic conditions and crop management practices are crucial to disease development.

In rice, the infection frequency of *P. oryzae* is very low, yet the disease potential under a conducive environment (e.g., upland, subtropical, and temperate) is very high. Once seedlings are infected from seedborne inoculum, even at a low infection rate, millions of conidia are produced for secondary infection. On the other hand, seedborne *F. moniliforme* often induces bakanae with only one cycle of infection. Therefore, the initial inocu-

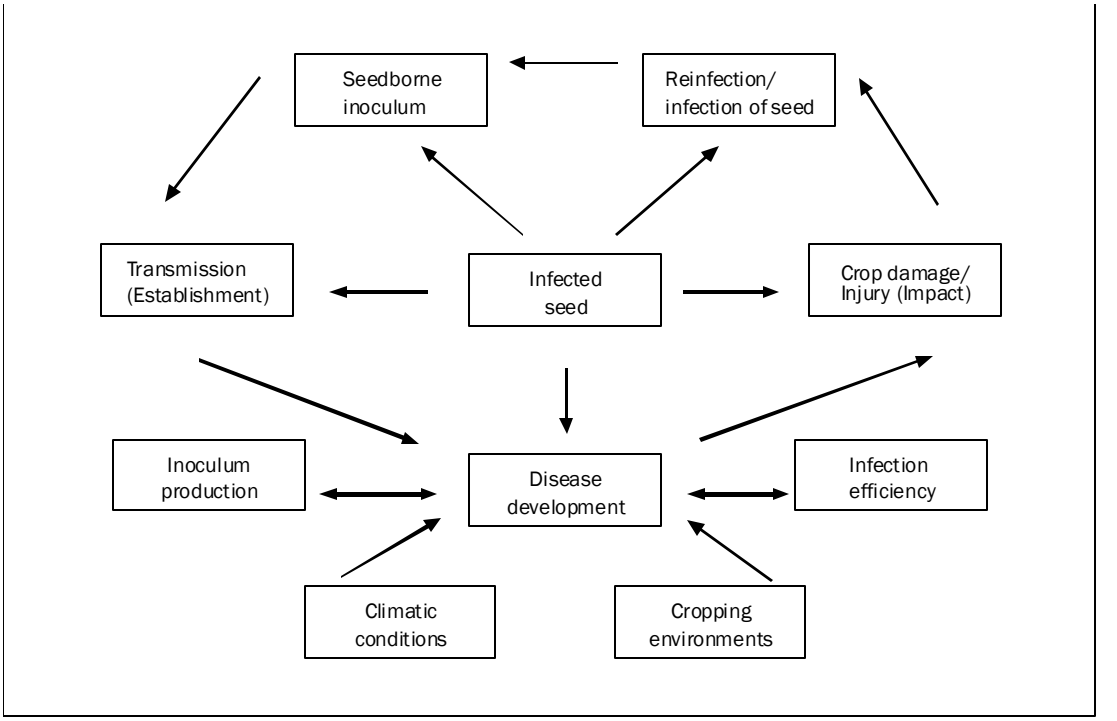

Fig. 2. Diseases and infection cycles of a seedborne fungal disease and its effect.

lum for *F. moniliforme* is important. Once the seedborne inoculum is minimized, the disease is likely to be controlled.

Changes in crop cultivation methods and cultural practices affect seedborne diseases. In traditional methods of cultivation, rice seedlings are raised in a seedbed with a saturated water supply. Because of the reduction in arable land and the decreasing productivity of available agricultural land, new methods of cultivation are being developed. These new methods are conducive to the transmission and development of seedborne diseases previously considered minor.

In epidemiological research, seed transmission and establishment of disease derived from seedborne inoculum should be considered. These data are essential for assessing the importance of seedborne pathogens.

Seed transmission

McGee (1995) indicated that one of the missing links in seed health testing is the lack of information on seed transmission. Based on postquarantine planting, one of the difficulties encountered is distinguishing between a disease that developed from inoculum derived from the seed and that from other sources. Polymerase chain reaction (PCR) DNA technology is useful in this regard. Based on DNA fingerprinting, patterns of a pathogen population can be distinguished from those of the pathogen manifesting a disease on the crop grown from the seed. This would establish the transmission of the seedborne inoculum and its relation to the disease on the crop in the field. In routine disease monitoring of field crops such as rice or other nursery crops, identifying disease foci in nursery beds may be an alternative. For rice, this appears feasible at the seedling stage in the seedbed. A disease focus is a patch of crop with disease limited in space and time (Zadoks and van den Bosch 1994) and is likely to have been caused by the initial source of inoculum. In Japan, the seedbox nursery for rice provides an ideal means to identify the disease foci of single or different seedborne pathogens. The paper towel method, a very common method for testing seed germination, resulted in more seedling mortality and thus less germination than the seedbed method (seedbed with field soil) used in crop production (Table 4). The method used for assessing the effect of seedborne fungal pathogens on seed germination varies.

Table 4. Germination (%) of untreated and treated seeds using paper towel and in-soil germination methods (400 seeds each; randomized complete block design).

Varieties	Normal[a]		Abnormal		Dead seeds	
	Paper towel	In-soil test	Paper towel	In-soil test	Paper towel	In-soil test
Untreated						
IR62	79.7 ab	91.7 a	16.0 a	5.3 a	4.3 a	3.0 b
SARBON	65.3 b	75.7 ab	20.3 a	12.0 a	14.3 a	12.3 ab
C22	94.0 a	84.0 ab	4.3 b	10.3 a	1.7 a	5.7 ab
BS1-10	68.0 b	72.7 b	18.3 a	11.0 a	13.7 a	16.3 a
Hot-water treatment						
IR62	86.7 a	85.3 a	5.0 b	7.7 b	8.3 b	7.0 b
SARBON	46.3 b	50.3 c	19.7 a	10.3 b	34.0 a	39.3 a
C22	92.3 a	94.3 a	5.0 b	4.0 b	2.7 b	1.7 b
BS1-10	76.3 a	67.7 b	13.7 ab	25.0 a	10.0 a	7.3 b

[a]In a column under each treatment, means followed by a common letter are not significantly different at the 5% level by Duncan's multiple range test.

Relationship between seedborne inoculum and disease development in the field

In determining the importance of a seedborne pathogen, it is essential to relate inoculum production and the efficiency of the secondary spread to the inoculum threshold and disease severity after establishment.

For a monocyclic disease, initial infection should be closely related to the initial inoculum provided by the seed. For a polycyclic disease, a low level of seedborne inoculum is adequate to begin infection from the seedbed to the main field, and increase disease intensity if climatic or crop-growing conditions are favorable. For instance, in rice blast caused by *P. oryzae* with low detection and infection frequencies, seed-carried inoculum is more important in temperate or subtropical environments than in a tropical lowland environment. In the former environments, the likelihood of seed-carried inoculum beginning an infection and producing a sufficient amount of inoculum for secondary infection is higher (Ou 1985).

Inoculum level and inoculum thresholds

In seed health testing for certification, the inoculum threshold of seedborne pathogens is defined as the amount of seed infection or infestation that can cause a disease in the field under conducive conditions and lead to economic losses (Kuan 1988). We believe that this should mean a minimal amount of seed infection or infestation. In principle and as Gabrielson (1988) indicated, one infected seed may give rise to one infected plant, but, under field conditions, this is hardly the case. The values of the inoculum threshold for different crop-pathogen combinations in different countries vary widely (Gabrielson 1988).

Our experience with rice has shown that the potential of a seedborne pathogen to cause a disease is determined by the type of pathogen in relation to the crop growth environment. Under conditions in a wet-bed nursery for rice seedlings, the likelihood of a fungal pathogen beginning an infection appears less than under tropical conditions. Perhaps this is because of the microbial competition or antagonism. On the other hand, if the level of seedborne inoculum is high (we have not had it quantified), then the probability of it causing infection is also high. As one infected seed begins one disease focus and this focal point expands, the probability of infection increases. In reality, disease establishment is affected by inoculum density and the crop cultivation environment. The more infected seeds there are (inoculum level), the higher the probability of having an infection.

We have monitored detection levels of seedborne fungal pathogens from imported seed lots by planting them in the field after seed treatment for postentry plant quarantine observation. Diseases observed were not related to seedborne pathogens (Table 2). Pathogens from harvested seeds from these plants were detected, but we are not sure whether these fungal pathogen populations were the same as those carried by the original seed or if they came from other sources in the field.

For other fungal pathogens, there is a close relation between seed infection and infected plants grown from these seeds. An example is blackleg of crucifer caused by *Phoma lingam* (*Leptosphaeria maculans*) (Gabrielson1983). The classical example from Heald (1921) indicated that the sporeload of seeds was highly correlated to the percentage of smut appearing in the field.

Inoculum thresholds vary according to cultural environments. In Japan, for instance, after rice cultivation became mechanized and seedlings were raised indoors in seedboxes, the occurrence of many seedborne fungal and bacterial pathogens increased. This is because the indoor conditions—high temperature and high humidity with artificial light—are very favorable for seedling disease development. As a result, the inoculum threshold is lower than that of seedlings raised outdoors under a field nursery. The inoculum becomes more efficient under certain conditions.

Inoculum efficiency is determined by various factors. The type of disease and crop-growing environments are important. Gabrielson (1988) cautioned that thresholds must be developed for average environmental conditions of crop growth because they are influenced by all factors affecting the epidemiology of each host-parasite combination. It is difficult to use a single threshold of a single disease for all cropping environments. There is no clear definition on levels of threshold for the different pathogens detected from the seed. In rice, different fungal pathogens are detected from the seed (Table 1) and all of them are distributed throughout the rice-growing countries worldwide. Disease potential, however, depends on the rice ecosystem (upland, rainfed, irrigated, tropical, subtropical, and temperate environments, and deepwater and tidal coastal areas), cultural conditions, and types of crop management and production. Whether there is a need to treat all diseases the same way or differently for different ecosystems and production levels needs careful study. There is a general agreement that the threshold level for a disease is zero in an area if it has not been reported there.

Risk analysis

Risk analysis should serve an important basis for developing plant quarantine regulations. Risk analysis based on seed health testing needs to consider the following factors:

1. type of pathogens
2. role of seed in the life cycle of the pathogen
3. disease or epidemic potential
4. genetic variability of the pathogen
5. type or site of initial infection
6. kind of crop production environment (Mew 1997)

The risk of infection from seedborne pathogens is a function of risk probability and risk magnitude. Furthermore, risk probability is determined by introduction risk, that is, the probability that a pathogen enters a region or a field through the seed, the epidemiological risk, the probability that the pathogen establishes infection through seedborne inoculum. Risk magnitude is the potential consequence of an epidemic caused by the pathogen. Consequences are considered from the viewpoint of yield loss. Seed health testing results provide actual data on a pathogen that could potentially be introduced into a region or a field. The risk magnitude can be computed from a yield loss database or from modeling. In rice, this kind of database is available at IRRI. The yield loss database provides an estimate of losses and "hazards" caused by a pathogen once the infection is established through seedborne inoculum.

However, data are lacking on the transmission efficiency of seedborne inoculum of many rice seedborne pathogens. A concerted effort is needed to compile this information through international collaboration. Research on seed pathology provides the basis for setting seed health testing policy, while information on pest or pathogen risk provides a starting point for seed health testing on target organisms for plant quarantine regulations. Very limited or no financial support is available for this important area of activities.

A yield loss database can estimate the "hazards" of a pathogen once an infection is established through the introduction of a seedborne inoculum. However, data on inoculum levels and thresholds are also needed to develop realistic assessment or measurement procedures for some important seedborne pathogens. Data on seed transmission of many pathogens and transmission efficiency of seedborne inoculum are currently not available.

Although conventional seed health testing provides adequate information on detection frequency and infection levels of some pathogens, we need to assess whether these pathogens cause any real injury to effect yield loss. In scientific literature, this information is not readily available.

Microorganisms associated with seed

Not all microorganisms associated with seed are pathogens. Some microorganisms possess biological control properties. The occurrence of nonpathogenic *Xanthomonas* has further complicated the issue of seedborne bacterial pathogens. Cottyn et al (2001) and Xie et al (2001) proved that seedborne antagonistic bacteria are present in rice and promote seed germination and seedling vigor, and also suppress disease with an inoculum from the seed. Microflora associated with the seed may be roughly categorized into pathogens and nonpathogens. The study by Cottyn et al (2001), supported by the Belgium Adminstration for Development Cooperation, and Xie et al (2001) showed that rice seed carries many bacteria belonging to 17 genera and over hundreds of species. Predominant were *Enterobacteriacae* (25%), *Bacillus* spp. (22%) and *Pseudomonas* spp. (14%). Other bacteria regularly present were *Xanthomonas* spp., *Cellulomonas flavigena*, and *Clavibacter michiganense*. We found that about 4% of the total bacterial population possesses biological control properties against most seedborne pathogens. Also, seedling vigor was enhanced after soaking seeds in bacterial suspension. These studies show that rice seed not only carries pathogens but also abundant microorganisms that act as biological control agents. Whether they play a bigger role in crop production and disease management needs further research. More support should be given to this research area, which is a vital part of a farmers' internal resource management for sustainable crop production and disease management.

Seed health management for crop production

In tropical Asia, the productivity of newly released modern rice cultivars declines rapidly because of seed health problems associated with the continuous use of the seed without adequate seed health management. At IRRI, we have conducted research on seed health management since the early 1990s. The research effort has focused on understanding farmers' seed health problems in relation to crop management and production. By improving farmers' seed health management, rice yield could be increased by 5–20%. Increasing farmers' yields generates more income and profit. The marginal cost-benefit ratio was estimated at 5, and even 10, depending on the quality of the farmers' original seed stock for planting (T.W., unpubl. data).

Seed health management is an important way of reducing pest damage and weed infestation in the field. By employing sound seed health management, farmers not only minimize the use of harmful agrochemicals, they also maximize the genetic yield potential of these modern rice cultivars. We found that the productivity of foundation seed is reduced by 1 t ha^{-1} in three crop seasons using current farmers' seed health management practices (L. Diaz, M. Hossain, V. Merca, and T.W. Mew, unpubl. data). Yield changes according to the level of "high-quality seed" in seed stock used by farmers. When the level of high-quality seed reached 90% of the seed stock for planting, the yield increase was not significant.

In rice seed health testing, little information exists on pathogen detection frequency on seed and on which part of the seed an organism is likely to be located. This handbbok contains information on rice seed health testing that we have been carrying out for the past 20 years. We hope to offer seed health testing technicians, college or graduate students, and teachers in plant pathology or seed technology a useful guide. Information on seed health testing can also be an important means of improving crop production practices of farmers. The information contained in this handbook is based on IRRI's rice seed health testing activities on both incoming and outgoing seeds. Thus, the material provides a reference for many seed health testing laboratories. In view of the increasing interest in international trade in rice, the handbook also serves as a basis for establishing plant quarantine guidelines for individual countries.

Identification of fungi detected on rice seed

The standard detection method used in identifying fungi on rice seed at IRRI is given below. Figure 3 shows the parts of a rice seed attacked by fungi. With this method, numerous fungi have been detected on rice seed. The profile of each fungus detected is presented in the following pages.

Methods and conditions of rice seed incubation for microorganism detection are listed below.

The International Rules for Seed Testing recommend the blotter test for detecting seedborne fungi. The procedure involves these steps:

1. Prepare materials (9.5-cm plastic petri dish, marking pencil, round blotter paper, distilled water, sampling pan, forceps, seed sample).
2. Label plates accordingly using a marking pencil.
3. Place 2–3 pieces of moistened round blotter paper in labeled plastic petri dishes.
4. Sow 25 seeds per plate making sure that seeds are sown equidistantly with 15 seeds on the outer ring, 9 seeds at the inner ring, and 1 seed in the middle.
5. Incubate seeded plates at 21 °C under a 12-h light and 12-h dark cycle. Light sources can be near ultraviolet (NUV) light or daylight fluorescent tubes. The NUV light source can be a 320–400 nm lamp, preferably Philips TLD 36W/08 or GE F 40 BL. Daylight fluorescent tubes can be Philips TL 40W/54 day light or its equivalent.
6. Examine each of the seeds after 5–7 d of incubation for fungal growth.

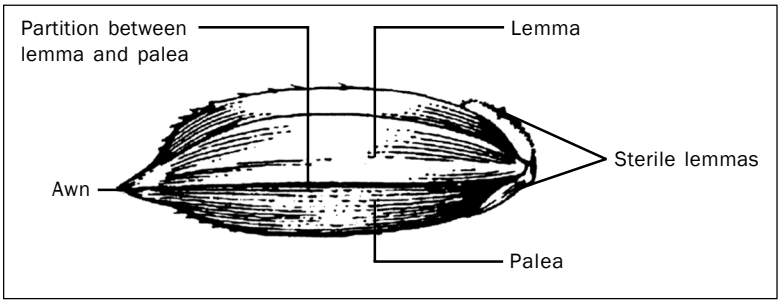

Fig. 3. Parts of a rice seed.

Seedborne fungi causing foliage diseases in rice

Alternaria padwickii (Ganguly) Ellis
syn. *Trichoconis padwickii* Ganguly
Trichoconiella padwickii (Ganguly) Jain

Disease caused: stackburn

a. Symptoms
On leaves—large oval or circular spots with a pale brown center and distinct dark brown margin. Color of center eventually becomes white and bears minute black dots.
On grains—pale brown to whitish spots with black dots at the center and dark brown border.
Roots and coleoptile of germinating seedlings—dark brown to black spots that eventually coalesce. Small, discrete, and black bodies are formed on the surface of the darkened area as decay proceeds.

b. Occurrence/distribution
Stackburn disease is widespread in most of the rice-growing countries worldwide (Fig. 4).

c. Disease history
The disease was first reported in the U.S. It resembles black rust of wheat on rice leaves, but only sclerotia and mycelium were observed. Later the fungus was observed in and on rice seeds.

d. Importance in crop production
Stackburn leaf spot disease is not considered to be of economic importance. However, seed infection results in grain discoloration, which may reduce germination and lower grain quality. The disease potential of stackburn is very low and the yield loss caused by *A. padwickii* in literature may be overestimated. The effect of infected seed on seed germination is not yet properly assessed.

Detection on seed

a. Incubation period on blotter
A. padwickii is easily observed on seeds using the blotter method 5 d after seeding on moistened blotter and incubated under NUV at 21 °C. The detection frequency is about 67.1% on seeds coming from different regions (Fig. 5a,b).

b. Habit character
Seed infected with *A. padwickii* after incubation shows abundant aerial mycelia, hairy to cottony, profusely branched, grayish or hyaline when

Fig. 4. Occurence of stackburn (Ou 1985, Agarwal and Mathur 1988, EPPO 1997).

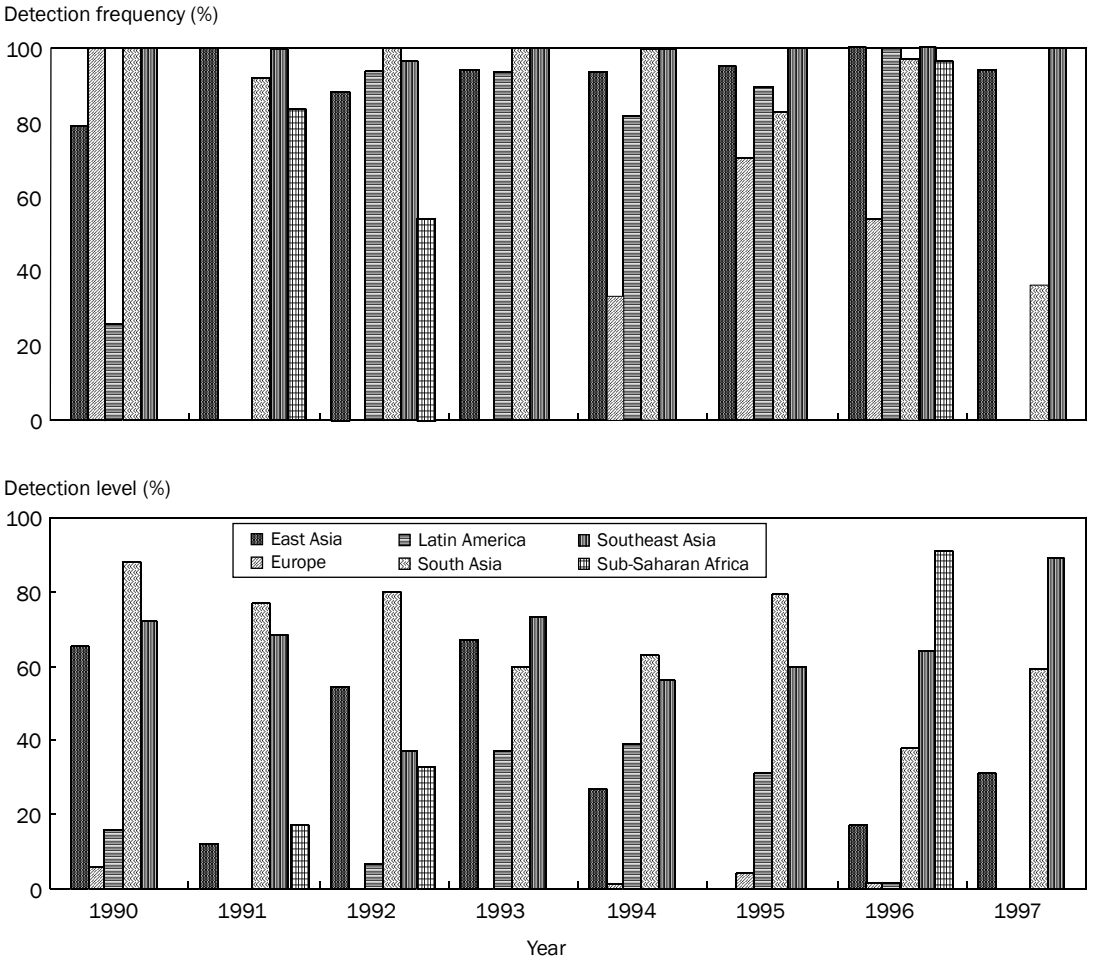

Fig. 5. Detection level (a) and frequency (b) of *Alternaria padwickii* from imported untreated seeds, 1990-97.

young, becoming creamy yellow when mature; pinkish to light violet pigmentation is produced on the blotter; conidia are borne singly per conidiophore; darker than mycelia; sterile appendage prominent (Fig. 6a-c).

c. Location on the seed
A. padwickii is most often observed growing over the entire seed surface (36%) (Fig. 7).

Microscopic character

a. Mycelia—septate, profusely branched; hyaline when young, becoming creamy yellow when mature; branches arising at right angles from the main axis (Fig. 6d).
b. Conidiophore—simple, not sharply distinguishable from mature hyphae, often swollen at the apex, hyaline when young, becoming creamy yellow when mature (Fig. 6e).
c. Conidia—straight, shape varies from fusiform to obclavate and rostrate or in some cases elongately fusoid; with long sterile appendage; at first hyaline, becoming straw-colored to golden brown; thick-walled; 3–5 septate; constricted at the septum; 4- to 5-celled, second cell from the base larger than the rest of the cells (Fig. 6f). Measurements: 81.42–225.40 µ long including appendage; 11.96–23.46 µ wide at the broadest part and 2.99–5.52 µ wide at the center of the appendage (PSA); 83.95–203.78 µ long including appendage; 9.66–17.48 µ wide in the broadest part and 3.45–5.75 µ wide at the middle of the appendage.

Colony characters on culture media (Fig. 8)

Colonies on potato dextrose agar (PDA) incubated at ambient room temperature (ART) (28–30 °C) grow

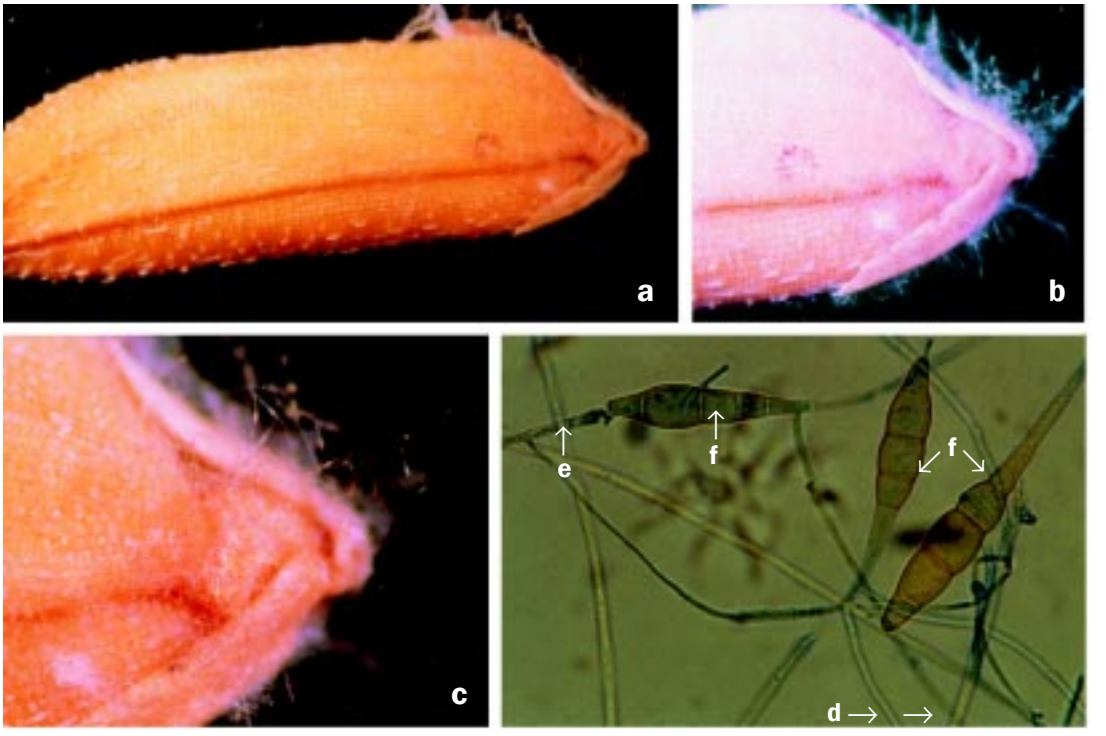

Fig. 6. Habit character of *Alternaria padwickii* (Ganguly) Ellis on (a) whole seed (8X) and on sterile lemmas at (b) 12.5X and (c) 25X. Photomicrograph of *A. padwickii* showing (d) mycelia, (e) conidiophore, and (f) conidia at 40X and stained with lactophenol blue.

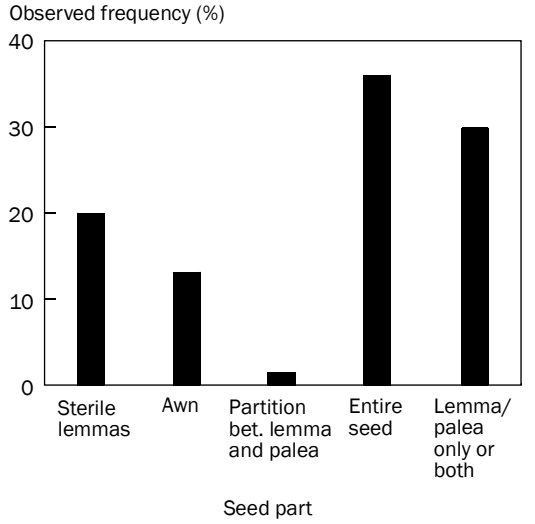

Fig. 7. Observed frequency of *Alternaria padwickii* occurrence on seed part.

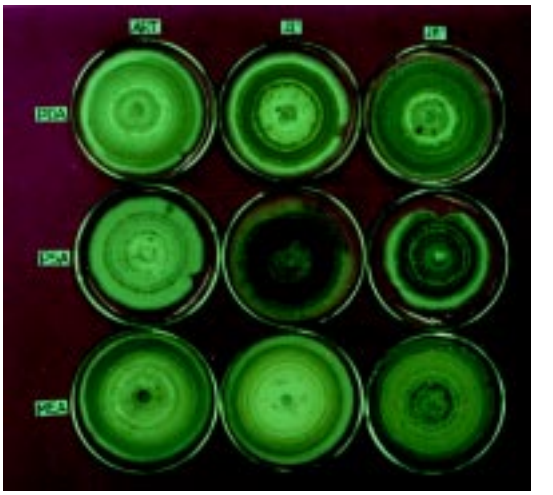

Fig. 8. Plate culture of *Alternaria padwickii* Ellis showing colony growths on potato dextrose agar (PDA), potato sucrose agar (PSA), and malt extract agar (MEA) incubated at ambient room temperature (ART), 21 °C, and 28 °C at 15 d after inoculation.

moderately fast and attain a 4.32-cm diam in 5 d. They are slightly zonated, thickly felted, and grayish, becoming light outward. On the reverse side of the agar plate, the colony is azonated, black, and lighter outward. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies grow moderately fast and attain a 4.14-cm diam in 5 d. They are azonated, becoming markedly zonated outward, felted, yellowish to greenish gray, with a 0.5-cm sterile white margin. On the reverse side of the agar plate, the colony appears zonated and black and light outward. At 28 °C under alternating 12-h light and 12-h darkness, colonies grow moderately fast and attain a 4.33-cm diam in 5 d. They are zonated, felted, and greenish gray. On the reverse side of the agar plate, the colony is zonated and black and yellowish brown outward.

Colonies on potato sucrose agar (PSA) incubated at ART (28–30 °C) grow moderately fast and attain a 4.18-cm diam in 5 d. They are deeply felted, zonated with an even margin, and gray. The colony appears zonated and black on the reverse side of the agar plate. At 21 °C under alternating 12-h NUV and 12-h darkness, colonies grow moderately fast and attain a 4.36-cm diam in 5 d. They are slightly zonated with a light gray submerged advancing margin, felted, and dark greenish gray. The colony appears slightly zonated, black, and lighter outward on the reverse side of the agar plate. At 28 °C under alternating 12-h light and 12-h darkness, colonies grow moderately fast and attain a 4.06-cm diam in 5 d. They are zonated, felted with a sinuate margin, yellowish to greenish gray, and lighter at the margins. The colony appears zonated and black, and yellowish brown outward on the reverse side of the agar plate.

Colonies on malt extract agar (MEA) incubated at ART (28–30 °C) grow moderately fast and attain a 4.53-cm diam in 5 d. They are zonated, felted, and light gray to gray. The colony appears zonated and black on the reverse side of the agar plate. At 21 °C under alternating 12-h NUV and 12-h darkness, colonies grow moderately fast and attain a 4.47-cm diam in 5 d. They are azonated, becoming markedly zonated outward, and white to yellowish gray and becoming gray outward. The colony appears zonated and black with a light gray margin on the reverse side of the agar plate. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow moderately fast and attain a 4.90-cm diam in 5 d. They are zonated, felted, and greenish gray, becoming gray at the margins. The colony appears slightly zonated and black on the reverse side of the agar plate.

Bipolaris oryzae (Breda de Haan) Shoem.
syn. *Drechslera oryzae* (Breda de Haan) Subram. & Jain
Helminsthosporium oryzae
teleomorph: *Cochliobolus miyabeanus* (Ito & Kurib)

Disease caused: brown spot (brown leaf spot or sesame leaf spot)
Helminsthosporium blight

a. Symptoms
On leaves—small and circular dark brown or purple brown spots eventually becoming oval (similar to size and shape of sesame seeds) and brown spots with gray to whitish centers, evenly distributed over the leaf surface; spots much larger on susceptible cultivars. A halo relating to toxin produced by the pathogen often surrounds the lesions.
On glumes—black or brown spots covering the entire surface of the seed in severe cases. Under favorable environments, conidiophore and conidia may develop on the spots, giving a velvety appearance.
Coleoptile—small, circular, or oval brown spots.

b. Occurrence/distribution
Brown spot is distributed worldwide and reported in all rice-growing countries in Asia, America, and Africa (Fig. 9). It is more prevalent in rainfed lowlands and uplands or under situations with abnormal or poor soil conditions.

c. Disease history
This fungus was first described in 1900 and named as *Helminthosporium oryzae.* In Japan, the teleomorph was found in culture and was named *Ophiobolus miyabeanus.* However, Drechsler decided it belonged to *Cochliobolus* and renamed

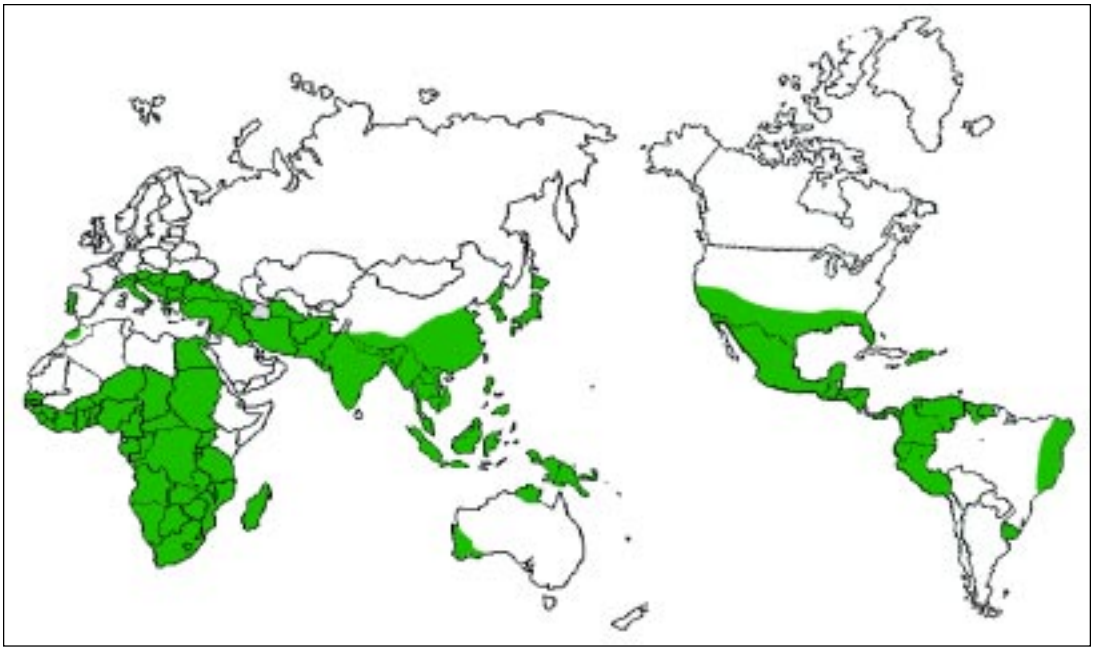

Fig. 9. Occurrence of brown spot (Ou 1985, Agarwal and Mathur 1988, EPPO 1997).

it *Cochliobolus miyabeanus*. Because of the bipolar germination of the conidia, the anamorph of *C. miyabeanus* was changed to *Bipolaris oryzae*.

d. Importance in crop production
Bipolaris oryzae causes seedling blight, necrotic spots on leaves and seeds, and also grain discoloration. Severely infected seeds may fail to germinate. Seedling blight is common on rice in both rainfed lowlands and uplands. Under these rice production situations, brown spot can be a serious disease causing considerable yield loss. In history, the Bengal famine of 1942 is attributed to brown spot.

Detection on seed

a. Incubation period on blotter
B. oryzae is easily observed on seeds using the blotter method 5 d after seeding on moistened blotter incubated under NUV light at 22 °C. The detection frequency is about 56.7% on seeds coming from different regions (Fig. 10a,b).

b. Habit character
There are two types of fungal detection on rice seed: type I shows less conidia and abundant aerial mycelia, fluffy to cottony; gray, greenish gray to black; conidiophores are usually slender and hard to distinguish from main mycelia; conidia are darker than mycelia, borne singly on the terminal portion of the hyphae.

Type II shows abundant conidia and aerial mycelia are either absent or scanty. Conidiophores are straight or flexuous, relatively long; simple, brown to dark brown, arising directly from seed surface either solitary or in small groups bearing conidia at the end and/or on the sides, usually with 3–5 conidia per conidiophore (Fig. 11a-c).

c. Location on seed
B. oryzae is often observed on the entire seed surface (about 32%) or on sterile lemmas (about 29%) (Fig. 12).

Microscopic character

a. Mycelium—gray to dark greenish gray, septate.

b. Conidiophores—septate, solitary, or in small groups; straight or flexuous, sometimes geniculate (bent like a knee); simple; pale to mid-brown; bearing conidia at the end and on sides (Fig. 11d).

c. Conidia—dark brown to olivaceous brown, obclavate, cymbiform, naviculart, fusiform, straight, or curved (slightly bent on one side). The largest conidia may have 13 pseudosepta with a prominent hilum or basal scar (Fig. 11e). Measurements: 5–9 septate, 39.56–101.89 µ × 11.96–

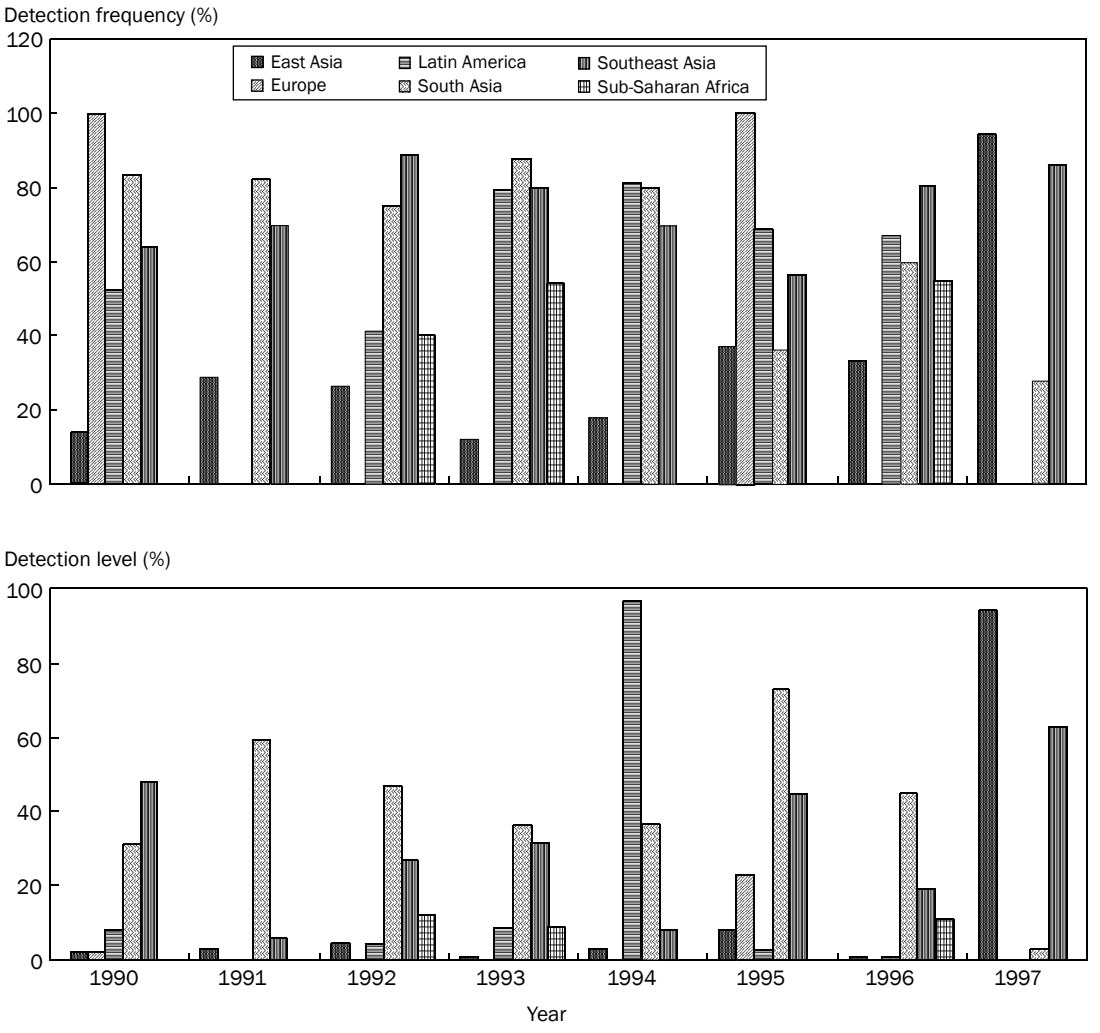

Fig. 10. Detection frequency (a) and level (b) of *Bipolaris oryzae* from imported untreated seeds, 1990-97.

16.10 µ (PDA); 4–11 septate, 43.47–101.43 µ × 12.19–16.10 µ (PSA); and 5–11 septate, 59.80–106.03 µ × 10.12–16.33 µ (MEA).

Colony characters on culture media (Fig. 13)
Colonies on PDA at ART (28–30 °C) grow slowly and attain a 3.38-cm diam in 5 d. They are azonated with sinuate margins, hairy at the center, becoming cottony toward the margin, yellowish gray at the center and gray toward the margin, and becoming grayish olive with age. The colony appears azonated and black on the reverse side of the agar plate. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies grow very slowly and attain a 2.38-cm diam in 5 d. They are fluffy, azonated with uneven margins, with olive gray aerial mycelia, becoming dark olive gray outward. The colony on the reverse side of the agar plate appears azonated and black. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow very slowly and attain a 2.53-cm diam in 5 d. They are fluffy with nil to scanty aerial mycelia, azonated with uneven margins, and olive black with 3.0-mm light gray advancing mycelia. The colony appears azonated and black with light gray margins on the reverse side of the agar plate.

Colonies on PSA incubated at ART (28–30 °C) grow moderately fast and attain a 4.48-cm diam in 5 d. They are fluffy, azonated with sinuate margins, and grayish yellow at the center, becoming dark olive gray outward. The colony appears azonated and olive black to black on the reverse side of the agar

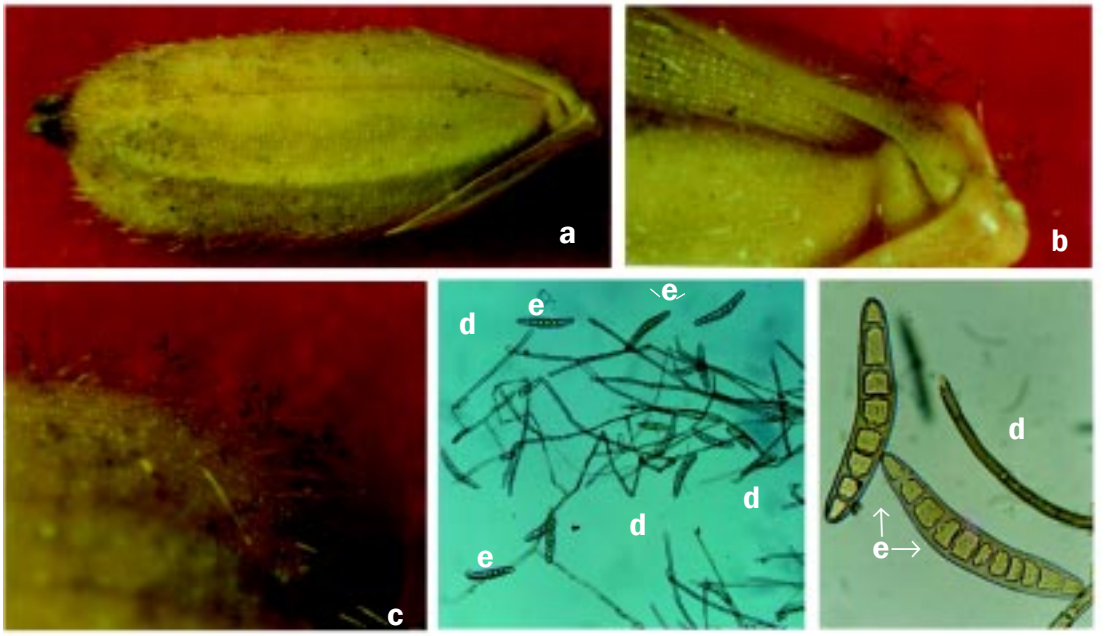

Fig. 11. Habit character of *Bipolaris oryzae* (Breda de Haan) Shoem. on (a) whole seed (10X), (b) sterile lemmas (40X), and (c) awn portion (40X). Photomicrograph of *B. oryzae* showing (d) conidiophore and (e) conidia at 10X and 40X.

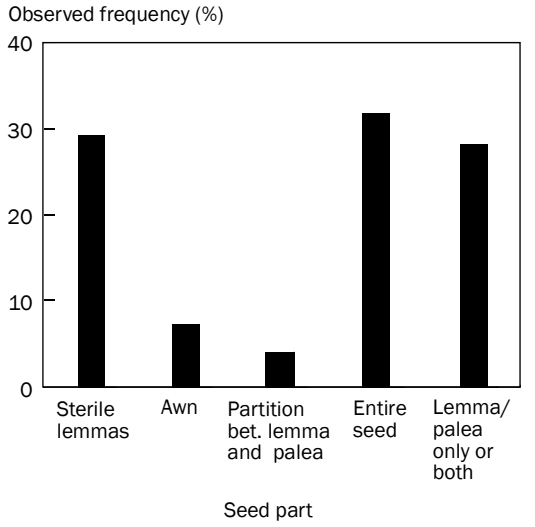

Fig. 12. Observed frequency of *Bipolaris oryzae* occurrence on the seed.

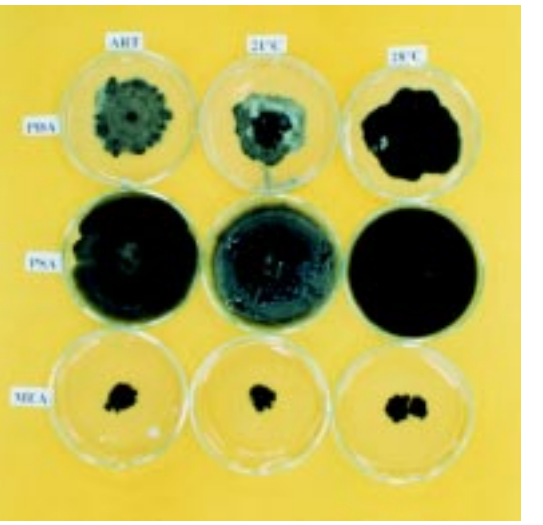

Fig. 13. Plate cultures of *Bipolaris oryzae* (Breda de Haan) Shoem. showing colony growths on PDA, PSA, and MEA incubated at ART, 21 °C, and 28 °C at 15 d after inoculation.

plate. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies spread moderately fast and attain a 4.62-cm diam in 5 d. They are fluffy, zonated with sinuate margins, and dark olive gray with olive gray mycelial tufts and 4-mm grayish advancing mycelia. The colony appears slightly zonated to zonated, black, and becomes dark olive gray outward on the reverse side of the agar plate. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow fast and attain a 5.10 cm diam in 5 d.

They are feathery to slightly fluffy, zonated with even to slightly uneven margins, and alternating olive yellow and dark olive with 5-mm light yellow margins. On the reverse side of the agar plate, the colony appears azonated to slightly zonated, black, and becomes dark greenish gray to olive black toward the margin.

Colonies on MEA at ART (28–30 °C) grow very slowly and attain a 2.29-cm diam in 5 d. Colonies are scanty with fluffy aerial mycelia, azonated with uneven margins, and olive gray with grayish yellow aerial mycelia. The colony appears azonated and olive black on the reverse side of the agar plate. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies are restricted in growth and attain a 1.71-cm diam in 5 d. They are azonated with crenate margins, velvety, and olive black with white to dark olive mycelial tufts. The colony appears zonated and olive black to black on the reverse side of the agar plate. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies are restricted in growth and attain a 1.71-cm diam in 5 d. They are azonated with crenate margins, velvety with slightly fluffy centers, and dark greenish gray to olive black. The colony on the reverse side of the agar plate appears azonated and black.

Cercospora janseana (Racib.) Const.
syn. *Cercospora oryzae* Miyake
teleomorph: *Sphaerulina oryzina* Hara

Disease caused: narrow brown leaf spot

a. Symptoms
Short, linear, brown lesions most common on leaves but also occur on leaf sheaths, pedicels, and glumes.

b. Occurrence/distribution
The disease has worldwide distribution (Fig. 14).

c. Disease history
The disease was first observed in North America before 1910 but its detailed description was re-

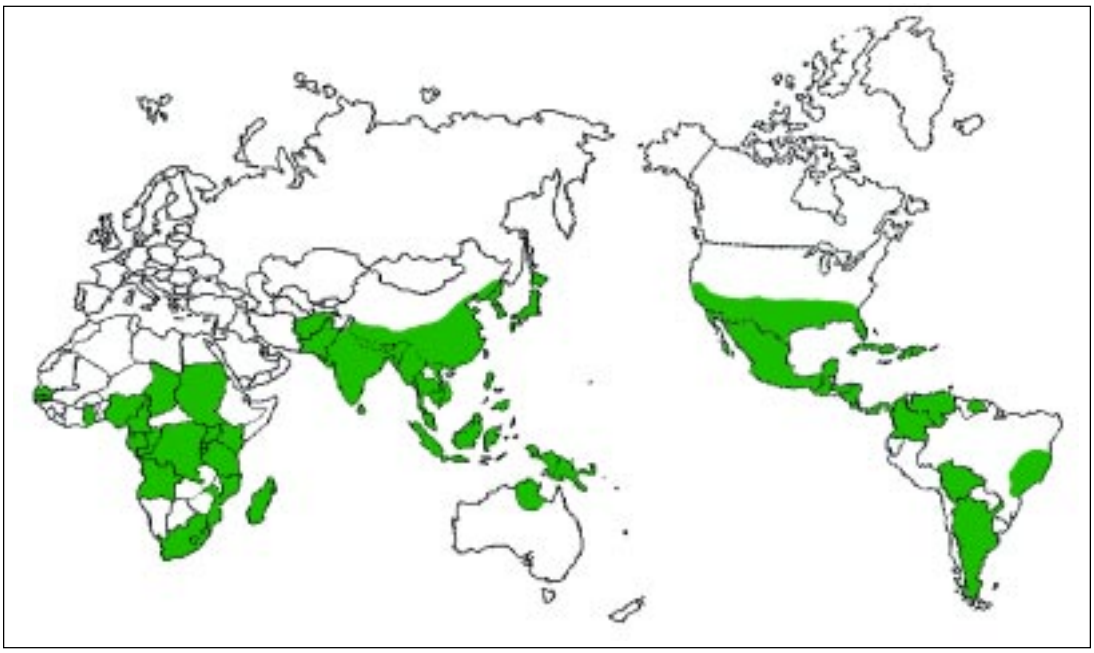

Fig. 14. Occurrence of narrow brown leaf spot (Ou 1985, Agarwal and Mathur 1988, EPPO 1997).

ported in 1910 in Japan. The causal fungus was named *Cercospora oryzae*. In 1982, the fungus was renamed as *C. janseana*.

d. Importance in crop production
The disease reduces effective leaf area of the plant and causes premature senescence of infected leaves and sheaths. Together with leaf scald, it may cause 0.1% yield loss across all rice production situations in Asia.

Detection on seed

a. Incubation on blotter
Using the blotter test, *C. janseana* can be observed on rice seed 7 d after incubation in NUV light at 21 °C. The frequency of detection is <1% on rice seed coming from different ecosystems.

b. Habit character
Aerial mycelium is absent. The glassy white conidia are borne on conidiophores that are brown, short, simple, and directly arising from the seed surface mostly from sterile glumes, singly or in groups of two or three (Fig. 15a-c).

c. Location on seed
Cercospora janseana is most often observed on sterile lemmas of the rice seed (about 96%) (Fig. 16).

Microscopic character

a. Mycelium—hyaline to light olive.

b. Conidiophores—brown, getting lighter at the apex; 3 or more septate; unbranched (Fig. 15d).

c. Conidia (sympodulospores)—cylindrical to clavate; 3–10 septate; hyaline or light olive, borne at the apical portion of the conidiophore (Fig. 15e). Measurements: 12.9–47.2 µ × 3.9-6.3 µ on the host and 10.6–72.9 × 3.3–6.4 µ in culture (Ou 1985).

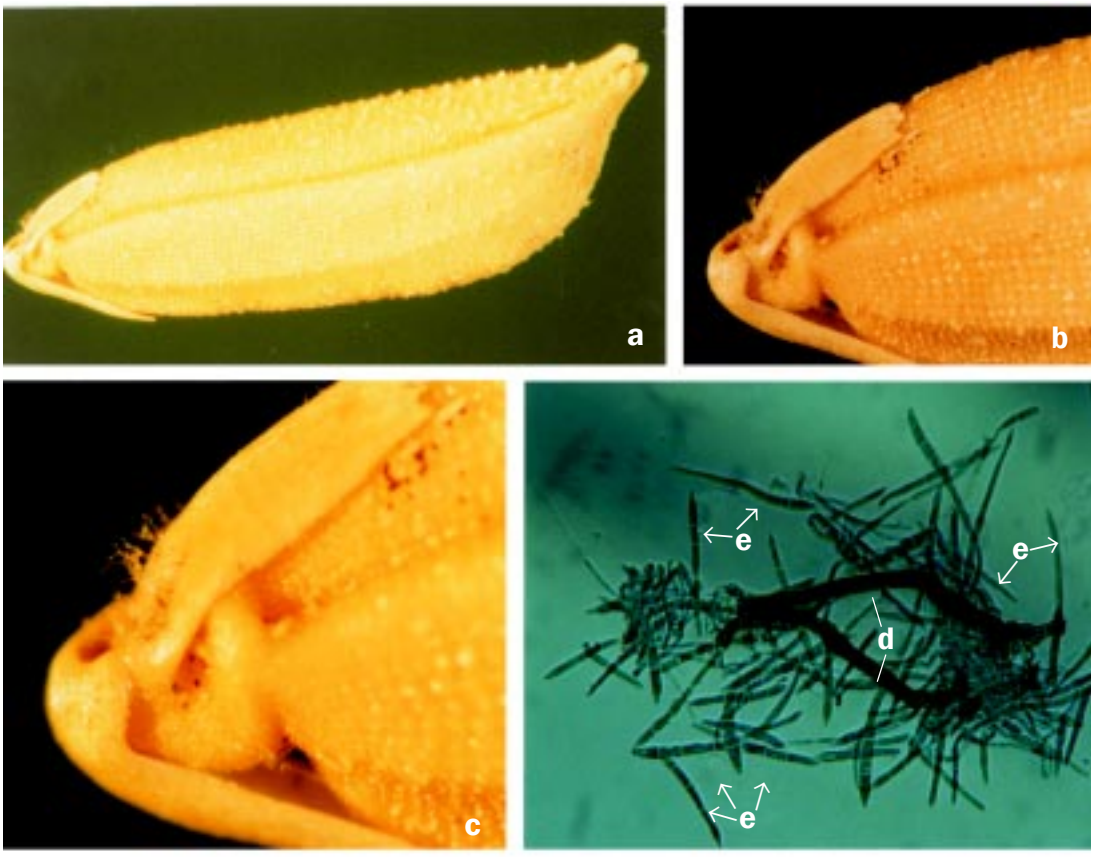

Fig. 15. Habit character of *Cercospora janseana* (Racib.) Const. on sterile lemmas at (a) 8X, (b) 16X, and (c) 32X. Photomicrograph of *C. janseana* showing (d) conidiophores, and (e) conidia at 40X and stained with lactophenol blue.

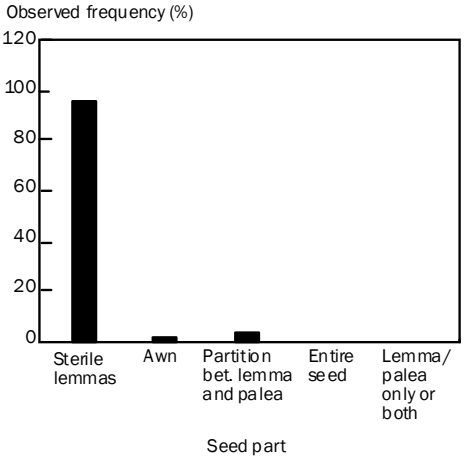

Fig. 16. Observed frequency of *Cercospora janseana* occurrence on the seed.

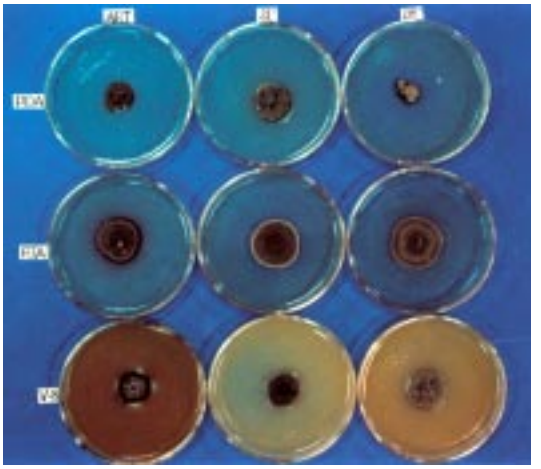

Fig. 17. Plate cultures *of Cercospora janseana* (Racib) Const. showing colony growths of PDA, PJA, and VJA incubated at ART, 21 °C, and 28 °C at 15 d after inoculation.

Colony characters on culture media (Fig. 17)

Colonies on PDA at ART (28–30 °C) grow very slowly and attain a 2.40-cm diam in 17 d. They are azonated, plane to slightly felted, with sinuate margins, slightly radial furrows, and dark gray. The colony appears azonated with radial wrinkles and black on the reverse side of the agar plate. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies grow very slowly and attain a 2.60-cm diam in 17 d. They are zonated, plane to felted, with sinuate margins and radial furrows, and gray and light gray at the margins. The colony appears azonated with radial wrinkles and black on the reverse side of the agar plate. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies are restricted in growth and attain a 1.4-cm diam in 17 d. They are zonated, felted, with even to sinuate margins and deep radial furrows, and light gray. The colony appears azonated with wrinkles and black on the reverse side of the agar plate.

Colonies on prune juice agar (PJA) at ART (28–30 °C) grow very slowly and attain a 2.40-cm diam in 17 d. They are azonated, plane, powdery to granular with slightly radial furrows and even margins, and dark gray to gray and becoming light at the margins. The colony on the reverse side of the agar plate appears azonated and black. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies grow slowly and attain a 3.10-cm diam in 17 d. They are slightly zonated, plane, granular, and gray with 0.5-cm white margins. The colony on the reverse side of the agar plate appears azonated and black with orange coloration. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow slowly and attain a 3.20-cm diam in 17 d. They are plane, zonated with radial furrows and sinuate margins, and light gray to gray. The colony on the reverse side of the agar plate appears azonated with radial wrinkles and black.

Colonies on V-8 juice agar (VJA) at ART (28–30 °C) are restricted in growth and attain a 2.20-cm diam in 17 d. They are zonated, felted, with sinuate margins and deep radial furrows, and light gray to gray with dark gray margins. The colony on the reverse side of the agar plate appears azonated with wrinkles and black. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies grow very slowly and attain a 2.30-cm diam in 17 d. They are zonated, felted, with even to sinuate margins and deep radial furrows, and light gray to dark gray. The colony on the reverse side of the agar plate appears azonated with wrinkles and black. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow very slowly and attain a 2.30-cm diam in 17 d. They are zonated with deep radial furrows and sinuate margins, felted, and brownish gray. The colony on the reverse side of the agar plate is azonated with radial wrinkles and black.

Microdochium oryzae (Hashioka & Yokogi) Samuels & Hallett
syn. *Gerlachia oryzae* (Hashioka & Yokogi) W. Gams.
Rhychosporium oryzae Hashioka & Yokogi
teleomorph: *Monographella albescens* (Thumen) Parkinson, Sivanesan & C. Booth
syn. *Metasphaeria albescens* Thum.
Metasphaeria oryzae-sativae Hara
Micronectriella pavgii R.A. Singh
Gripospharella albescens (Thumen) Von Arx

Disease caused: leaf scald

a. Symptoms
Lesions are usually observed on mature leaves. Characteristic symptoms include zonated lesions that start at leaf edges or tips. The lesion shape is more or less oblong with light brown halos measuring 1–5 cm long and 0.5–1 cm wide. Individual lesions enlarge and eventually coalesce. As lesions become old, zonations fade.

b. Occurrence/distribution
Leaf scald has been reported in all rice-growing countries worldwide (Fig. 18).

c. Disease history
Leaf scald was first reported in 1955 in Japan, and the causal organism was named as *Rhynchosporium oryzae*. However, the disease was known under different names. The causal fungus was confused with *Fusarium nivale* as the anamorph and with *Micronectriella nivalis* as the teleomorph. Later it was proved that the leaf scald fungus is not *F. nivale*. The anamorph and teleomorph of the leaf scald fungus have undergone many changes and are now known as *Gerlachia oryzae* and *Monographella albescens*, respectively.

d. Importance in crop production
Leaf scald is very common on rice in tropical Asia. It is considered a relatively minor problem causing little yield loss alone in rice production.

Detection on seed

a. Incubation period on blotter
Using the blotter test, *M. oryzae* can be observed on rice seeds 7 d after seeding and incubation under NUV light at 21 °C. The detection frequency is about 28.2% on seeds coming from different regions (Fig. 19a,b).

b. Habit character
Aerial mycelia are absent; light pinkish or light orange to bright orange irregular masses

Fig. 18. Occurrence of leaf scald (Ou 1985, Agarwal and Mathur 1988).

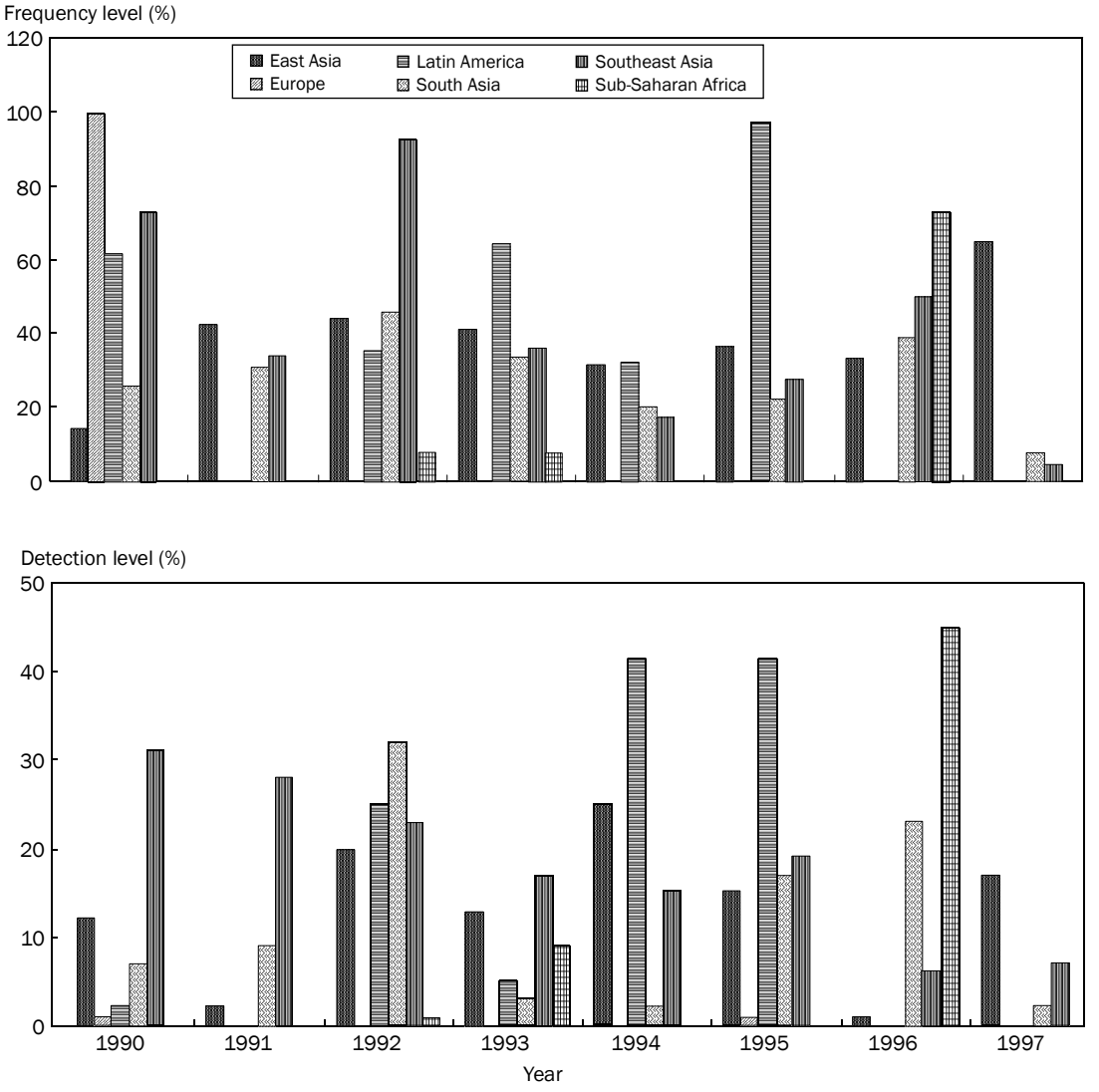

Fig. 19. Detection frequency (a) and level (b) of *Microdochium oryzae* from imported untreated seeds, 1990-97.

(pionnotes) varying in size and thickness are scattered on seed surface (Fig. 20a-c).

c. Location on seed
M. oryzae is most likely observed growing on sterile lemmas of the rice seed (about 55%) (Fig. 21).

Microscopic character
Conidia (epispore)—borne on superficial stromata arising on lesions, bow-shaped; single-celled when young, 2-celled when mature; one septum; occasionally 2–3 septate; not considered at septum; thin-walled, hyaline, pink in mass, hyaline under the microscope (Fig. 22d). Measurements: 8.97–17.48 µ × 2.53–5.98 µ (PDA); 8.51–18.17 µ × 6.21–8.51 µ (PSA); and 10.36–15.64 µ × 2.30–5.52 µ (MEA).

Colony characters on culture media (Fig. 22)
Colonies on PDA at ART (28–30 °C) grow moderately fast, thinly spreading, and attain a 4.20-cm diam in 5 d. They are evenly zonated with uneven margins, orange with scanty, white aerial mycelia, and somewhat pressed to the media. Colonies appear wet at the center, spreading outward with age. The colony on the reverse side of the agar plate appears evenly zonated and light orange. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies are thinly spreading, grow moderately fast, and attain

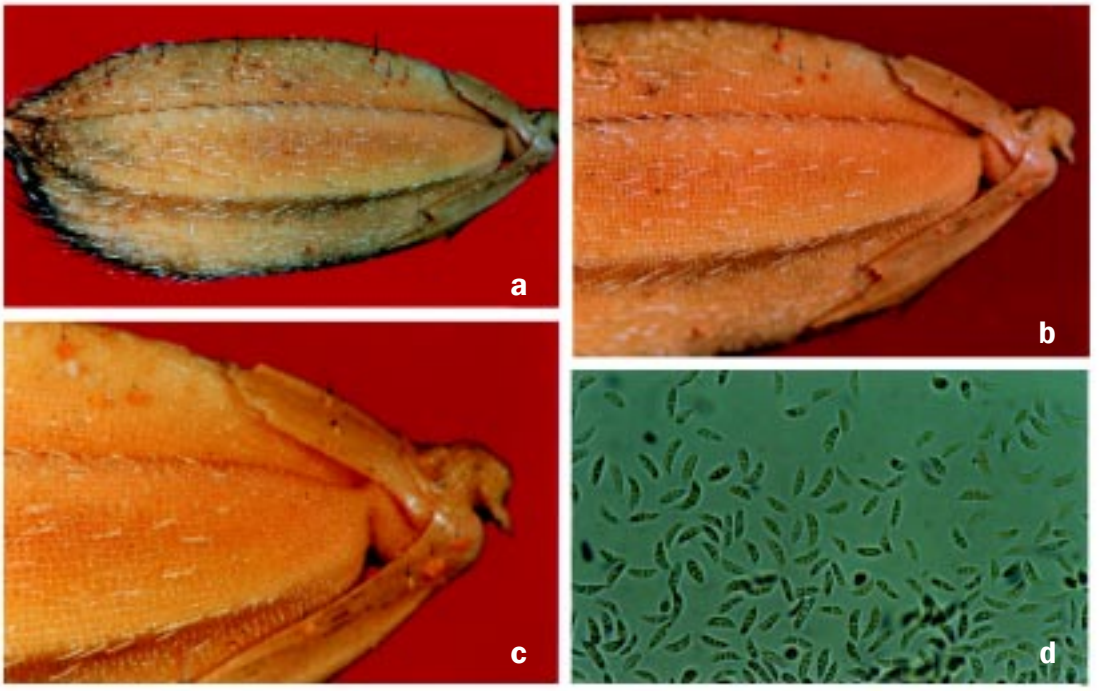

Fig. 20. Habit character of *Microdochium oryzae* (Hashioka and Yokogi) Sam. and Hal. showing orange pionnotes on the seed surface at (a) 8X, (b) 12.5X, and (c) 20X. Photomicrograph of *M. oryzae* showing lunar-shaped conidia (40X).

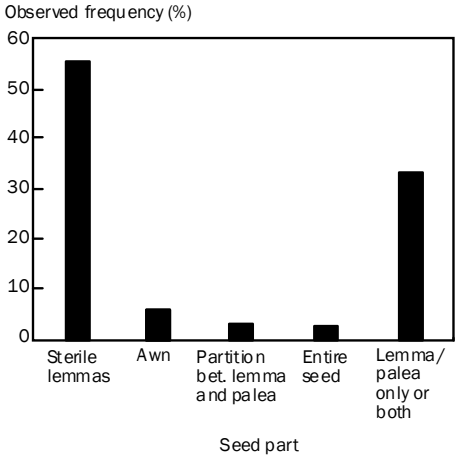

Fig. 21. Observed frequency of *Microdochium oryzae* occurrence on the seed.

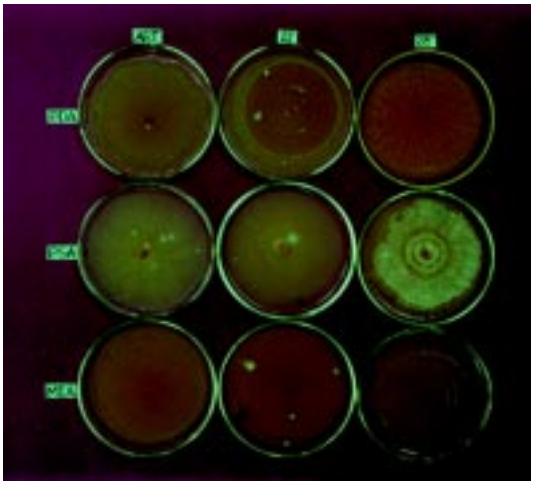

Fig. 22. Plate cultures of *Microdochium oryzae* (Hashioka and Yokogi) Samuels and Hallet showing colony growths on PDA, PSA, and MEA incubated at ART, 21 °C, and 28 °C at 5 d after inoculation.

a 4.90-cm diam in 5 d. They are evenly zonated, orange with white aerial mycelia that appear to be pressed to the media, and wet at the center. The colony on the reverse side of the agar plate is slightly zonated and orange to light orange outward. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow moderately fast and attain a 5.0-cm diam in 5 d. They are orange without aerial mycelia. Colonies appear wet and slightly zonated with radial furrows and even margins. The colony on the reverse side of the agar plate is slightly zonated with radial wrinkles and orange, becoming light outward.

Colonies on PSA at ART (28–30 °C) are thinly spreading, grow moderately fast, and attain a 4.87-cm diam in 5 d. They are azonated with even margins and light orange with scarce white aerial mycelia. White mycelial tufts are produced as colonies age. The colony on the reverse side of the agar plate appears azonated and light orange. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies are thinly spreading, grow moderately fast, and attain a 4.48-cm diam in 5 d. They are slightly zonated at the center, with even margins, and light orange with scarce white aerial mycelia that are pressed to the media. The colony on the reverse side of the agar plate is slightly zonated at the center and light orange. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow moderately fast and attain a 5.89-cm diam in 5 d. They are zonated at the center with about 1.5-cm submerged advancing mycelia and sinuate margins. Colonies are orange with white, densely floccose aerial mycelia. The colony on the reverse side of the agar plate appears zonated at the center and orange.

Colonies on MEA at ART (28–30 °C) are thinly spreading, grow moderately fast, and attain a 4.93-cm diam in 5 d. They are zonated, with even margins, and orange with scarce white aerial mycelia that are somewhat pressed to the media. The colonies appear wet. The colony on the reverse side of the agar plate is zonated and orange, At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies are thinly spreading, grow moderately fast, and attain a 5.67-cm diam in 5 d. They are zonated, with few radial furrows and even margins, and orange with scarce white aerial mycelia that are somewhat pressed to the media. The colonies appear wet at the center and spread outward with age. The colony on the reverse side of the agar plate appears zonated with few radial wrinkles and orange. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies are thinly spreading, grow fast, and attain a 6.03-cm diam in 5 d. They are zonated with serrated margins, orange with scarce white aerial mycelia that are somewhat pressed to the media, especially at the center, and become wet with age. The colony on the reverse side of the agar plate appears zonated with few radial wrinkles and orange.

Pyricularia oryzae Cav.
syn. *Pyricularia grisea* (Cooke) Sacc.
Pyricularia grisea
Pyricularia oryzae Cavara
Dactylaria oryzae (Cav.) Sawad
Trichothecium griseum Cooke
teleomorph: *Magnaporthe grisea* (Hebert) Barr
Ceratospaeria grisea Hebert
Phragmoporthe grisea (Hebert) Monod

Disease caused: blast

a. Symptoms

The fungus can infect rice plants at any growth stage although it is more frequent at the seedling and flowering stage.

On the leaves—Initially, lesions appear as small whitish or grayish specks that eventually enlarge and become spindle-shaped necrotic spots with brown to reddish brown margins. The size, shape, and color of the spots vary depending upon the susceptibility of the variety and environmental conditions.

On the panicle base—Infected tissue shrivels and turns black. It breaks easily at the neck and hangs down.

On the nodes—Infected nodes rot and turn black.

b. Occurrence/distribution
Rice blast is widely distributed in all rice-growing countries (Fig. 23). It is most prevalent in temperate subtropical environments and also in rice grown in upland conditions.

c. Disease history
Records of this disease can be traced back to as early as 1637 in China. It was reported in 1704 in Japan, in 1828 in Italy, and in 1907 in South Carolina, USA. In India, it was first recorded in 1913. Its causal fungus, *Pyricularia oryzae*, was named in 1891 in Italy. It was recently renamed *P. grisea* but *P. oryzae* has widespread usage.

d. Importance in crop production
Blast is generally considered as the principal disease of rice because of its wide distribution and destruction in causing crop failure and epidemics. The epidemic potential is very high under favorable conditions where susceptible cultivars are planted. Blast may cause total crop failure but, because resistant cultivars are grown widely in major rice production environments, it accounts for 1–3% yield loss across all rice production situations in Asia.

Detection on seed

a. Incubation period on blotter
Using the blotter test, *P. oryzae* can be observed on rice seeds 3–4 d after incubation in NUV light at 21 °C. The detection frequency is about 9.9% on seeds coming from different regions (Fig. 24a,b).

b. Habit character
Aerial mycelia are rarely present or in most cases absent. If present, mycelia are branched, hyaline to olivaceous. If aerial mycelium is absent, conidiophores arise directly from the seed surface singly or in small groups or bundles. They are moderately long, simple, and light brown. Conidia are hyaline, pale olive or grayish, and borne sympodially (Fig. 25a-c).

c. Location on seed
P. oryzae is observed mostly on sterile lemmas of the seed (91%) (Fig. 26).

Microscopic characters

a. Mycelium—septate, branched, and hyaline.

b. Conidiophores—simple to rarely branched, moderately long, septated, light brown, slightly thickened at the base with denticles at the apex (Fig. 25d).

c. Conidia (sympodulosphores)—pyriform to obclavate, hyaline to pale olive; usually 2 septate, rarely 1 or 3 septate (observed in PJA); apex narrow, base rounded with a prominent appendage or hilum (Fig. 25e). Measurements: 15.64–22.54 µ × 7.82–10.81 µ (PDA); 16.56–31.97 µ × 8.51–12.42 µ (PJA); and 15.18–25.76 µ × 7.13–10.81 µ(VJA).

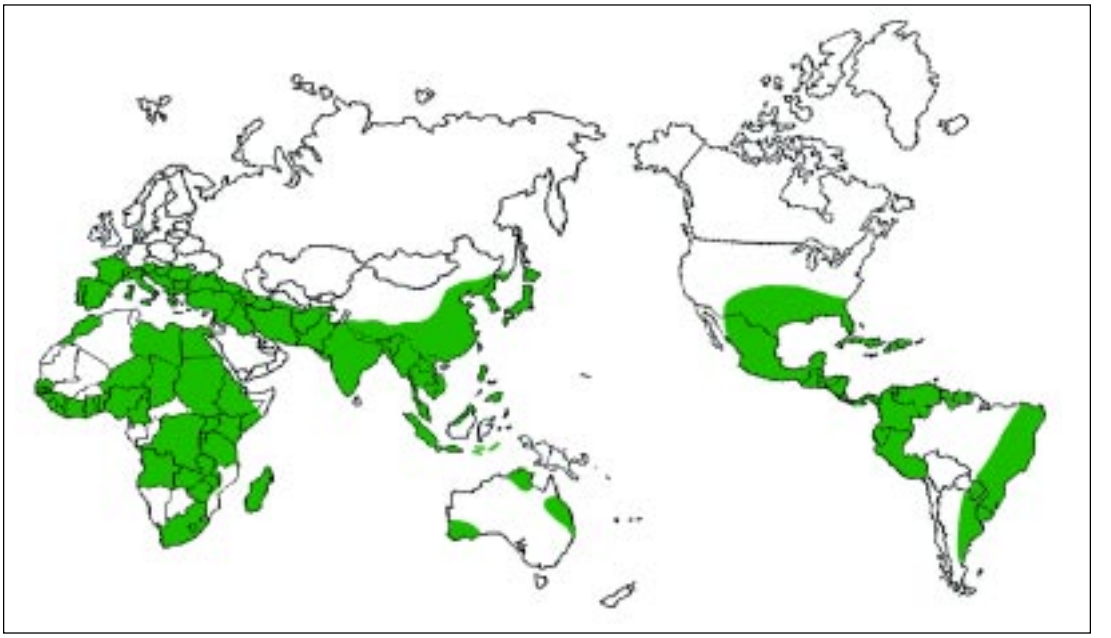

Fig. 23. Occurrence of blast (Ou 1985, CMI 1981).

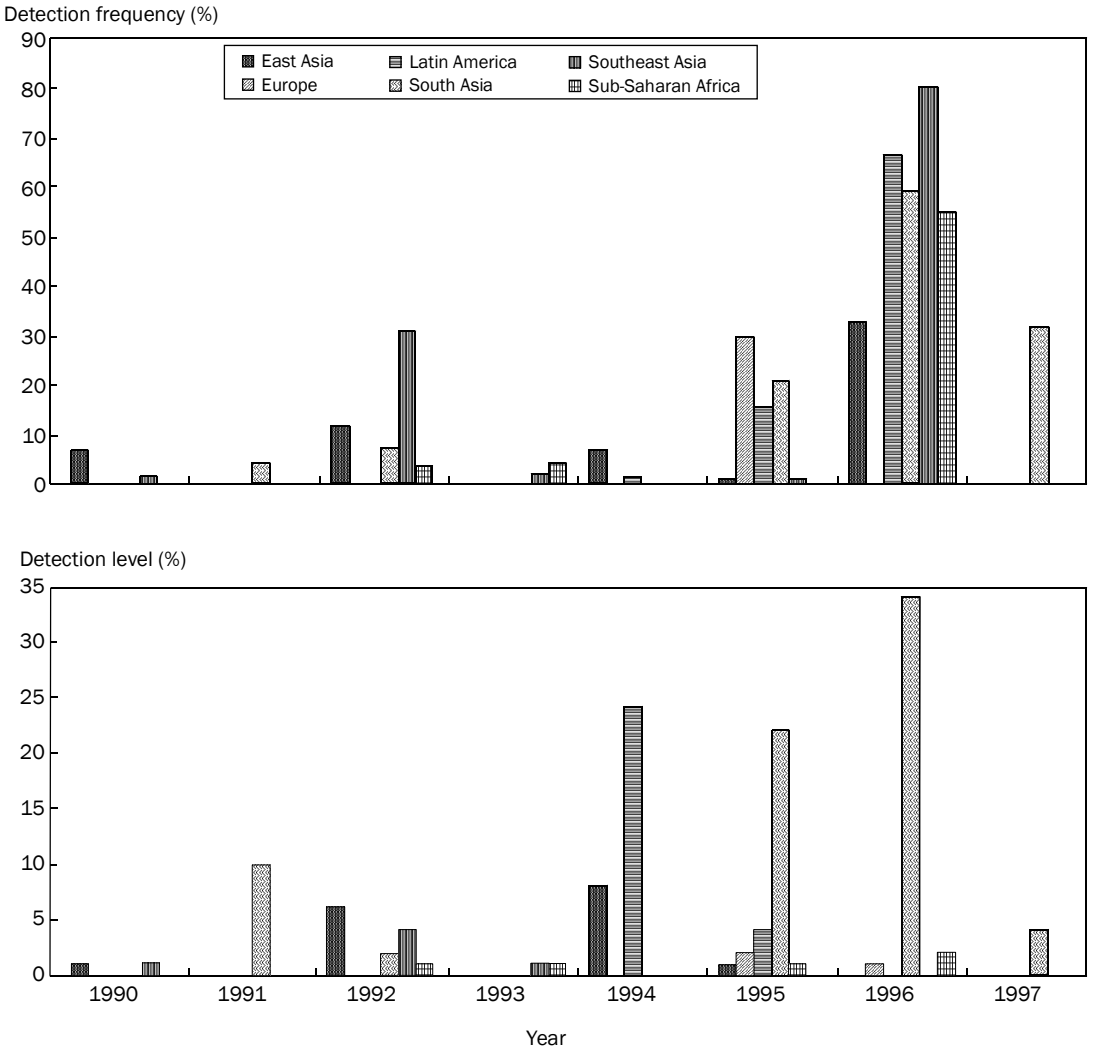

Fig. 24. Detection frequency (a) and level (b) of *Pyricularia oryzae* from imported untreated seeds, 1990-97.

Colony characters on culture media (Fig. 27) Colonies on PDA at ART (28–30 °C) grow very slowly and attain a 3.04-cm diam in 5 d. They are azonated, slightly felted, with aerial mycelia that are white with brownish gray portions, even margins, and with about 1-mm advancing mycelia submerged. Saltation of colonies is observed in some plates. The colony on the reverse side of the agar plate is zonated and black, turning light outward. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies grow very slowly and attain a 2.17-cm diam in 5 d. They are zonated, slightly felted with even margins, and brownish gray. The colony on the reverse side of the agar plate appears zonated and black with a lighter color outward. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow very slowly and attain a 2.78-cm diam in 5 d. They are azonated and become zonated toward the margin, floccose to slightly felted. Aerial mycelia are white with brownish gray portions. The colony on the reverse side of the agar plate is azonated and becomes zonated near the margins, and appears white with greenish gray centers.

Colonies on PJA at ART (28–30 °C) grow very slowly and attain a 2.87-cm diam in 5 d. They are azonated, becoming zonated toward the margins, velvety, becoming granular with age, with 0.8-cm submerged advancing mycelia, gray to light gray

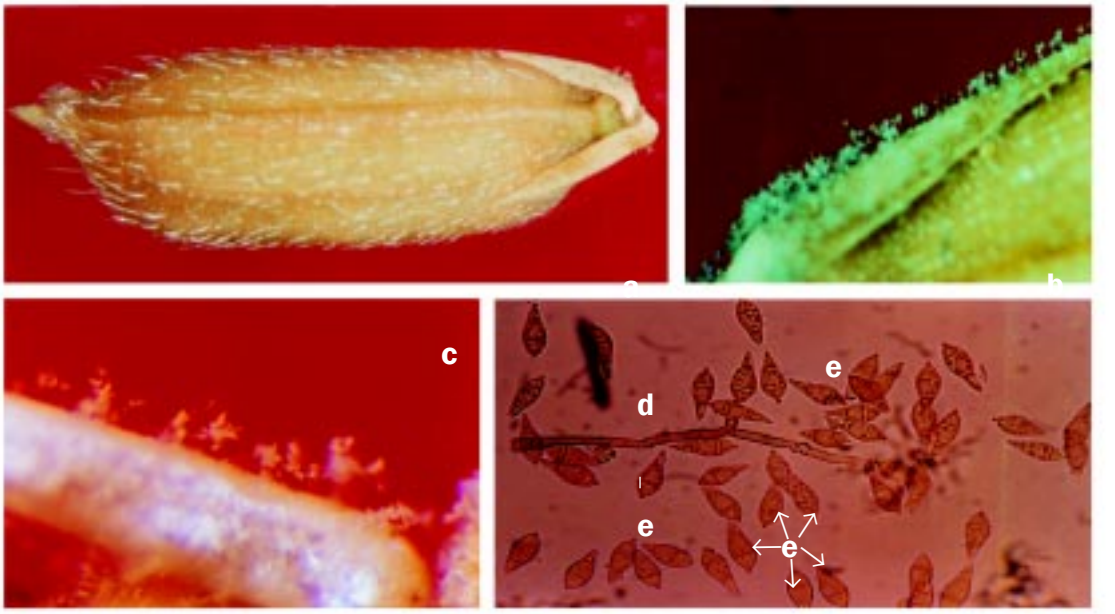

Fig. 25. Habit character of *Pyricularia oryzae* Cav. On sterile lemmas at (a) 10X, (b) 40X, and (c) 50X. Photomicrograph of *P. oryzae* showing (d) conidiophore and (e) conidia at 40X.

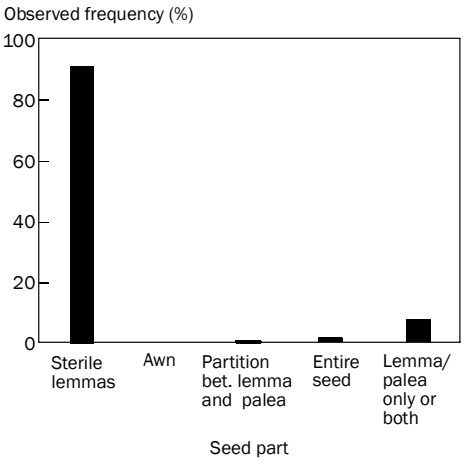

Fig. 26. Observed frequency of *Pyricularia oryzae* occurrence on the seed.

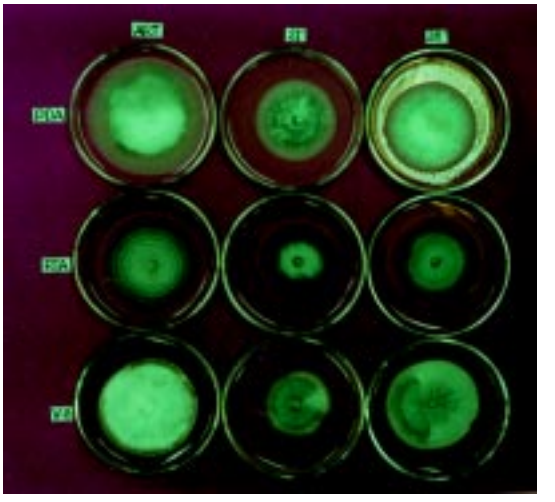

Fig. 27. Plate cultures of *Pyricularia oryzae* showing colony growths on PDA, PJA, and VJA, incubated at ART, 21 °C, and 28 °C at 15 d after inoculation.

near the margins. The colony on the reverse side of the agar plate appears azonated and dark purplish gray. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies grow very slowly and attain a 2.50-cm diam in 5 d. They are zonated, velvety with 0.5-cm submerged advancing mycelia, and gray, becoming dark gray outward. The colony on the reverse side of the agar plate is zonated and dark purplish gray, becoming lighter outward. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow very slowly and attain a 3.17-cm diam in 5 d. They appear slightly zonated and

gray, becoming dark near the margins with 1-cm submerged advancing mycelia. The colony on the reverse side of the agar plate is slightly zonated and dark purplish gray, becoming lighter outward.

Colonies on VJA incubated at ART (28–30 °C) grow very slowly and attain a 2.96-cm diam in 5 d. They appear azonated, felted with even margins, and white with light gray portions. The colony on the reverse side of the agar plate appears azonated and brown-purple. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies grow very slowly and attain a 2.04-cm diam in 5 d. They appear zonated, slightly floccose to felted with radial furrows, and gray, becoming light gray toward the margins. The colony on the reverse side of the agar plate is zonated with radial wrinkles and brown-purple, becoming lighter toward the margin. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow very slowly and attain a 2.96-cm diam in 5 d. They appear azonated, becoming slightly zonated toward the margin, slightly felted with radial furrows and even margins, and gray, becoming lighter outward. The colony on the reverse side of the agar plate is azonated, becoming zonated toward the margins, with radial wrinkles and brown-purple, becoming lighter outward.

Seedborne fungi causing stem, leaf sheath, and root diseases in rice

Fusarium moniliforme Sheld.
syn. *Fusarium heterosporum* Nees
Fusarium verticillioides (Sacc.) Nirenberg
Lisea fujikuroi Sawada
teleomorph: *Gibberella fujikuroi* (Sawada) S. Ito
Gibberella moniliformis Wineland
Gibberella moniliforme

Disease caused: bakanae, foot rot

a. Symptoms
The most conspicuous and common symptoms are the bakanae tillers or seedlings—an abnormal elongation of seedlings that are thin and yellowish green. These can be observed in the seedbed and in the field. In mature crops, infected plants may have a few tall, lanky tillers with pale green flag leaves; leaves dry up one after the other from below and eventually die. If the crop survives, panicles are empty.

b. Occurrence/distribution
The disease is widely distributed in all rice-growing countries (Fig. 28). The pathogen detected in Africa is closely associated with that from maize and sorghum.

c. Disease history
This disease has been known since 1828 in Japan. In India, the disease was described as causing foot rot in 1931. Fujikuroi found the teleomorph and the fungus was placed in the genus *Gibberella* as *G. fujikuroi* with *Fusarium moniliforme* as its anamorph.

d. Importance in crop production
The disease can be observed in seedbeds and in the field. Infected seedlings are either taller than normal seedlings or stunted. Infected mature plants eventually wither and die. When such plants reach the reproductive stage, they bear empty panicles. Across different rice production situations, bakanae can cause 0.01% yield loss in Asia.

Detection on seed

a. Incubation on blotter
Using the blotter test, *F. moniliforme* can be observed on rice seeds 5 d after incubating seeds under NUV light at 21 °C. The detection frequency is about 28.1% on seeds coming from different regions (Fig. 29a,b).

b. Habit character
There are abundant aerial mycelia, floccose to felted, with loose and abundant branching, dirty white to peach. The conidiophores terminate in false heads and dirty white to peach pionnotes may be present (Fig. 30a-c).

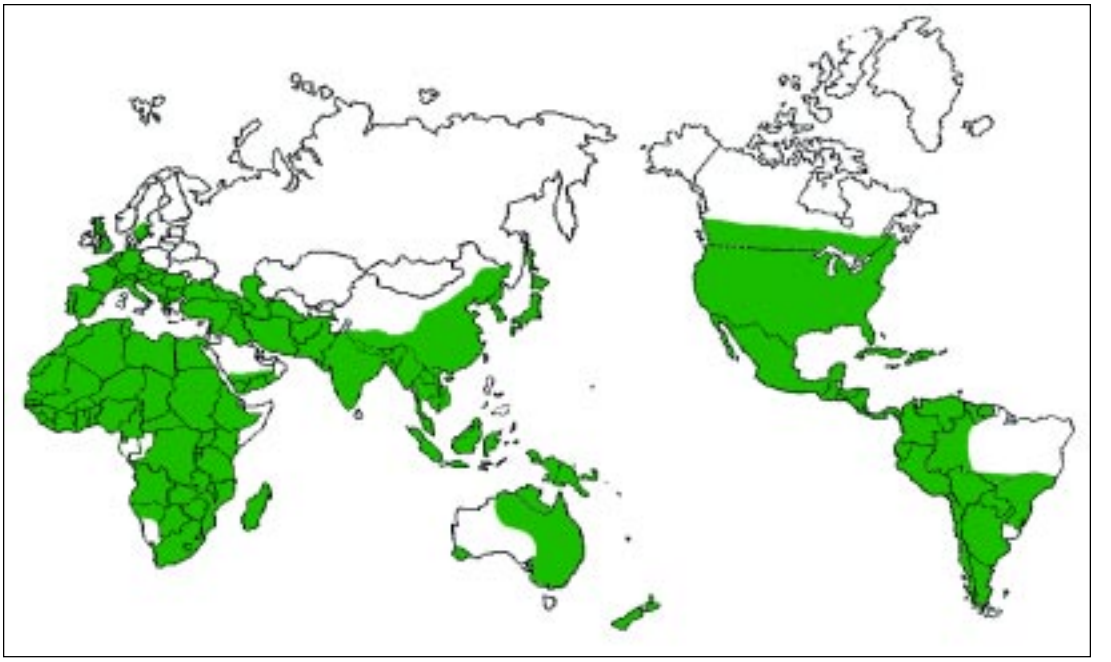

Fig. 28. Occurrence of bakanae (Ou 1985, Agarwal and Mathur 1988, EPPO 1997).

c. Location on seed
F. moniliforme is most likely observed on the entire rice seed (about 57%) (Fig. 31).

Microscopic character

a. Mycelia—hyaline, septated (Fig. 30d).
b. Microconidiophore—single, lateral, subulate phialides formed from aerial hyphae, tapering toward the apex (Fig. 30e).
c. Macroconidiophore—consisting of a basal cell bearing 2–3 phialides that produce macroconidia.
d. Microconidia—hyaline, fusiform, ovate or clavate; slightly flattened at both ends; one- or two-celled; more or less agglutinated in chains, and remain joined or cut off in false heads (Fig. 30f). Measurements: 2.53–16.33 µ × 2.30–5.75 µ (PDA); 5.06–14.26 µ × 1.61–4.83 µ (PSA); and 4.60–10.35 µ × 1.61–4.83 µ (OA, oatmeal agar).
e. Macroconidia—hyaline, inequilaterally fusoid; slightly sickle-shaped or almost straight; thin-walled; narrowed at both ends, occasionally bent into a hook at the apex and with a distinct foot cell at the base; 3–5 septate, usually 3 septate, rarely 6–7 septate; formed in salmon orange sporodochia or pionnotes (Fig. 30g). Measurements: 18.86–40.71 µ × 2.76–4.60 µ (PDA); 16.10–35.42 µ × 2.07–4.60 µ (PSA); and 21.39–39.56 µ × 2.53–4.60 µ (OA).

Colony characters on culture media (Fig. 32)

Colonies on PDA at ART (28–30 °C) grow moderately fast and attain a 5.20-cm diam in 5 d. They are slightly zonated; floccose to slightly felted, and become powdery with age; white tinged with pink at the center. The colony appearance on the reverse side of the agar plate is slightly zonated and white with a purplish center. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies grow slowly and attain a 3.72-cm diam in 5 d. They are slightly zonated, cottony to slightly felted with submerged advancing margins and pink. The colony on the reverse of the agar plate appears slightly zonated and dark pink and light toward the margin. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow moderately fast and attain a 5.10-cm diam in 5 d. They are zonated and appear cottony to slightly felted with sinuate margins, purplish at the center and light outward. Saltation of colonies is occasionally observed in some plates. The colony on the reverse side of the agar plate is zonated and purple and light purple outward.

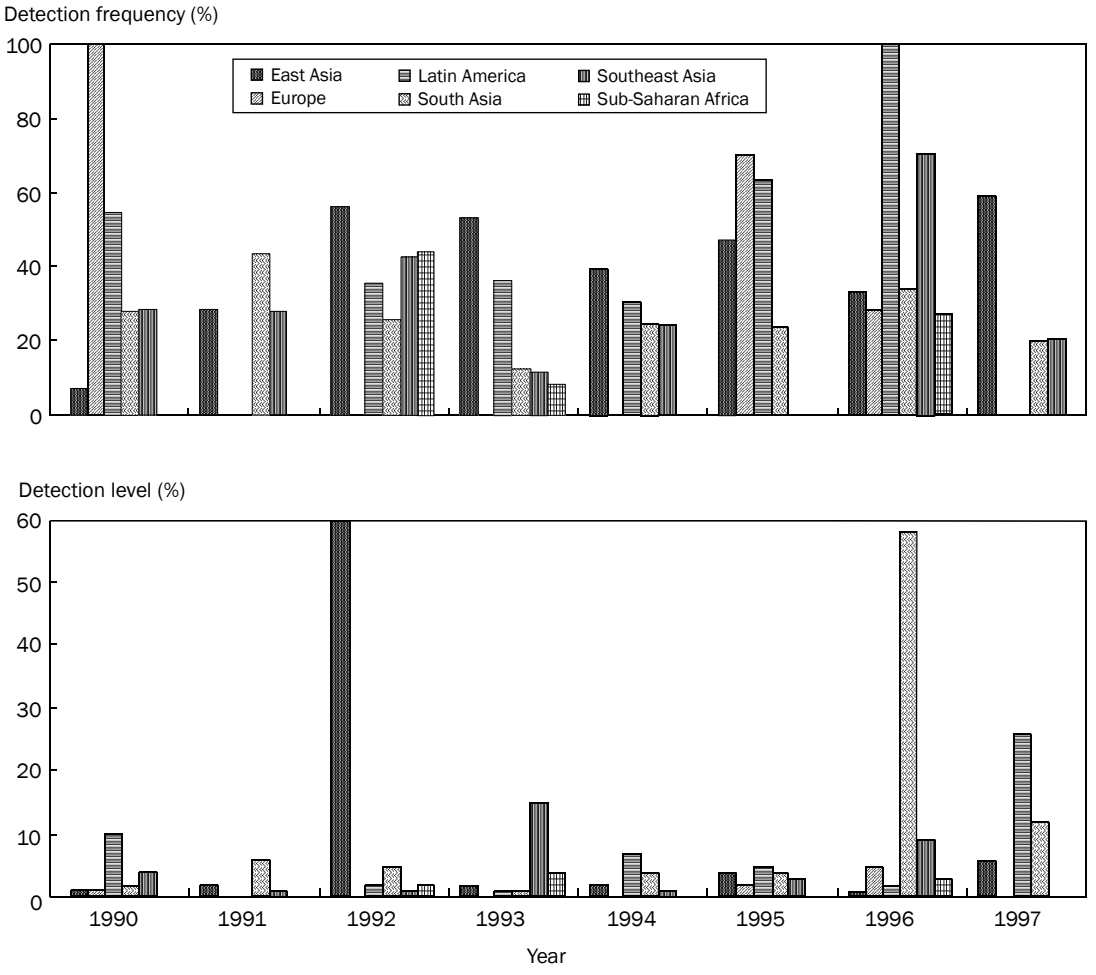

Fig. 29. Detection frequency (a) and level (b) of *Fusarium moniliforme* from imported untreated seeds, 1990-97.

Colonies on PSA at ART (28–30 °C) are spreading and grow moderately fast, attaining a 5.30-cm diam in 5 d. They are azonated, floccose with serrate margins, and white tinged with pink at the center. The colony on the reverse side of the agar plate is slightly zonated and white with a purplish tinge at the center. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies grow moderately fast and attain a 5.34-cm diam in 5 d. They are slightly zonated, floccose to slightly felted with serrate margins, and purplish at the center and light purple outward. The colony on the reverse side of the agar plate appears slightly zonated and white to creamy. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow moderately fast and attain a 5.90-cm diam in 5 d. They are slightly zonated, densely floccose with serrate margins, and white; they later become creamy at the center. The colony on the reverse side of the agar plate is slightly zonated and white to creamy.

Colonies on OA at ART (28–30 °C) grow moderately fast and attain a 5.78-cm diam in 5 d. They are azonated and floccose to deeply felted with even to slightly sinuate margins. Colonies are white and become purple at the center. The colony on the reverse side of the agar plate appears azonated and white with dark purple centers. At 21 °C under alternating NUV light and 12-h darkness, colonies grow slowly and attain a 4.93-cm diam in 5 d. They are zonated, slightly felted with even margins, and white to purple. Saltation of colonies was observed in some plates. The colony on the reverse side of the agar

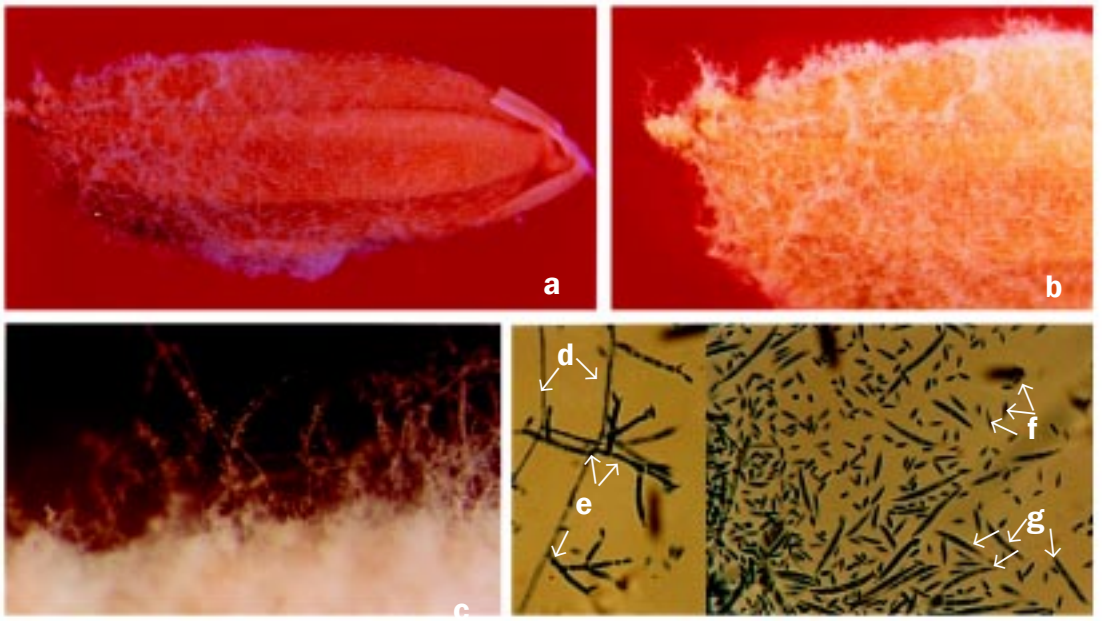

Fig. 30. Habit character of *Fusarium moniliforme* Sheld. on (a) whole seed (10X) and (b) awn portion (17X). (c) Mycelial growth of *F. moniliforme* showing false heads (49X). Photomicrograph of *F. moniliforme* showing (d) mycelia, (e) microconidiophores, (f) microconidia, and (g) macroconidia at 40X and stained with lactophenol blue.

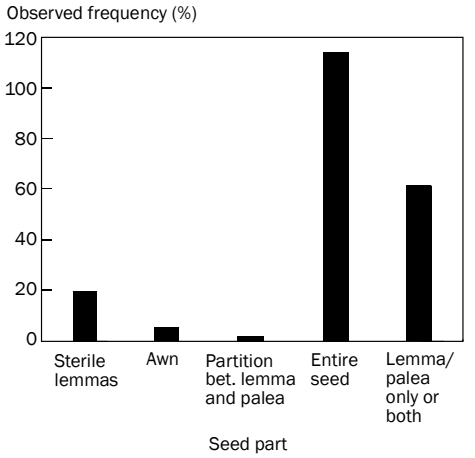

Fig. 31. Observed frequency of *Fusarium moniliforme* occurrence on the seed.

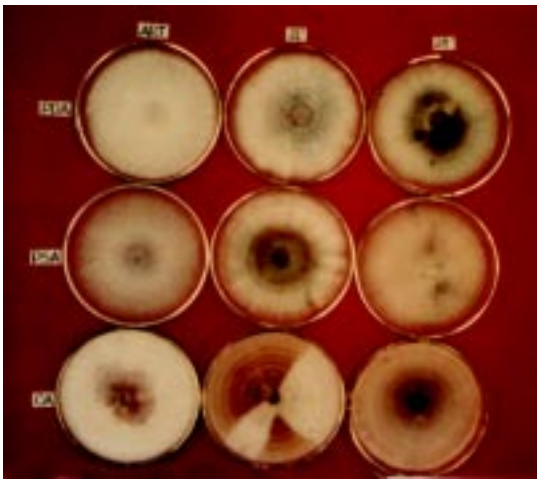

Fig. 32. Plate cultures of *Fusarium moniliforme* Sheld. showing colony growths on PDA, PSA, and oatmeal agar (OA) incubated at ART, 21 °C, and 28 °C at 15 d after inoculation.

plate is zonated and white to dark purple. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow moderately fast and attain a 5.73-cm diam in 5 d. They are slightly zonated, floccose with even margins, and white with light purplish coloration at the center. The colony on the reverse side of the agar plate appears slightly zonated and dark purple and lighter outward.

Sarocladium oryzae (Sawada) W. Gams & D. Hawks.
syn. *Acrocylindrium oryzae* Saw.
Sarocladium attenuatum W. Gams & D. Hawks.

Disease caused: sheath rot

a. Symptoms
Lesions start at the uppermost leaf sheath enclosing young panicles as oblong or irregular spots, with brown margins and gray center or brownish gray throughout. Spots enlarge and coalesce covering most of the leaf sheath. Panicles remain within the sheath or may partially emerge. Affected leaf sheaths have abundant whitish powdery mycelium. The pathogen infects rice plants at all growth stages, but it is most destructive after the booting stage.

b. Occurrence/distribution
Sarocladium oryzae is present in all rice-growing countries worldwide (Fig. 33). Sheath rot has become more prevalent in recent decades and is very common in rainfed rice or rice during the rainy season.

c. Disease history
Sawada first described sheath rot of rice in 1922 from Taiwan. He named the causal organism as *Acrocylindrium oryzae*. In 1975, Gams and Hawksworth reclassified the causal organism as *Sarocladium oryzae* after comparing their isolates with those of Sawada.

d. Importance in crop production
Densely planted fields and those infested by stem borers are susceptible to *S. oryzae* infection. The fungus tends to attack leaf sheaths enclosing young panicles, which retards or aborts the emergence of panicles. Seeds from infected panicles become discolored and sterile, thereby reducing grain yield and quality.

Detection on seed

a. Incubation period on blotter
Using the blotter test, *S. oryzae* can be observed on rice seeds 7 d after seeding and incubated under NUV light conditions at 21 °C. The detection frequency is about 21.3% on seeds coming from different regions (Fig. 34a,b).

b. Habit character
The mycelia are white, sparsely branched, septated, scanty to moderate, creeping close to the

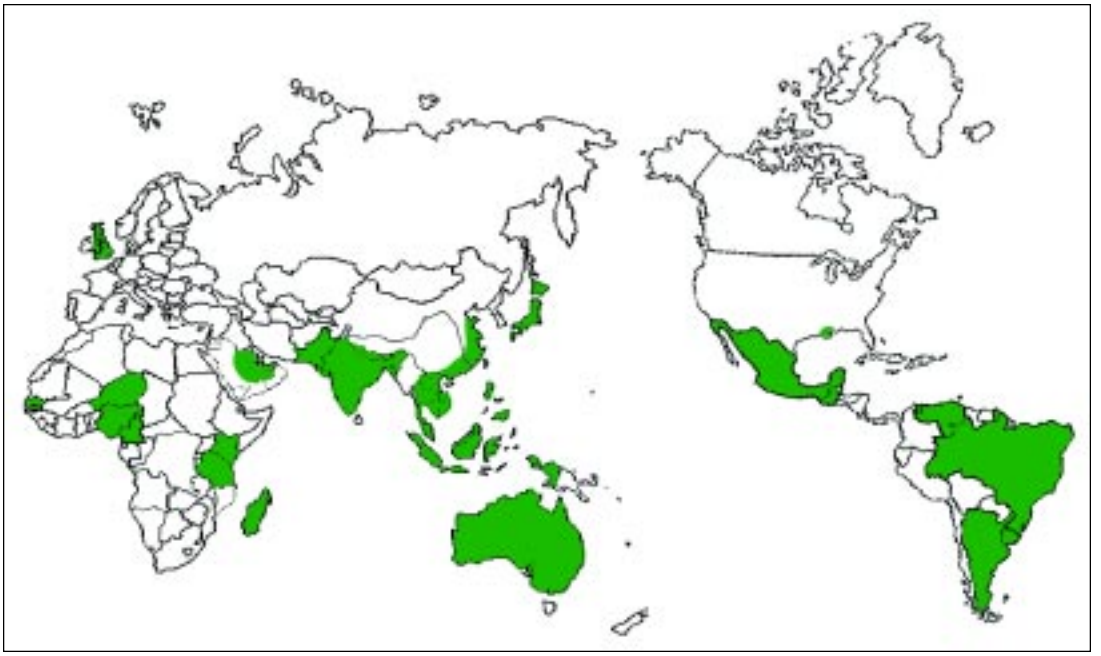

Fig. 33. Occurrence of sheath rot (Ou 1985, EPPO 1997).

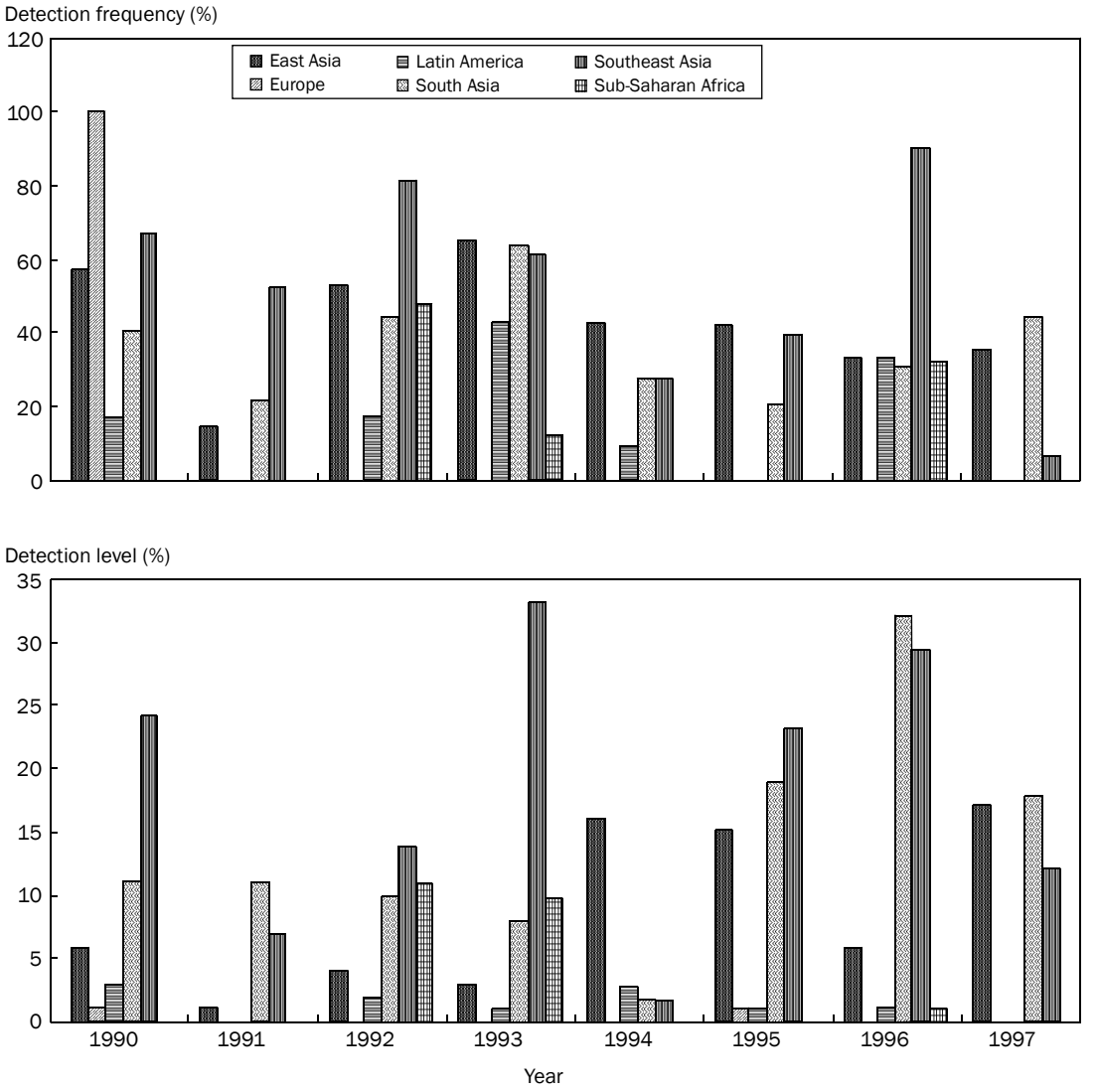

Fig. 34. Detection frequency (a) and level (b) of *Sarocladium oryzae* from imported untreated seeds, 1990-97.

seed surface, rarely becoming aerial. Conidiophores are very short with conidia collected in a slime drop that are globose and shiny (Fig. 35a-c).

c. Location on seed
S. oryzae is mostly observed on the entire seed (about 46%) and on the lemma and/or palea (about 31%) (Fig. 36).

Microscopic character

a. Mycelia—white, sparsely branched, septate (Fig. 35d).
b. Conidiophores—slightly thicker than the vegetative hyphae, simple, or branched either once or twice; terminal branches tapering at the tip (Fig. 35e).
c. Conidia—hyaline, smooth, single-celled, cylindrical with rounded ends; straight, sometimes slightly curved, formed singly (Fig. 35f). Measurements: 2.07–8.74 µ × 1.15–3.68 µ (PDA); 4.14–8.28 µ × 1.38–3.68 µ (PSA); and 4.14–7.13 µ ×1.38–3.91 µ (MEA).

Colony characters on culture media (Fig. 37)

Colonies on PDA at ART (28–30 °C) are restricted in growth and attain a 4.33-cm diam in 15 d. They are azonated, plane, velvety with even margins, and pale

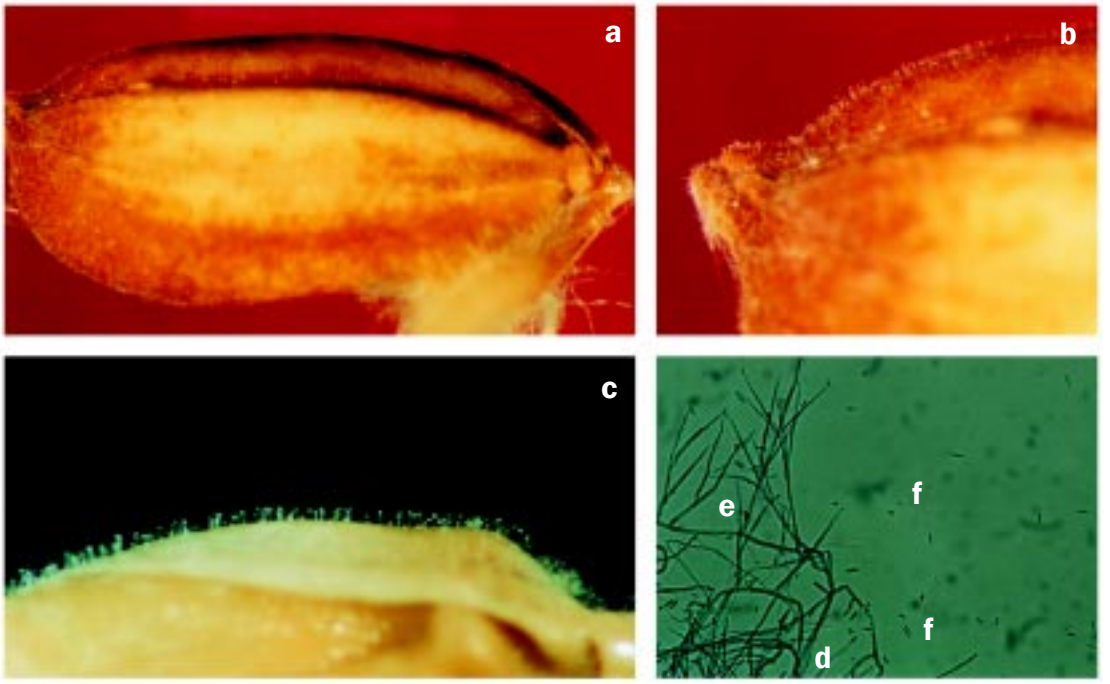

Fig. 35. Habit character of *Sarocladium oryzae* (Sawada) W. Gams. and D. Hawks. on (a) whole seed (10X), (b) awn portion (32X), and (c) sterile lemmas (50X) showing minute, shiny, and globose false heads. Photomicrograph of *S. oryzae* showing (d) mycelia, (e) conidiophores, and (f) conidia at 40X and stained with lactophenol blue.

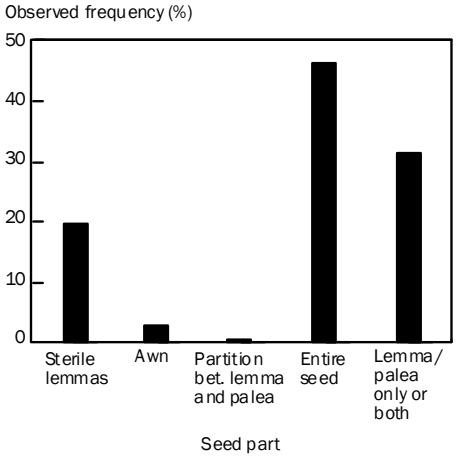

Fig. 36. Observed frequency of *Sarocladium oryzae* occurrence on the seed.

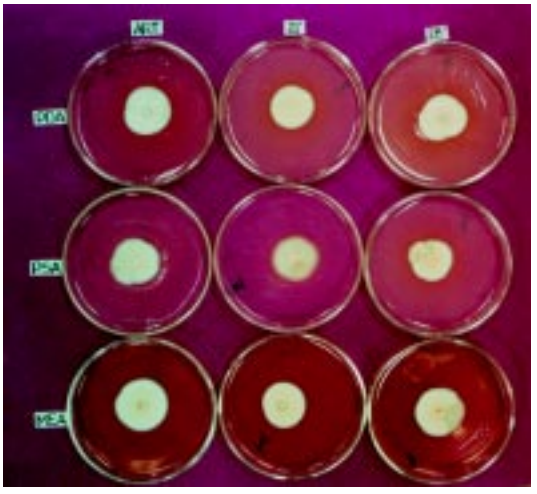

Fig. 37. Plate cultures of *Sarocladium oryzae* (Sawada) W. Gams and D. Hawks. showing colony growths on PDA, PSA, and MEA incubated at ART, 21 °C, and 28 °C at 15 d after inoculation.

orange. On the reverse side of the agar plate, the colony looks azonated and yellowish brown. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies are restricted in growth and attain a 3.96-cm diam in 15 d. They are azonated, plane, velvety with even to slight sinuate margins, pale orange, and moisture is produced with age. The colony on the reverse side of the agar plate appears azonated and yellowish brown. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies are restricted in growth and attain a 4.23-cm diam in 15 d. They are zonated, plane, velvety with sinuate margins, and pale orange. On the reverse side of the agar plate, the colony appears slightly zonated and yellowish brown.

Colonies on PSA at ART (28–30 °C) are restricted in growth and attain a 4.80-cm diam in 15 d. They are slightly zonated, slightly felted with sinuate margins, and pale orange. The colony on the reverse side of the agar plate appears slightly zonated and pale yellow-orange. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies are restricted in growth and attain a 4.21-cm diam in 15 d. They are azonated, plane, slightly velvety, with a few slight radial furrows, sinuate margins, and pale orange. The colony appears azonated, with a few radial wrinkles and pale yellow-orange on the reverse side of the agar plate. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies are restricted in growth and attain a 4.05-cm diam in 15 d. They are slightly zonated, slightly felted with a few slight radial furrows in some plates, with slightly sinuate to even margins, and pale orange; moisture is produced with age. The colony appears slightly zonated with a few slight radial wrinkles and pale yellow-orange on the reverse side of the agar plate.

Colonies on MEA at ART (28–30 °C) are restricted in growth and attain a 4.84-cm diam in 15 d. They are slightly zonated, plane, velvety, and pale orange. The colony appears slightly zonated and dull orange with pale yellow-orange margins on the reverse side of the agar plate. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies are restricted in growth and attain a 4.37-cm diam in 15 d. They are zonated, felted with slight sinuate margins, and pale orange. On the reverse side of the agar plate, the colony appears azonated and dull orange with pale yellow-orange margins. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies are restricted in growth and attain a 4.47-cm diam in 15 d. They are plain to felted, zonated at the center, and become azonated toward the margins, with slight radial furrows and slight sinuate margins. Colonies are pale orange and whitish toward the margins. On the reverse side of the agar plate, the colony appears zonated with a few radial wrinkles and dull orange with pale yellow-orange margins.

Seedborne fungi causing grain and inflorescence diseases in rice

Curvularia sp.

Disease caused: black kernel

a. Symptoms
   Black discoloration on grains.
b. Occurrence/distribution
   Curvularia sp. is frequently isolated from discolored rice grains. Several species have been reported on rice from different countries (Fig. 38), but *C. lunata* and *C. geniculata* are the most common ones.
c. Importance in crop production
   Curvularia sp. causes little or no yield loss under normal rice production situations. Infected grains, after being polished, may produce black kernels, thus reducing their market value.

Detection on seed

a. Incubation period on blotter
   On blotters incubated under NUV light at 21 °C, the fungus can be observed growing on rice seed 7 d after seeding. The detection frequency is about 70.6% on seeds coming from different regions (Fig. 39a,b).
b. Habit character
   Aerial mycelia are scanty or absent; if present, they are light brown to brown with abundant branching. Conidiophores are solitary or in groups; dark brown; straight, sometimes bent; simple; arising directly from the seed surface. Conidia are borne more or less at the tip in a whorl or in thick panicles (Fig. 40a-c).

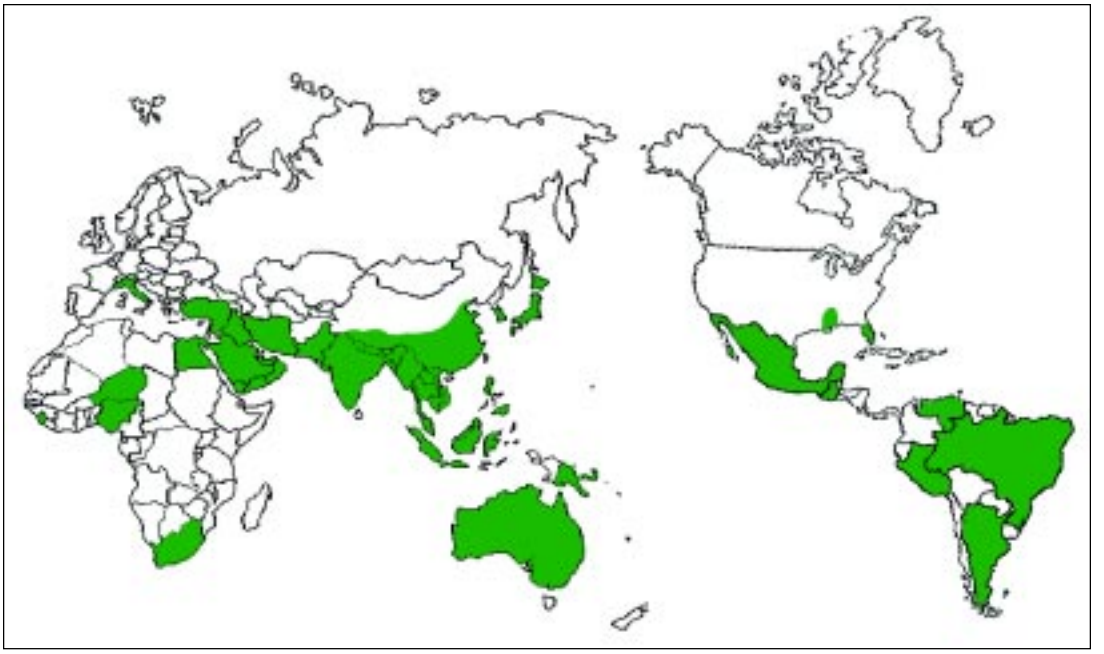

Fig. 38. Occurrence of black kernel (Ou 1985, CABI/EPPO 1997).

c. Location on seed
Curvularia sp. is observed most often on the lemma and/or palea (about 66%) of the seed (Fig. 41).

Microscopic character

a. Mycelia—septated, branched, subhyaline to light brown, in some cases dark brown (Fig. 40d).
b. Conidiophores—dark brown, unbranched, septate, sometimes bent and knotted at the tip (Fig. 40e).
c. Conidia—dark brown, boat-shaped, rounded at the tip, mostly a little constricted at the base; with hilum scarcely or not at all protuberant, smooth-walled, light to dark brown, with three septa; the 2nd cell is larger than the 1st, 3rd, and 4th cells; bent on the 2nd cell; borne at the tip, arranged in a whorl one over another or more or less spirally arranged or in thick panicles (Fig. 40f). Measurements: 16.33–24.84 µ × 7.36–13.34 µ (PDA); 17.48–27.37 µ × 8.28–13.11 µ (PSA); and 15.64–26.91 µ × 7.36–12.65 µ (MEA).

Colony characters on culture media (Fig. 42)

Colonies on PDA at ART (28–30 °C) grow fast and attain an 8.40-cm diam in 5 d. Colonies are zonated and felted; the conidial area is greenish gray with a 3-mm sterile advancing margin and abundant grayish mycelial tufts. The colony appearance on the reverse side of the agar plate is zonated and gray. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies grow moderately fast and attain a 5.94-cm diam in 5 d. They are cottony to slightly felted with slight radial furrows and 5-mm even, sterile margins, zonated, and black, becoming gray toward the margins. The colony appearance on the reverse side of the agar plate appears zonated and black at the center and lighter outward. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow very fast and attain an 8.30-cm diam in 5 d. Colonies are zonated, hairy to slightly felted, and the conidial area is olive gray to greenish gray with a 2-mm sterile white margin. The colony appearance on the reverse side of the agar plate is slightly zonated and black.

Colonies on PSA at ART (28–30 °C) grow very fast and attain an 8.50-cm diam in 5 d. They are slightly zonated, slightly cottony, and somewhat depressed to the media. The conidial area is black with 3-mm sterile white margins becoming black as conidia are produced. The colony on the reverse side of the agar plate appears zonated and slightly black. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies grow fast and attain a 6.91-cm diam in 5 d. They are zonated, slightly cottony, with a

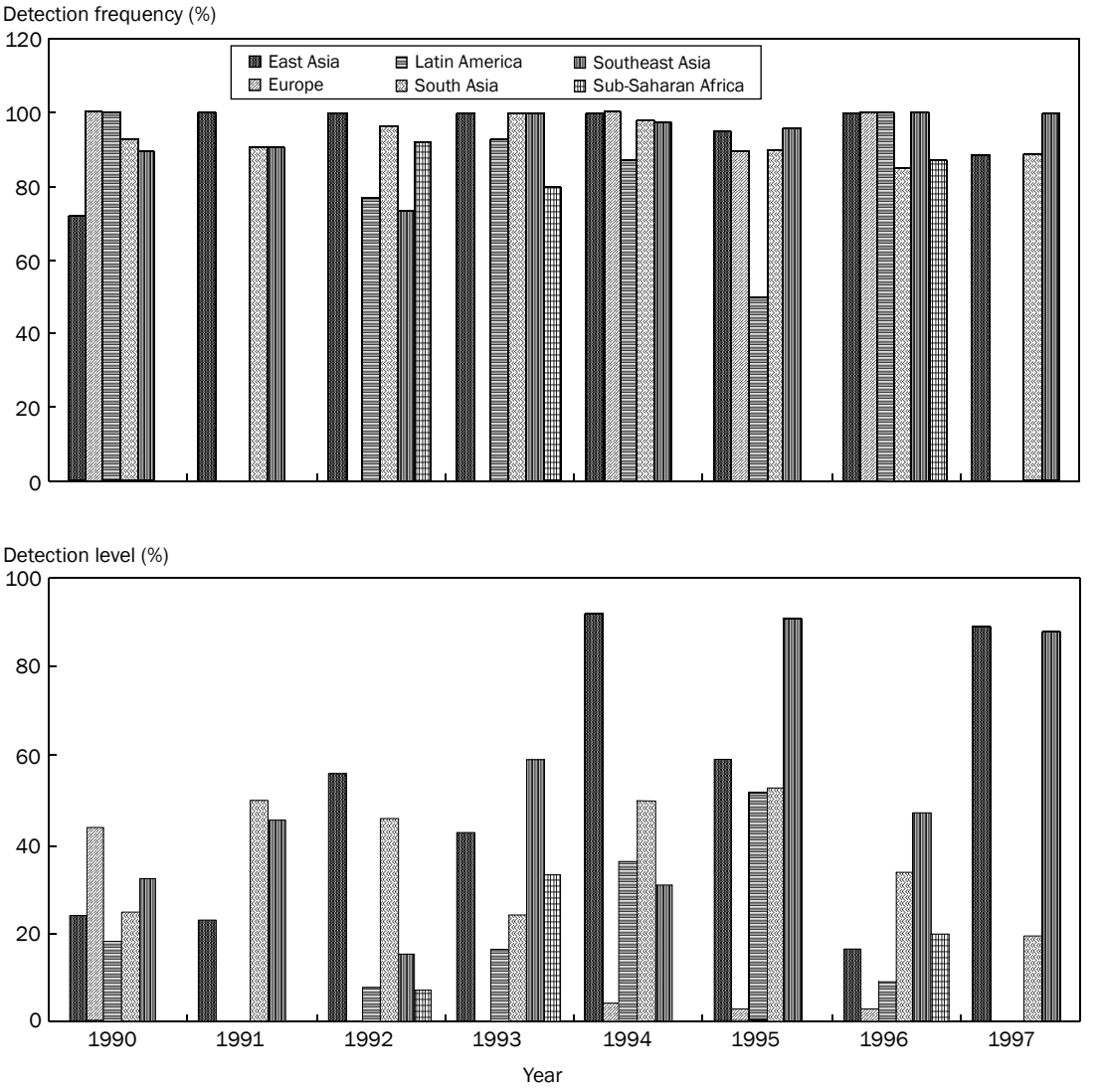

Fig. 39. Detection frequency (a) and level (b) of *Curvularia* sp. from imported untreated seeds, 1990-97.

black conidial area with 3-mm sterile white margins. The colony on the reverse side of the agar plate appears zonated, black, and light outward. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow very fast and attain a 9.0-cm diam in 5 d. They are zonated, slightly cottony, and the conidial area is black with 5-mm sterile white margins turning black as conidia are produced. The colony on the reverse side of the agar plate appears slightly zonated, black, and light outward.

Colonies on MEA at ART (28–30 °C) grow very fast and attain an 8.17-cm diam in 5 d. They are markedly zonated, felted, and greenish gray. The colony on the reverse side of the agar plate appears zonated and black. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies grow moderately fast and attain a 6.53-cm diam in 5 d. They are zonated, brown, and light outward. The colony on the reverse side of the agar plate appears zonated and brown, becoming lighter outward. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow very fast and attain an 8.23-cm diam in 5 d. They are zonated, slightly felted, olivaceous brown, and become light outward with 2-mm sterile white margins. The colony on the reverse side of the agar plate appears slightly zonated and black.

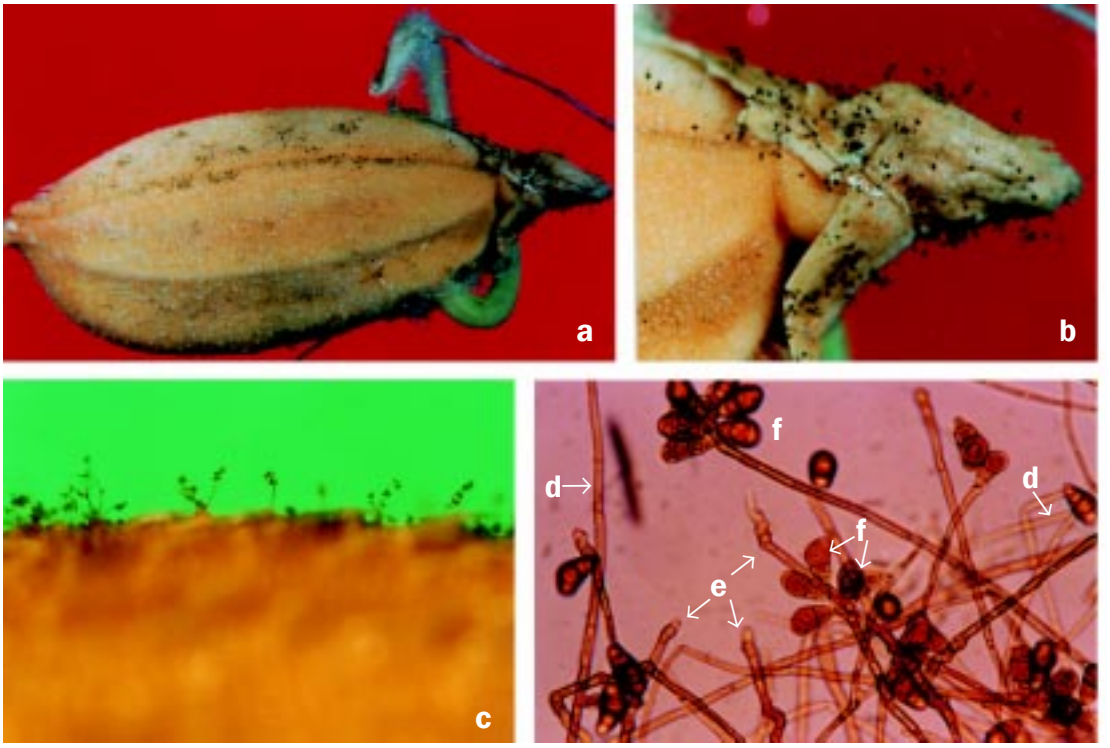

Fig. 40. Habit character of *Curvularia* sp. on (a) whole seed (10X), (b) sterile lemmas (20X), and (c) lemma (32X). Photomicrograph of *Curvularia* sp. showing (d) mycelia, (e) conidiophores, and (f) conidia at 40X.

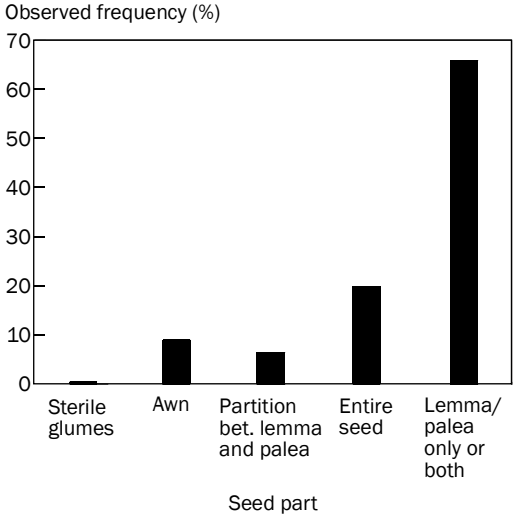

Fig. 41. Observed frequency of *Curvularia* sp. occurrence on the seed.

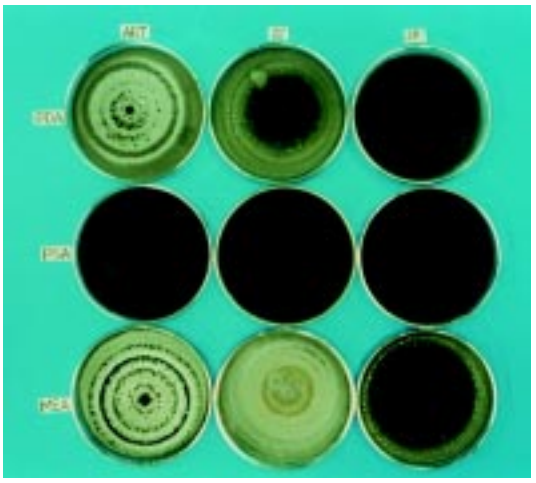

Fig. 42. Plate cultures of *Curvularia lunata* (Wakker) Boedijin showing colony growths on PDA, PSA, and MEA incubated at ART, 21 °C, and 28 °C at 15 d after inoculation.

Fusarium solani (Mart.) Sacc.
syn. *Fusisporium solani* Martius
Fusarium javanicum Koorders
Fusarium solani var. *martii* (Apel & Wollenw.) Wollenw.
Fusarium solani var. *striatum* (Sherbakov) Woellenw.
teleomorph: *Hyphomyces solani*
Nectria haematococca var. *brevicona* (Wollenw.) Gerlach

Disease caused: none reported in rice

a. Occurrence/distribution
F. solani is a rice seedborne pathogen that occurs in low frequency. The fungus may be involved in grain discoloration. However, it is detected on seed coming from different regions and rice ecosystems.

Detection on seed

a. Incubation on blotter
Using the blotter test, *F. solani* can be observed on rice seeds 5 d after incubation in NUV light at 21 °C. The detection frequency is <1% on seed coming from different regions.
b. Habit character
Aerial mycelia are rarely present on seed. If present, they are scanty, creeping close to the seed surface and loosely branched. Aerial mycelia appear white with small, beadlike, dirty to creamy white false heads borne on long, simple, upright to slightly bent conidiophores. Pionnotes appear as irregular creamy white masses on the seed surface, usually on the embryonal side (Fig. 43a-e).
c Location on seed
F. solani is most often observed on sterile lemmas (about 48%) of the rice seed (Fig. 44).

Microscopic character

a. Conidiophore—short, simple to multibranched, hyaline (Fig. 43f).
b. Macroconidia—hyaline, 4-septate; inequilaterally fusoid with widest diam at the middle cell (boat-shaped); rounded foot cell; apical cell pointed and somewhat beaked (Fig. 43g). Measurements: 48.30–73.14 µ × 4.37–7.59 µ (PDA); 30.36–66.70 µ × 3.22–8.51 µ (PSA); and 41.17–74.29 µ × 4.14–8.05 µ (OA).
c. Microconidia—aggregated in slime heads; hyaline, broadly oval; single-celled to 4-celled with thick walls (Fig. 43h). Measurements: 1–2 celled, 8.97–16.10 µ × 2.30–8.51 µ (PDA); 6.90–18.40 µ × 2.30–6.44 µ (PSA); and 5.75–15.87 µ × 1.84–6.44 µ (OA).

Colony characters on culture media (Fig. 45)

Colonies on PDA at ART (28–30 °C) spread thinly but relatively fast and attain a 5.81-cm diam in 5 d. They are evenly zonated with even margins, pale yellow, and become powdery with age. The colony on the reverse side of the agar plate appears zonated and yellow. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies spread thinly but relatively fast and attain a 5.11-cm diam in 5 d. They are evenly zonated with even margins and are light yellow-orange. The colony on the reverse side of the agar plate appears evenly zonated and yellow. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies spread thinly but relatively fast and attain a 5.53-cm diam in 5 d. They are evenly zonated with even margins and colored light yellow-orange. The colony on the reverse side of the agar plate appears evenly zonated and yellow.

Colonies on PSA at ART (28–30 °C) spread thinly but relatively fast and attain a 5.88-cm diam in 5 d. They are slightly zonated with even margins; aerial mycelia are pressed to the media, light gray, shiny, and become powdery with age. The colony on the reverse side of the agar plate appears slightly zonated and light gray. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies spread relatively fast and attain a 5.21-cm diam in 5 d. They are zonated with even margins, hairy, and light gray. The colony on the reverse side of the agar plate appears zonated and light gray. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies spread thinly but relatively fast and attain a 5.68-cm diam in 5 d. They are evenly zonated with even margins and the aerial mycelia are hairy and slightly pressed to the media and are light gray. The colony on the reverse side of the agar plate appears evenly zonated and pale yellow.

Colonies on OA at ART (28–30 °C) spread moderately fast and attain a 4.42-cm diam in 5 d. They are azonated and aerial mycelia are scanty and hairy and then become powdery and finally creamy with age. The color is dull reddish brown, which becomes dark brown with age, with light gray and advancing margins. The colony appearance on the re-

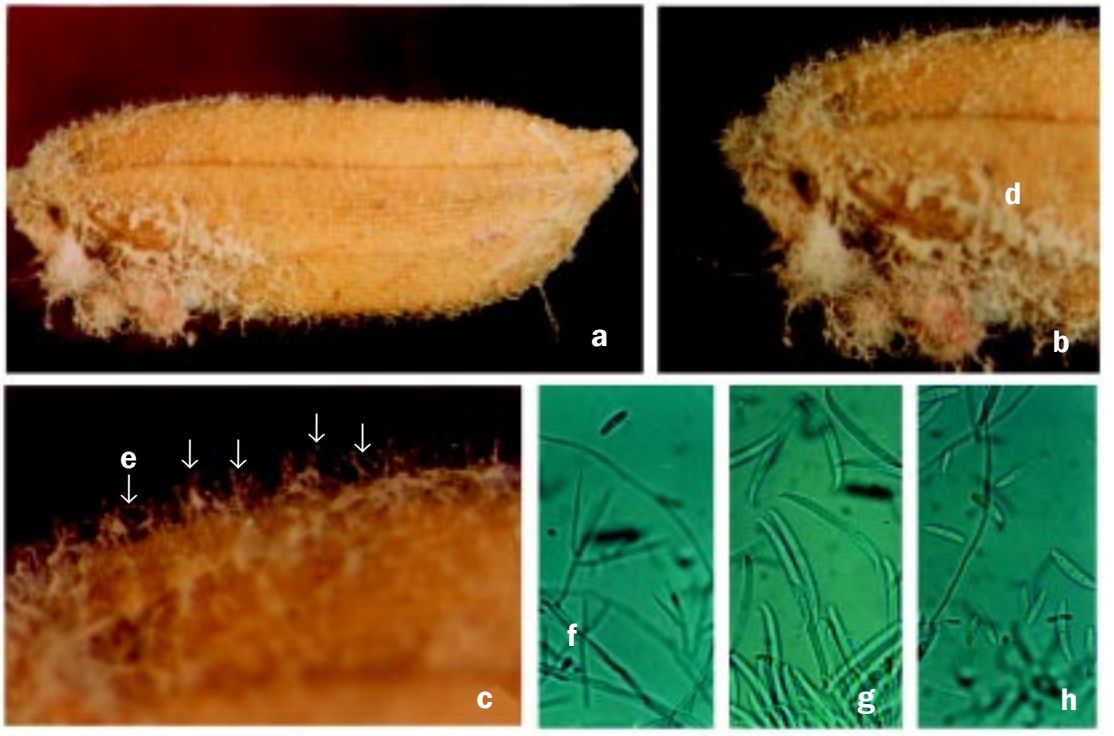

Fig. 43. Habit character of *Fusarium solani* (Mart.) Sacc. on (a) whole seed (11X) and sterile lemmas at (b) 21X and (c) 40X showing (d) pionnotes and (e) false heads. Photomicrograph of *F. solani* showing (f) conidiophore, (g) macroconidia, and (h) microconidia at 40X stained with lactophenol blue.

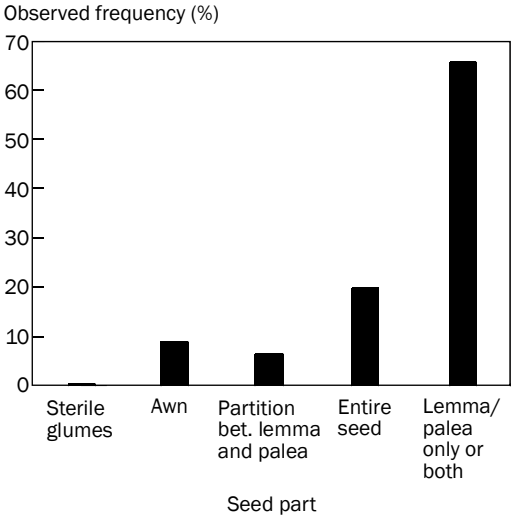

Fig. 44. Observed frequency of *Fusarium solani* occurrence on the seed.

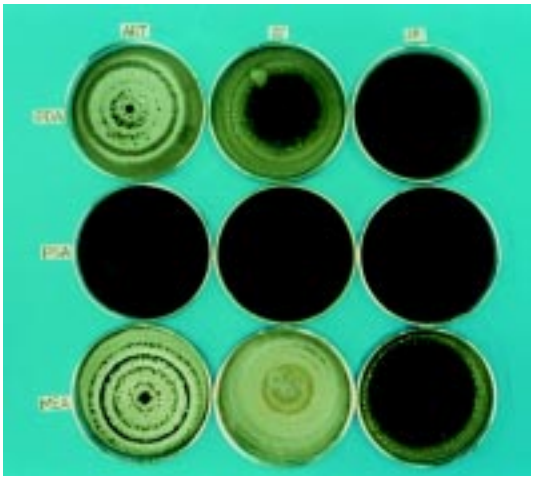

Fig. 45. Plate cultures of *Fusarium solani* (Mart.) Sacc. showing colony growths on PDA, PSA, and OA incubated at ART, 21 °C, and 28 °C at 15 d after inoculation.

verse side of the agar plate is zonated. The color is dark reddish brown. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies spread relatively fast and attain a 5.16-cm diam in 5 d. They are azonated; aerial mycelia are nil to scanty, slightly pressed to the media, powdery, becoming creamy with age, and light yellow at the center, becoming dull reddish brown n with light gray margins. The colony on the reverse side of the agar plate appears azonated and dull reddish brown. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies spread relatively fast and attain a 5.28-cm diam in 5 d. They are zonated with even margins and aerial mycelia are scanty and hairy, with 6-mm submerged advancing mycelia. The color is dull brown to brown, becoming lighter toward the margin. The colony on the reverse side of the agar plate appears zonated with a dull reddish brown color.

Nigrospora sp.
teleomorph: *Khushia oryzae* Huds.

Disease caused: minute leaf and grain spot

a. Symptoms
   Presence of numerous minute black pustules (<0.5 mm diam) in old or dead parts of rice plants.
b. Occurrence/distribution
   Many *Nigrospora* species have been reported throughout the world (Fig. 46). Four species are found on rice but *N. oryzae* (Berk. & Br.) Petch and *N. sphaerica* (Sacc.) Mason are the most common. They are all considered saprophytes.
c. Importance in crop production
   Nigrospora sp. has been reported to affect glumes, culms, leaves, or other parts of rice plants that are weakened because of nutritional or climatic conditions, or suffering from disease or insect attack. It has little economic importance in rice production.

Detection on seed

a. Incubation period on blotter
   Using the blotter test, *Nigrospora* sp. can be observed on rice seeds 7 d after seeding and incubation under NUV light at 21 °C. The detection frequency is about 33.4% on seeds coming from different regions (Fig. 47a,b).
b. Habit character
   Aerial mycelia are either scanty or absent. If aerial mycelium is absent, conidia appear to be scattered on the seed surface. Conidia are globose, shiny, and black. If aerial mycelium is present, it is hairy, not branched, and grayish white to light brown. Conidia appear to be borne on the sides of mycelia (Fig. 48a-c).
c. Location on seed
   Nigrospora sp. is most likely to be observed on sterile lemmas (about 65%) of the rice seed (Fig. 49).

Microscopic character

a. Mycelium—light brown; not branched, septated (Fig. 52d).
b. Conidiophores—short, simple, inflated below the tip (Fig. 52e).
c. Conidia (aleuriospore)—globose or subglobose, smooth, dark, one-celled, borne apically and singly (Fig. 52f). Measurements: 10.35–13.80 µ × 12.19–15.64 µ (PDA); 9.89–15.41 µ × 11.96–15.87 µ (PSA); and 10.12–14.72 µ × 10.12–16.10 µ (MEA).

Colony characters on culture media (Fig. 50)

Colonies on PDA at ART (28–30 °C) grow moderately fast and attain a 5.58-cm diam in 5 d. They are slightly zonated, grayish, and later become light outward with sinuate margins. The colony on the reverse side of the agar plate appears azonated and gray. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies grow very fast and attain an 8.07-cm diam in 5 d. They are azonated, becoming azonated toward the margins, slightly floccose and pressed to the media, and gray. The colony on the reverse side of the agar plate appears azonated and black. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow very fast and attain an 8.30-cm diam in 5 d. Colonies are slightly zonated and floccose, and black with 0.5-cm white and sinuate margins. The colony on the reverse side

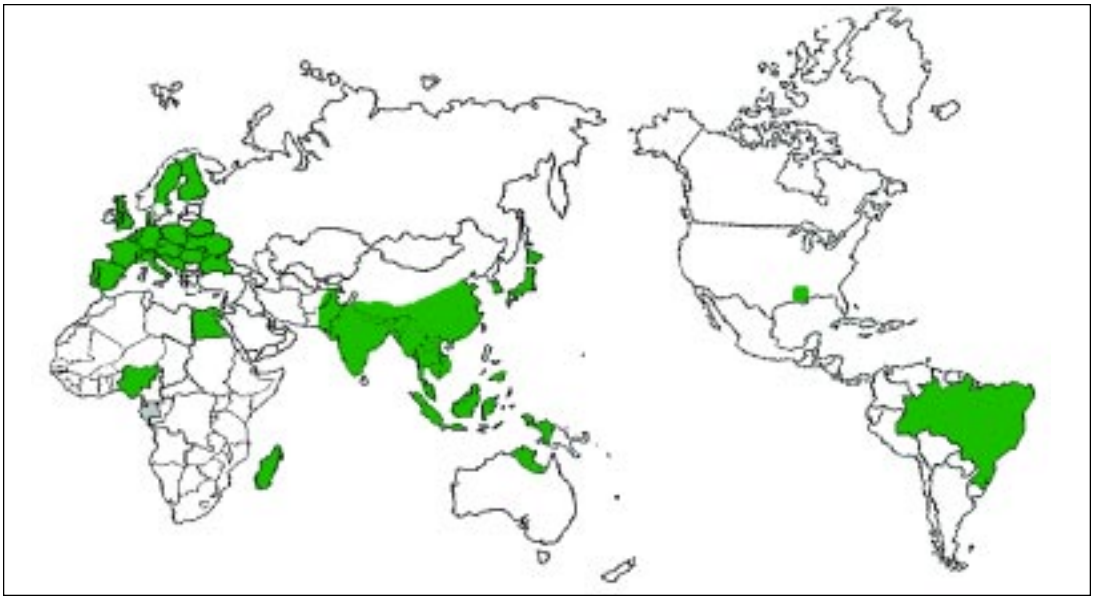

Fig. 46. Occurrence of minute leaf and grain spot (EPPO 1997).

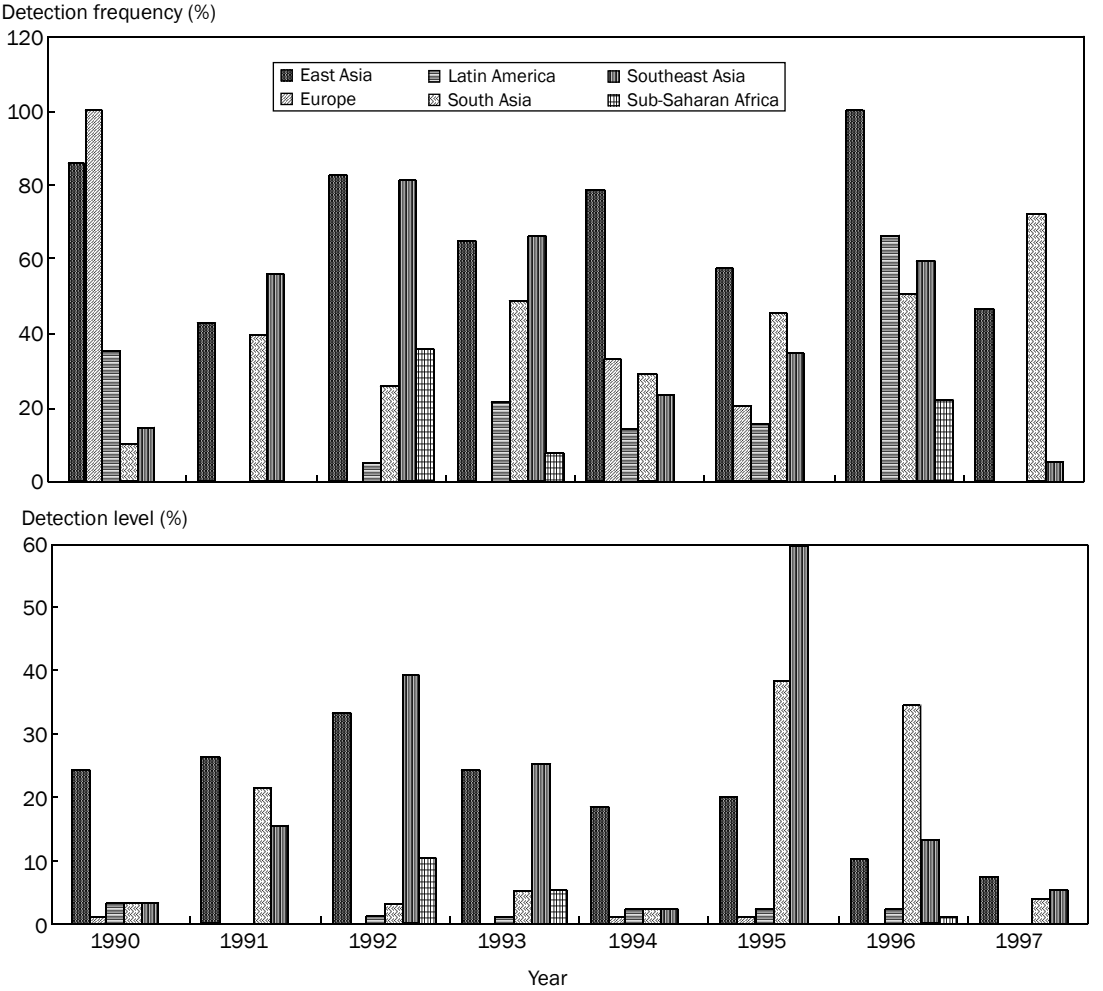

Fig. 47. Detection frequency (a) and level (b) of *Nigrospora* sp. from imported untreated seeds, 1990-97.

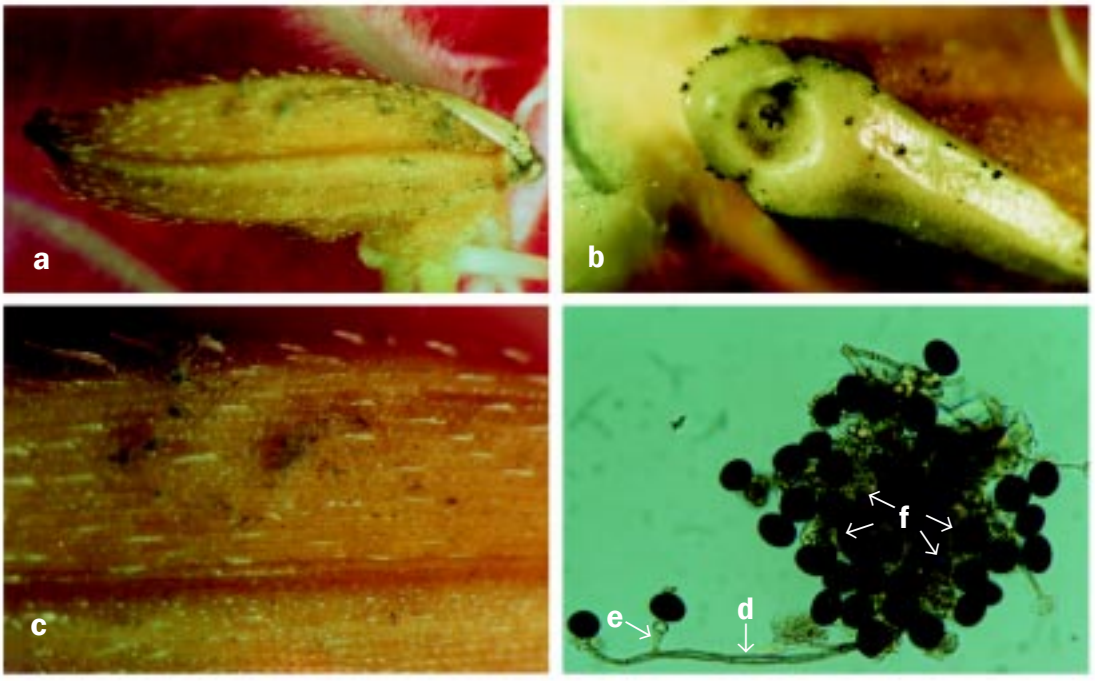

Fig. 48. Habit character of *Nigrospora* sp. on (a) whole seed (10X), (b) sterile lemmas (32X), and (c) plea (32X) showing shiny, black, and globose conidia. Photomicrograph of Nigrosopra sp. showing (d) mycelia, (e) conidiophore, and (f) conidia at 40X.

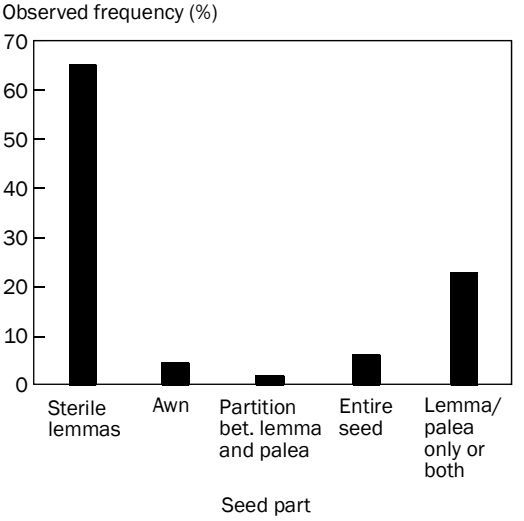

Fig. 49. Observed frequency of *Nigrospora* sp. occurrence on the seed.

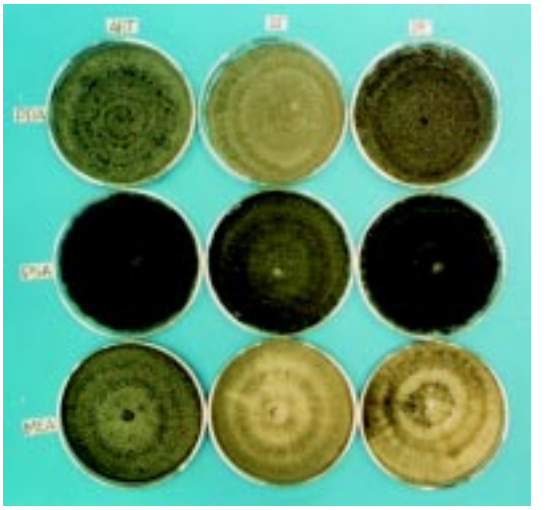

Fig. 50. Plate cultures of *Nigrospora* sp. showing colony growths on PDA, PSA, and MEA incubated at ART, 21 °C, and 28 °C at 15 d after inoculation.

of the agar plate appears slightly zonated and black.

Colonies on PSA at ART (28–30 °C) grow moderately fast and attain a 6.38-cm diam in 5 d. They are slightly zonated and densely floccose with sinuate margins, black, and later become light toward the margins. The colony on the reverse side of the agar plate appears slightly zonated and black. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies grow fast and attain a 7.78-cm diam in 5 d. They are slightly zonated, densely floccose, black, and lighter toward the margins. The colony on the reverse side of the agar plate appears zonated and black. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow fast and attain a 7.56-cm diam in 5 d. They are slightly zonated, densely floccose, black, and become lighter outward with sinuate margins. The colony of the reverse side of the agar plate appears slightly zonated and black.

Colonies on MEA at ART (28–30 °C) grow very fast and attain an 8.00-cm diam in 5 d. They are zonated, slightly floccose to felted, grayish to black, and become lighter outward. The colony on the reverse side of the agar plate appears zonated and black. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies grow moderately fast and attain a 6.53-cm diam in 5 d. They are zonated, slightly felted, and alternating white and light gray. The colony of the reverse side of the agar plate appears zonated, dark gray, and light toward the margins. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies spread fast and attain a 9.00-cm diam in 5 d. They are zonated, felted, and alternating gray and light gray. The colony on the reverse side of the agar plate appears zonated and dark gray.

Phoma sorghina (Sacc.) Boerema et al
teleomorph: *Mycosphaerella holci* Tehon

Disease caused: glume blight

a. Symptoms
Lesions are initially small, oblong, and brown, then gradually enlarge and coalesce, becoming whitish with small black dots.

The fungus infects glumes during the second or third week following emergence of panicles. When infection occurs early, no grain is formed. On the other hand, when infection is late, grains are partially filled or become discolored and brittle.

b. Occurrence/distribution
This is a disease of the grain. It is widely distributed and the pathogen is often detected on rice seed from different regions and rice production ecosystems (Fig. 51).

c. Disease history
The disease was first reported in the U.S. and Japan and later reported in other rice-growing areas as well. The fungus *P. sorghina* has been reported under different names, including *Phyllosticta glumarum* (Ell. & Tracy) Miyake, *Ph. oryzina* Padw., and *Ph. glumicola* (Speg.) Hara, and *Phoma oryzicola* Hara with *Trematosphaerella oryzae* (Miyake) Padw. as its teleomorph.

d. Importance in crop production
The disease is a relatively minor problem of rice. Together with other diseases of the grain, the loss is <0.01% across all rice production situations in Asia. The frequency of detection and observation on seed is shown in Figure 52a,b.

Detection on seed

a. Incubation on blotter
Using the blotter test, *P. sorghina* can be detected on rice seeds 7 d after incubation under NUV light at 21 °C. The detection frequency is about 57.8% on seeds coming from different regions.

b. Habit character
Aerial mycelia are rarely present. If present, mycelia are scanty, hairy, and brownish. Pycnidia are scattered on the seed surface either solitary or in groups erumpent or superficial. They are dark brown and globose or subglobose with protruding ostioles (Fig. 53a-c).

c. Location on seed
P. sorghina is most often observed on sterile lemmas (about 39%) of the rice seed (Fig. 54).

Microscopic character

a. Mycelium—dark brown, septated, loosely branched.

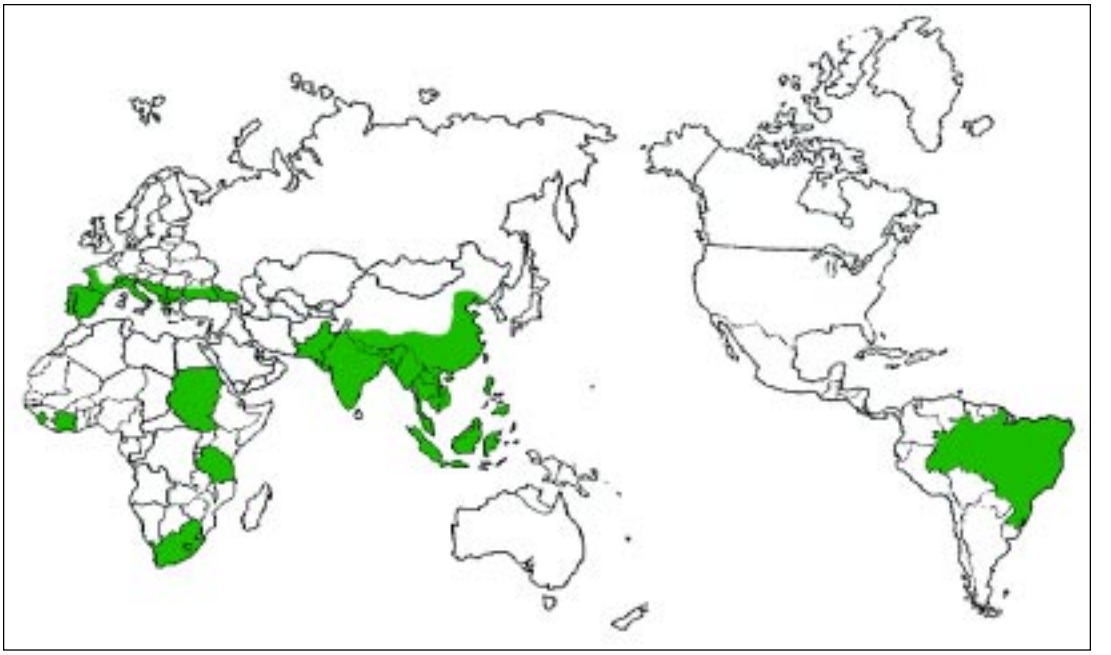

Fig. 51. Occurrence of glume blight (EPPO 1997).

b. Pycnidia—dark brown, globose or subglobose with protruding ostioles (Fig. 53d).
c. Conidia—oblong to ovoid, hyaline to slightly pigmented, single-celled (Fig. 53e). Measurements: 2.99–6.21 µ × 1.84–3.68 µ (PDA); 3.68–8.74 µ × 1.84–7.59 µ (PSA); and 3.45–6.67 µ × 1.38–4.60 µ (MEA).

Colony characters on culture media (Fig. 55)
Colonies on PDA at ART (28–30 °C) spread very fast and attain a 7.03-cm diam in 5 d. They are slightly zonated with even margins, thickly felted, and brownish gray. The colony on the reverse side of the agar plate appears zonated and is brownish gray with brownish black spots. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies spread very fast and attain a 7.73-cm diam in 5 d. They are zonated with even margins, felted, dull yellowish brown at the center, and greenish gray outward with 4-mm light brownish gray advancing margins. The colony on the reverse side of the agar plate appears zonated and dark reddish brown at the center and reddish orange outward. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow very fast and attain an 8.11-cm diam in 5 d. They are zonated, cottony to felted with even margins, and grayish olive and light gray outward. On the reverse side of the agar plate, the colony appears zonated and alternating brownish black and dull yellow-orange.

Colonies on PSA at ART (28–30 °C) spread very fast and attain a 7.52-cm diam in 5 d. They are azonated and fluffy to slightly floccose with even margins. The color is grayish yellow-brown at the center, becoming dark grayish yellow to grayish yellow. On the reverse side of the agar plate, the colony appears slightly zonated to zonated and is dull yellowish brown to brownish black with dull yellow-orange margins. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies spread very fast and attain a 7.58-cm diam in 5 d. They are azonated to slightly zonated, felted to cottony with even margins, and grayish yellow and gray outward. On the reverse side of the agar plate, the colony appears zonated, black at the center, and alternating dark olive and grayish olive outward. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies spread very fast and attain a 7.70-cm diam in 5 d. They are azonated with even margins, cottony to fluffy, and olive black, becoming light gray outward. On the reverse side of the agar plate, colony appears zonated. The color is black, becoming brownish black to dull yellow brown toward the margins.

Colonies on MEA at ART (28–30 °C) spread very fast and attain a 6.68-cm diam in 5 d. They are

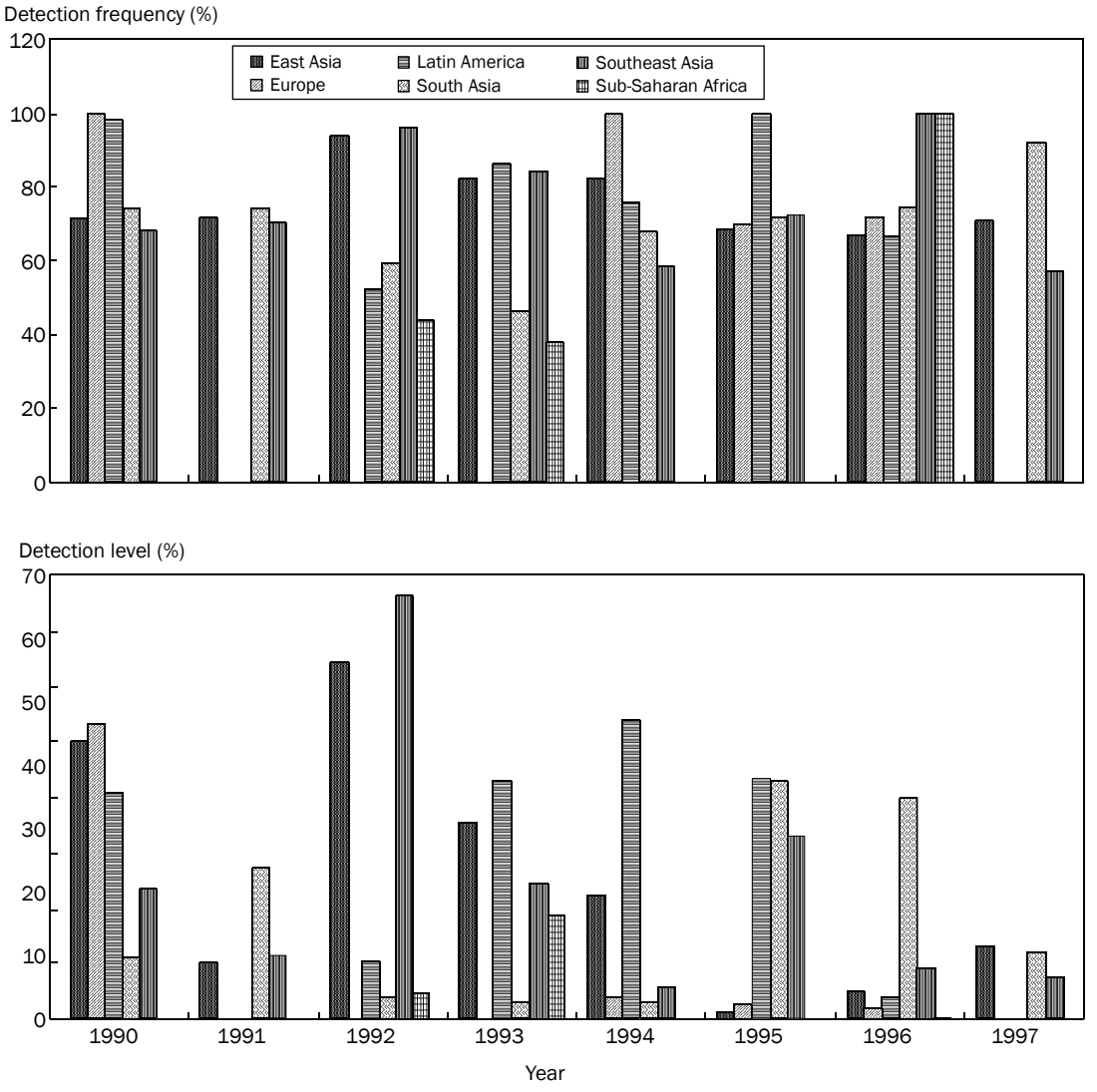

Fig. 52. Detection frequency (a) and level (b) of *Phoma* sp. from imported untreated seeds, 1990-97.

azonated and loosely floccose to hairy with even margins. Aerial mycelia are pressed to the media, olive black at the center, and become grayish olive to olive yellow outward. On the reverse side of the agar plate, the colony appears zonated. It is dark olive at the center and becomes grayish olive to olive yellow toward the margins. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies are thin but spread very fast and attain a 6.89-cm diam in 5 d. They are azonated with even margins. Aerial mycelia are pressed to the media. The color is dark olive green at the center and grayish olive outward. On the reverse side of the agar plate, the colony appears azonated. The color is olive black at the center and dark olive outward. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies spread thinly but very fast and attain a 7.10-cm diam in 5 d. They are azonated to slightly zonated, hairy to loosely floccose with even submerged margins, and grayish olive. On the reverse side of the agar plate, the colony appears slightly zonated and is dark olive, becoming lighter outward.

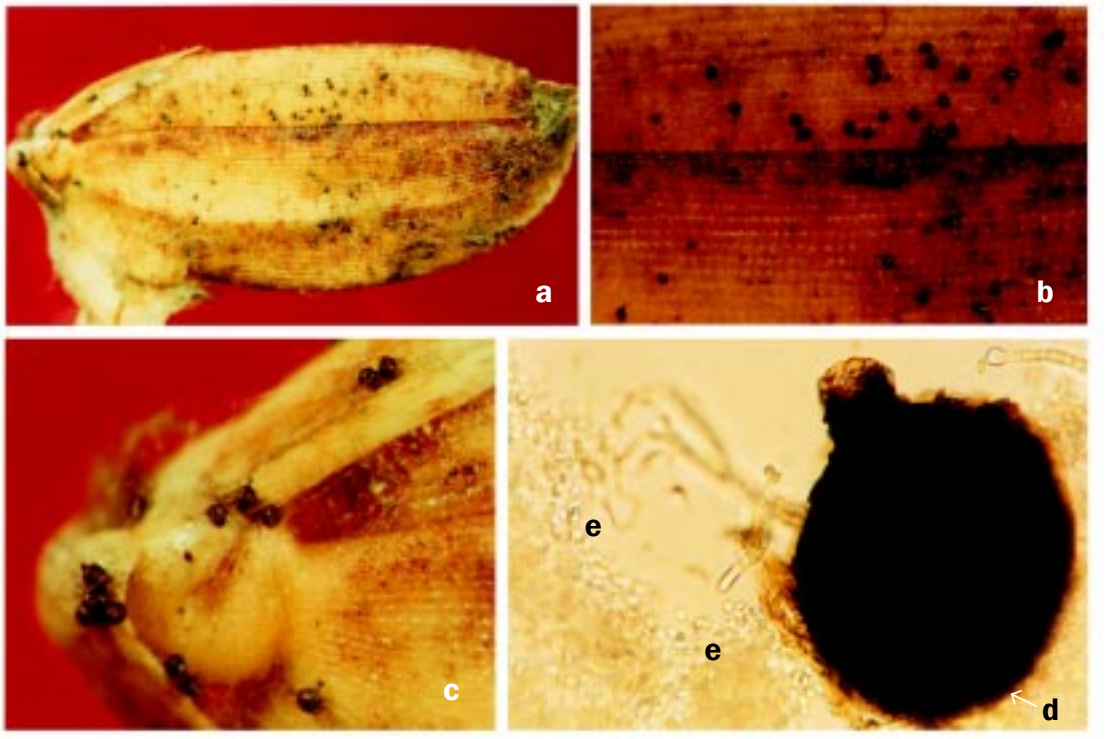

Fig. 53. Habit character of *Phoma sorghina* (Sacc.) on (a) whole seed (10X), (b) palea and lemma (25X), and (c) sterile lemmas (40X) showing dark, globose to subglobose, ostiolate pycnidia. Photomicrograph of *P. sorghina* showing (d) pycnidia and (e) conidia at 40X.

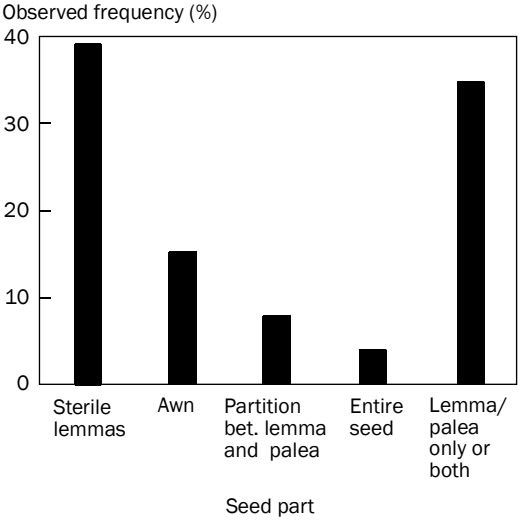

Fig. 54. Observed frequency of *Phoma* sp. occurrence on the seed.

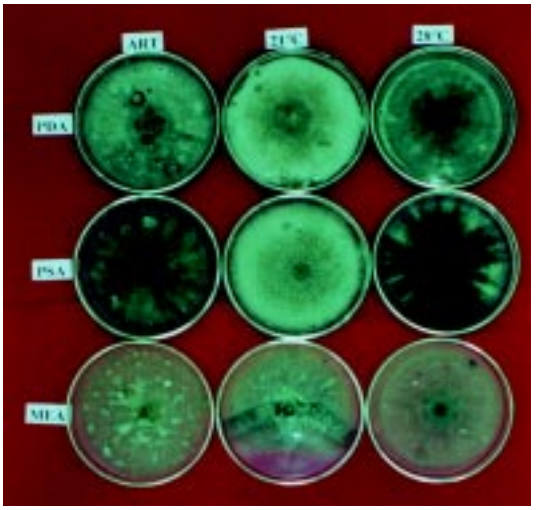

Fig. 55. Plate cultures of *Phoma* sp. showing colony growths on PDA, PSA, and MEA incubated at ART, 21 °C, and 28 °C at 15 d after inoculation.

Disease caused: seed rot

a. Symptoms
   Gray lesions on plumules.
b. Occurrence/distribution
   Pinatubo oryzae is frequently encountered in rice seed grown in the Philippines and other countries occurring on both germinated and nongerminating seeds (Fig. 56).
c. Disease history
   This fungus was previously identified as *Verticillium cinnabarinum* and re-identified as *Pinatubo oryzae* in 1996. It has been detected from rice seeds since 1982. It is highly probable that the organism was already present earlier but there are no literatures to document any efforts to identify the fungus.
d. Importance in crop production
   This fungus is a rice grain pathogen. It is minor in importance to rice production.

Detection on seed

a. Incubation period on blotter
   Using the blotter test, *P. oryzae* can be observed on rice seeds 5 d after incubation in NUV light at 21 °C. The detection frequency is about 25.2% on rice seeds coming from different regions.
b. Habit character
   Aerial mycelia are sparse to abundant and white with loose and abundant branching. Conidia are borne terminally and arranged in a flower-like manner. Pionnotes present on the seed surface are wet and creamy to pink or they hang under a thin cover of aerial hyphae (Fig. 57 a-c).
c. Location on seed
   P. oryzae is most often observed over the entire seed surface (about 46%) (Fig. 58).

Microscopic character

a. Mycelia—hyaline, septate (Fig. 57d).
b. Conidiophore—simple or branched, short, septate with denticles at the terminal portion (Fig. 57e).
c. Conidia—elongately oval, single- to 2-celled, very rarely 3-celled; pointed at the basal portion and rounded at the apical portion, hyaline (Fig. 57f). Measurements: 5.06–10.81 µ × 2.70–6.21 µ (PDA); 5.75–12.88 µ × 2.76–5.98 µ (PSA); and 5.75–11.73 µ × 2.53–5.06 µ (MEA).

Colony characters on culture media (Fig. 59)

Colonies on PDA at ART (28–30 °C) grow relatively fast and attain a 5.02-cm diam in 5 d. They are zonated with even margins, floccose, and reddish or-

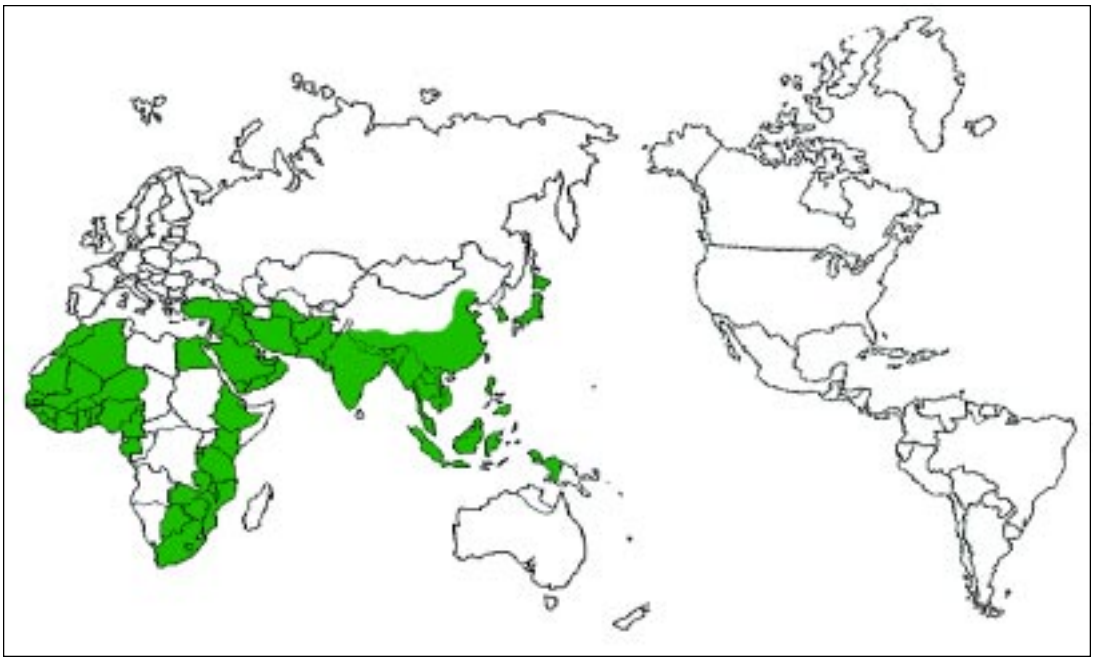

Fig. 56. Occurrence of *Pinatubo oryzae* on rice seed from different countries received at IRRI (IRRI-SHU unpublished data 1990-97).

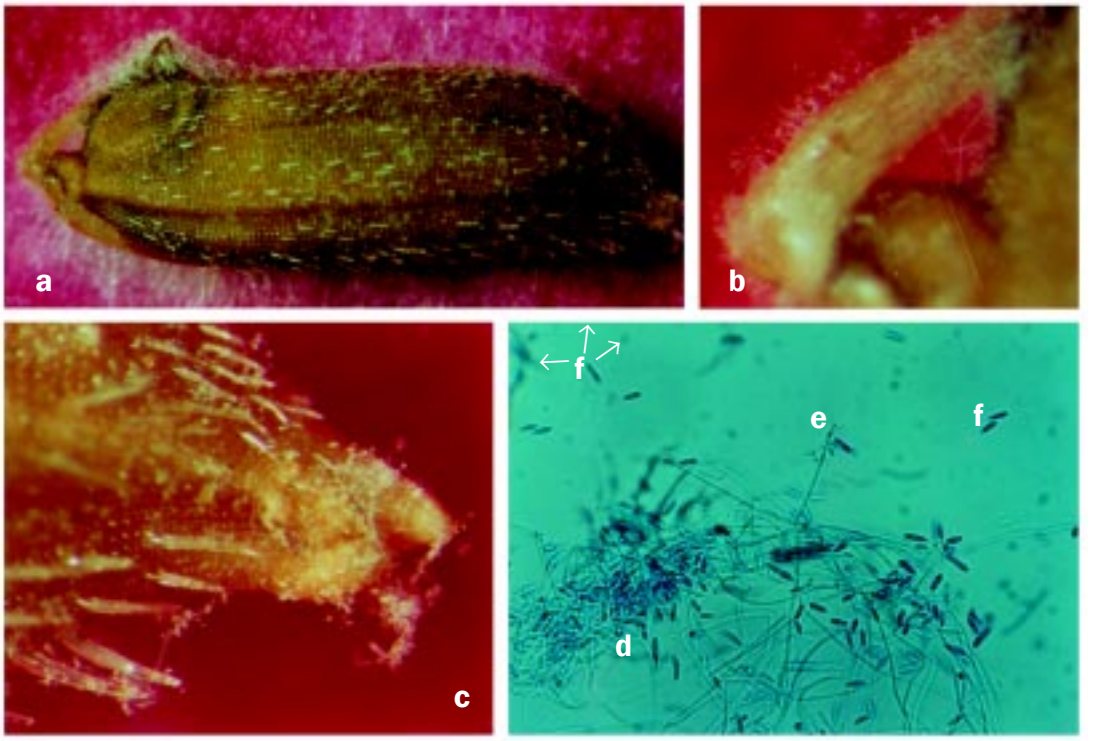

Fig. 57. Habit character of *Pinatubo oryzae* Manandhar and Mew on (a) whole seed (12X), (b) sterile lemmas (50X), and (c) awn portion (50X). Photomicrograph of *P. oryzae* showing (d) mycelia, (e) conidiophore, and (f) conidia at 40X and stained with lactophenol blue.

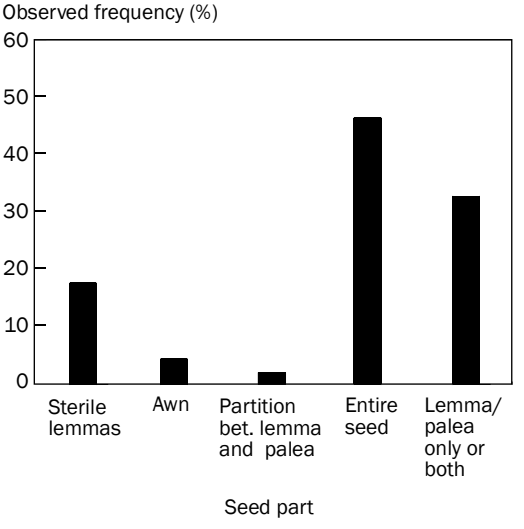

Fig. 58. Observed frequency of *Pinatubo oryzae* occurrence on the seed.

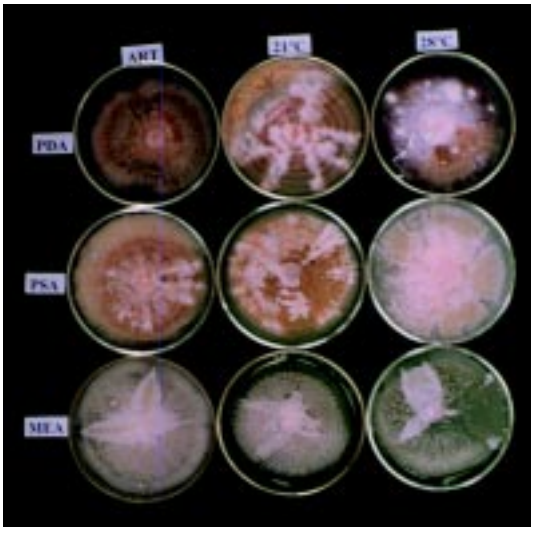

Fig. 59. Plate cultures of *Pinatubo oryzae* Manandhar and Mew showing colony growths on PDA, PSA, and MEA incubated at ART, 21 °C, and 28 °C at 15 d after inoculation.

ange with orange. The pionnotes are wet. On the reverse side of the agar plate, the colony appears slightly zonated and becomes azonated toward the margins. The color is orange to light yellow-orange toward the margins. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies grow fast and attain a 6.26-cm diam in 5 d. They are azonated with even margins and pale orange to grayish red. Pionnotes are wet and appear as reddish orange small dots. The colony appears azonated to slightly zonated on the reverse side of the agar plate. The color is orange interspersed with dull reddish brown. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow relatively fast and attain a 5.20-cm diam in 5 d. They are zonated with even margins, floccose, and alternating pale orange and orange with pale orange mycelial tufts. The colony appears slightly zonated to zonated and is alternating orange and light yellow in color on the reverse side of the agar plate.

Colonies on PSA at ART (28–30 °C) grow relatively fast and attain a 5.40-cm diam in 5 d. They are slightly zonated with even margins, slightly felted, and orange to light yellow-orange, becoming reddish brown with age. The colony appears slightly zonated on the reverse side of the agar plate. The color is orange to bright reddish brown, becoming light yellow-orange toward the margins. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies grow relatively fast and attain a 5.70-cm diam in 5 d. They are azonated with even margins and slight radial furrows, felted, and pale orange with shiny reddish orange pionnotes. The colony appears azonated to slightly zonated and alternating yellow-orange and orange on the reverse side of the agar plate. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow relatively fast and attain a 5.33-cm diam in 5 d. They are azonated to slightly zonated with even margins, slightly felted to fluffy, becoming wet with age, and pale orange to orange. The colony appears slightly zonated and orange on the reverse side of the agar plate.

Colonies on MEA at ART (28–30 °C) grow moderately fast and attain a 4.92-cm diam in 5 d. They are azonated with even margins, floccose, and light yellow-orange, becoming powdery with age. On the reverse side of the agar plate, the colony appears slightly zonated and pale yellow to yellow. At 21 °C under alternating 12-h NUV light and 12-h darkness, colonies grow relatively fast and attain a 5.18-cm diam in 5 d. They are azonated with even margins and thin aerial mycelia that are pressed to the media. The color is pale orange. The colony appears azonated and dull yellow-orange on the reverse side of the agar plate. At 28 °C under alternating 12-h fluorescent light and 12-h darkness, colonies grow moderately fast and attain a 4.77-cm diam in 5 d. They are zonated with even margins. Aerial mycelia are thin and pressed to the media. The color is pale orange and becomes powdery with age. On the reverse side of the agar plate, the colony appears slightly zonated to zonated and the color is pale orange.

Tilletia barclayana (Bref.) Sacc. & Syd.
syn. *Neovossia barclayana* Bref.
Tilletia horrida Tak.
Neovossia horrida (Tak.) Padw. & Kahn

Disease caused: kernel smut (bunt)

a. Symptoms
Infected grains show very small black pustules or streaks bursting through the glumes. When infection is severe, rupturing glumes produce a short beak-like outgrowth or the entire grain is replaced by powdery black mass of smut spores.

b. Occurrence/distribution
The disease is known to occur in many countries worldwide (Fig. 60).

c. Disease history
In 1986, the causal fungus of this disease was originally called *Tilletia horrida*. Later it was identified as *Neovossia barclayana*. Further studies made placed it in the genus *Tilletia*; it is now known as *Tilletia barclayana*.

d. Importance in crop production
The disease can be observed in the field at the mature stage of the rice plant. It is considered economically unimportant, causing stunting of

seedlings and reduction in tillers and yield when smutted seeds are planted.

Detection on seed

a. Dry seed inspection
Infection on seeds can be detected by direct inspection using a stereo binocular microscope (Fig. 61a,b).

b. Habit character
Aerial mycelia absent. Dull black and globose teliospores scattered on seed surface and cotyledon (Fig. 62a-c).

c. Microscopic character
Teliospores are globose to subglobose, light to dark brown with spines, and measure 22.5–26.0 µ × 18.0–22.0 µ (Fig. 62d).

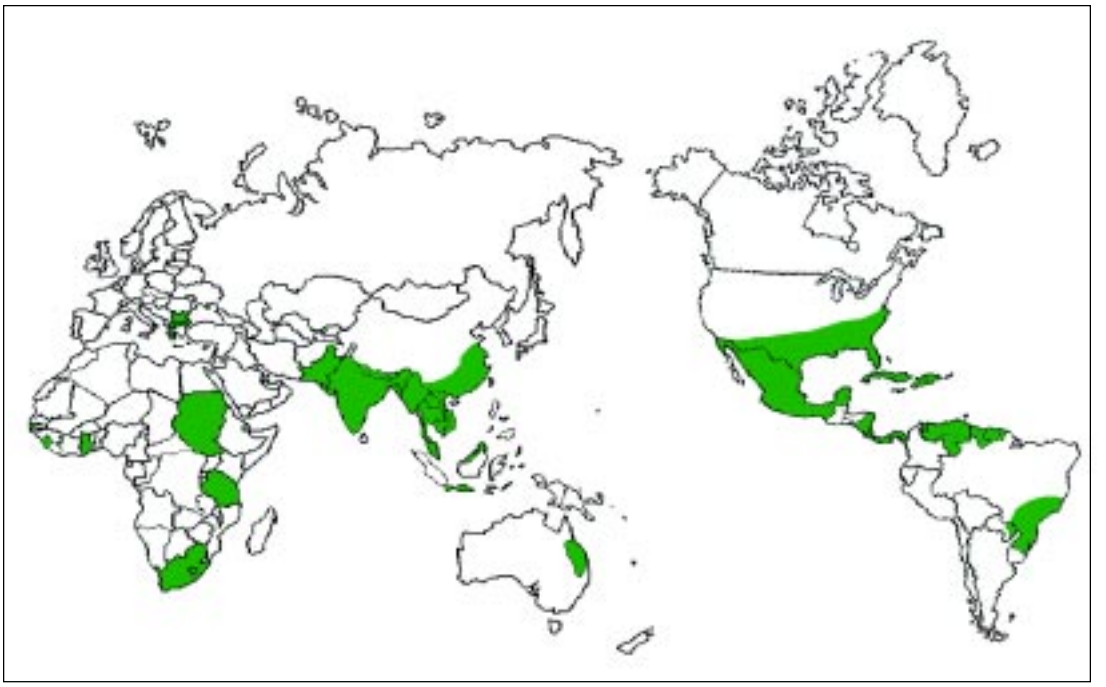

Fig. 60. Occurrence of kernel smut (Ou 1985, CMI 1991).

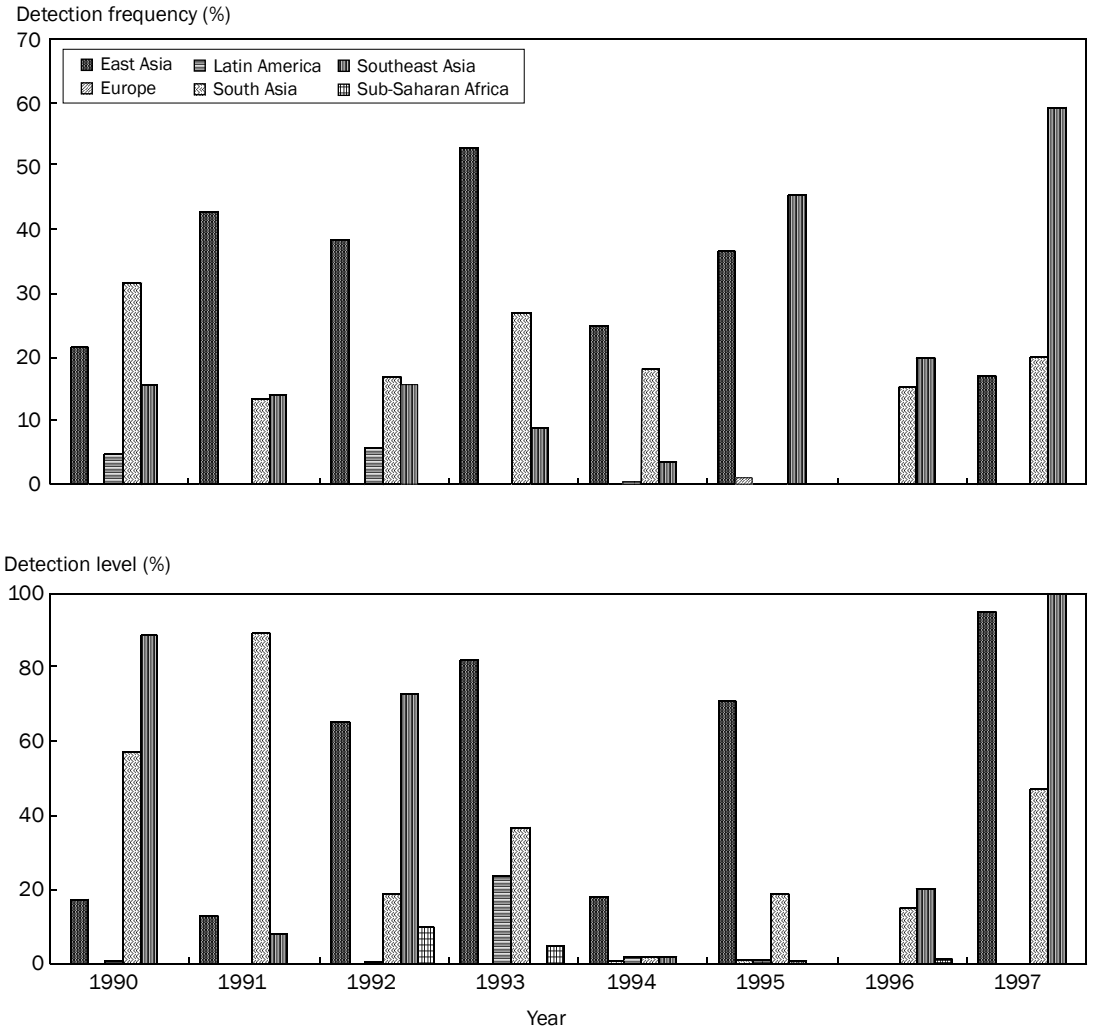

Fig. 61. Detection frequency (a) and level (b) of *Tilletia barclayana* from imported untreated seeds, 1990-97.

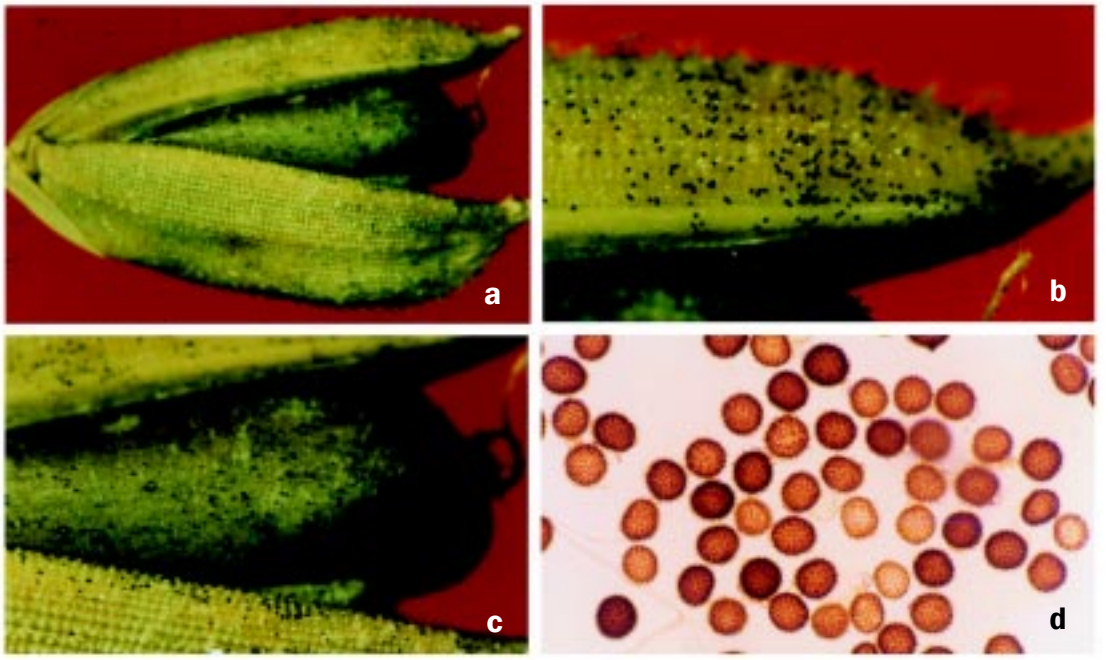

Fig. 62. Habit character of *Tilletia barclayana* (Bref.) Sacc. and Syd. (Duran and Fischer) on (a) whole seed (16X), (b) palea (40X), and (c) cotyledon and portion of lemma (40X). Photomicrograph of *T. barclayana* showing (d) teliospores (40X).

Other fungi detected on rice seeds

Other fungi are detected on rice seeds from different countries. Some, such as *Nakataea sigmoidea*, the conidial state of *Sclerotium rolfsii*, cause stem rot, which is important in specific ecosystems. However, most of these "other fungi" are not known to cause diseases of economic importance. These fungi are listed in Table 5 and photomicrographs of their habit and microscopic characters are shown.

Table 5. List of other fungi detected on rice seeds.

Fungi	Incidence[a]
Acremoniella atra	+
Acremoniella verrucosa	+
Alternaria longissima	++
A. tenuissima	+
Aspergillus clavatus	+
A. flavus-oryzae	++
A. niger	++
Chaetomium globosum	+
Cladosporium sp.	++
Curvularia eragrostidis	+
Drechslera hawaiiensis	+
Epicoccum purpurascens	+
Fusarium avenaceum	+
F. equiseti	+
F. larvarum	+
F. nivale	+
F. semitectum	+++
Gilmaniella humicola	+
Memnoniella sp.	+
Microascus cirrosus	+
Monodictys putredinis	+
Myrothecium sp.	+
Nakataea sigmoidea	++
Nectria heamatococca	+
Papularia sphaerosperma	+
Penicillium sp.	++
Pestalotia sp.	+
Phaeoseptoria sp.	+
Phaeotrichoconis crotolariae	+
Pithomyces sp.	++
Pyrenochaeta sp.	+
Rhizopus sp.	++
Septogloeum sp.	+
Sordaria fimicola	+
Spinulospora pucciniiphila	+
Sterigmatobotrys macrocarpa	+
Taeniolina sp.	+
Tetraploa aristata	+
Trichoderma sp.	+
Trichothecium sp.	+
Tritirachium sp.	+
Ulocladium botrytis	+

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

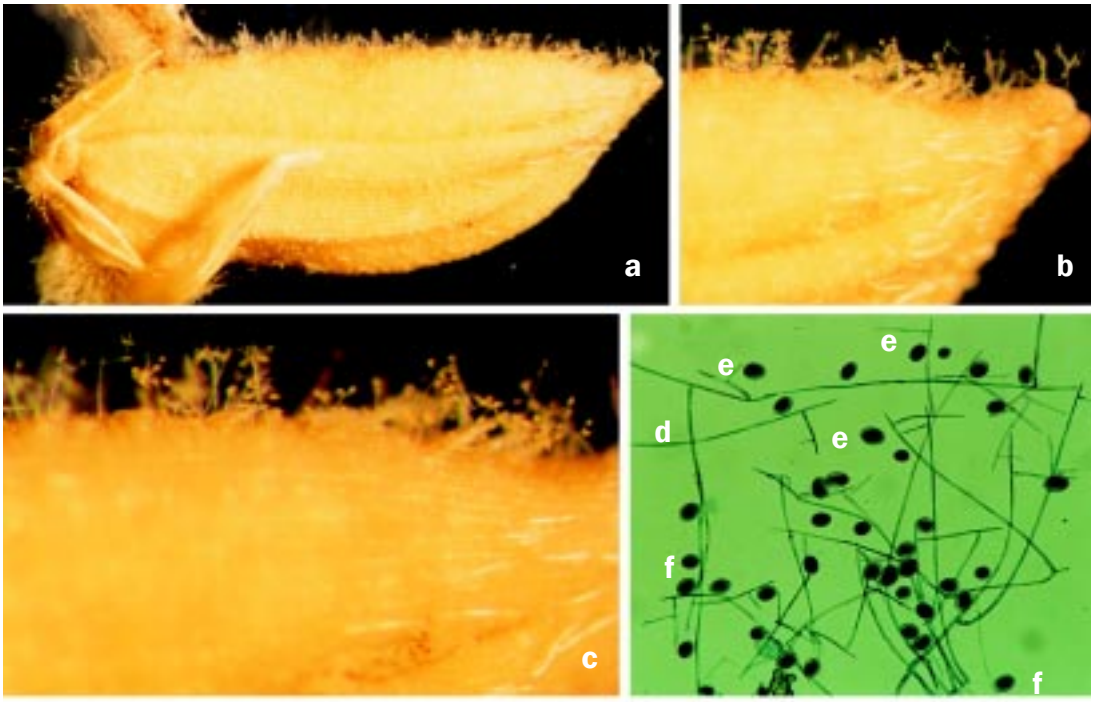

Fig. 63. Habit character of *Acremoniella atra* (Corda) Sacc. on (a) whole seed (10X) and palea at (b) 25X and (c) 40X. Photomicrograph of *A. atra* showing (d) mycelia, (e) conidiophores, and (f) conidia at 10X and stained with lactophenol blue.

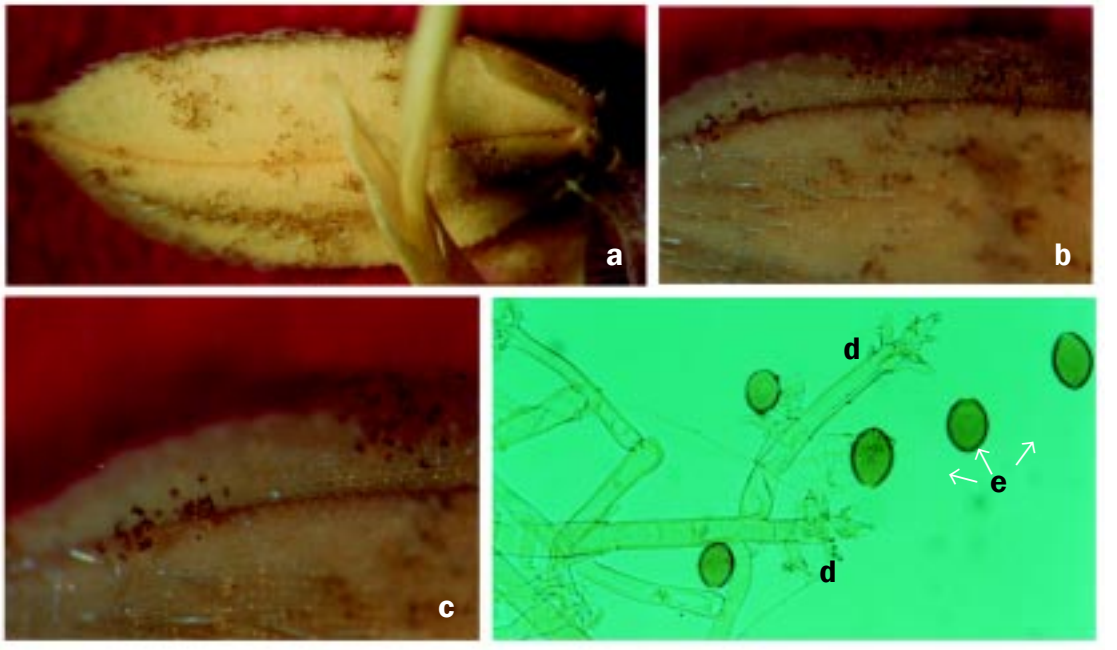

Fig. 64. Habit character of *Acremoniella verrucosa* Tognini on (a) whole seed (12X) and awn area at (b) 25X and (c) 50X. Photomicrograph of *A. verrucosa* showing (d) conidiophores and (e) conidia at 40X.

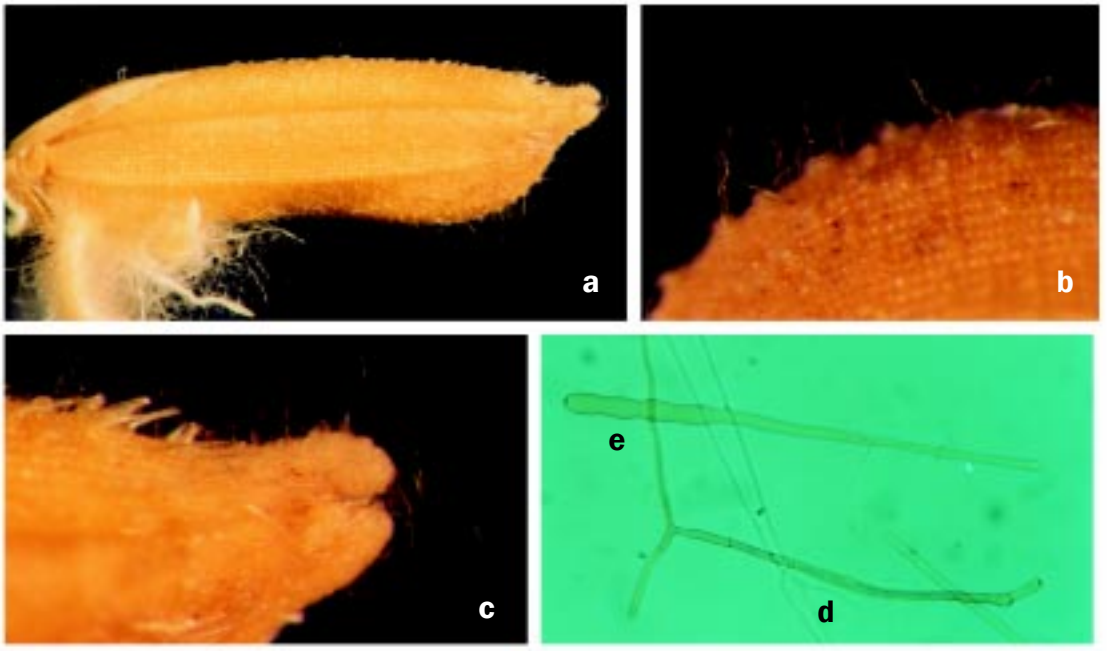

Fig. 65. Habit character of *Alternaria longissima* Deighton & MacGarvie on (a) whole seed (10X), (b) lemma (40X), and (c) awn (40X). Photomicrograph of *A. longissima* showing (d) conidiophore and (e) conidia at 40X.

Fig. 66. Habit character of *Alternaria tenuissima* (Kunze ex Pers.) Wiltshire on awn area at (a) 9X, (b) 25X, and (c) 50X. Photomicrograph of *A. tenuissima* showing (d) conidia (40X).

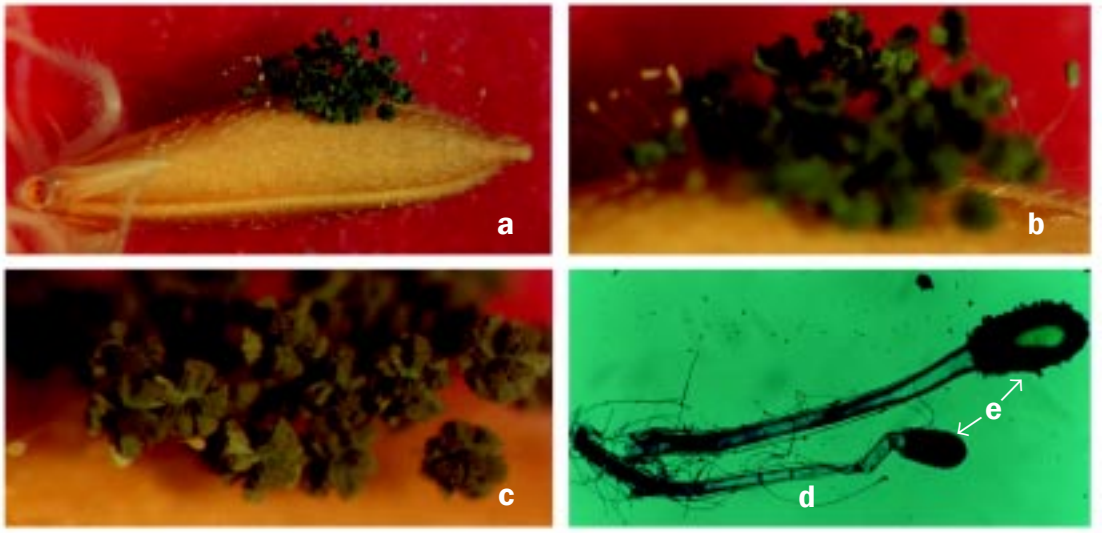

Fig. 67. Habit character of *Aspergillus clavatus* Desmazieres on palea and lemma at (a) 10X, (b) 25X, and (c) 40X. Photomicrograph of *A. clavatus* showing (d) conidiophore and (e) conidial head at 40X and stained with lactophenol blue.

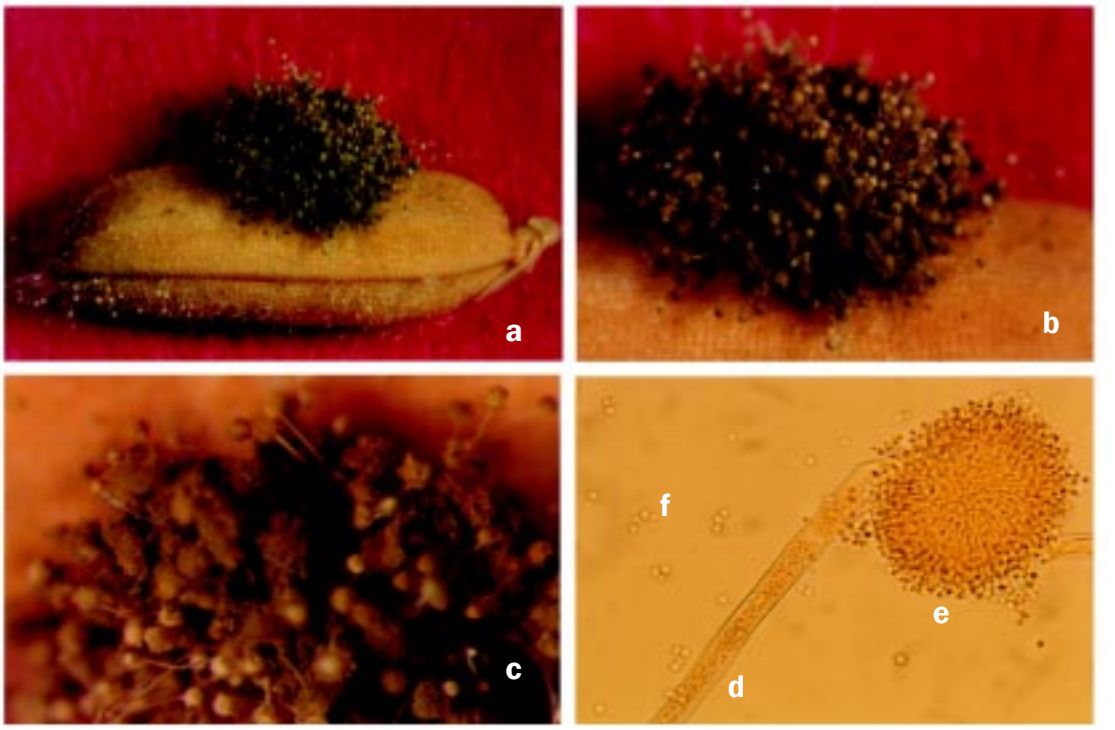

Fig. 68. Habit character of *Aspergillus flavus-oryzae* Thom & Raper on (a) whole seed (8X) and lemma at (b) 16X and (c) 30X. Photomicrograph of *A. flavus-oryzae* showing (d) conidiophore, (e) conidial head showing sterigmata, and (f) conidia at 40X.

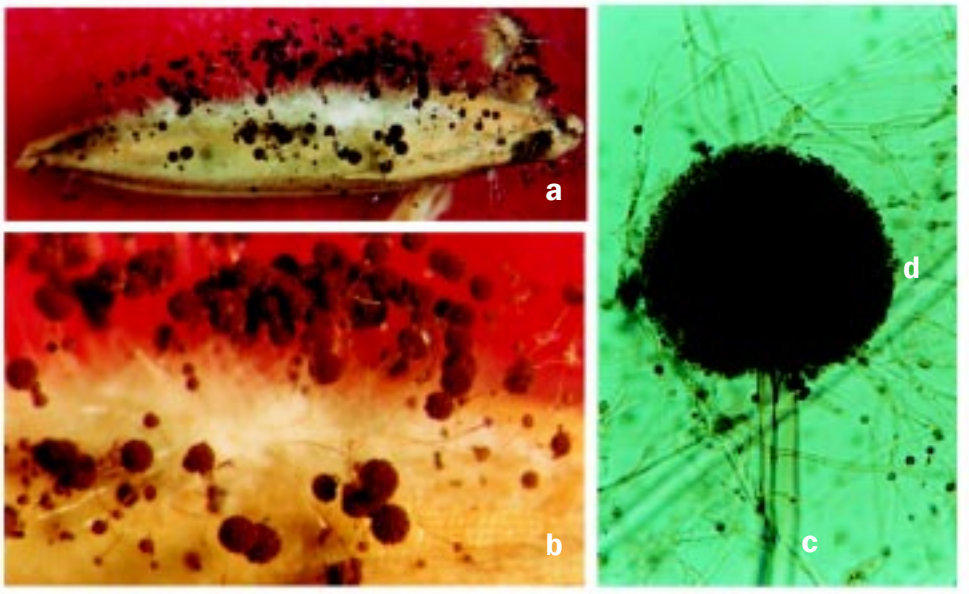

Fig. 69. Habit character of *Aspergillus niger* van Tiegh. showing black conidial heads on whole seed at (a) 9X and (b) 25X. Photomicrograph of *A. niger* showing (c) portion of conidiophore and (d) conidial head showing sterigmata and conidia at 40X.

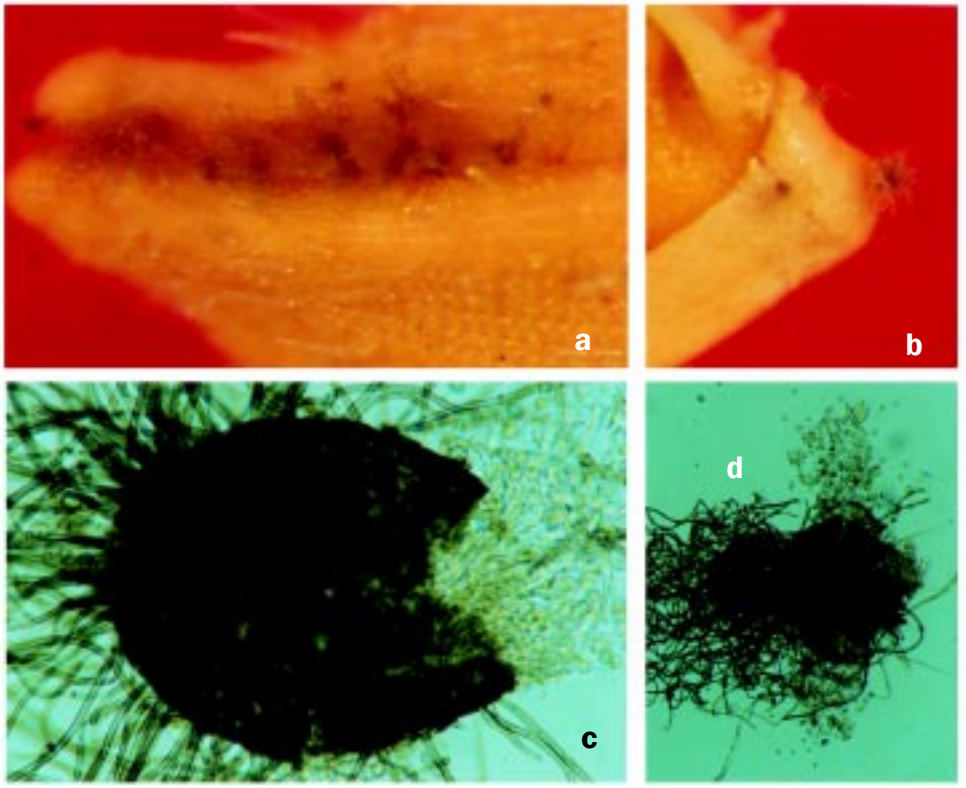

Fig. 70. Habit character of *Chaetomium globosus* Kunze. Fr. showing dark, ostiolate, sub-globose perithecium with brown flexuous hairs at (a) awn area (40X) and (b) sterile lemma (50X). Photomicrograph of *C. globosum* showing (c) perithecium with hairs (40X) and (d) mature ascospores (10X).

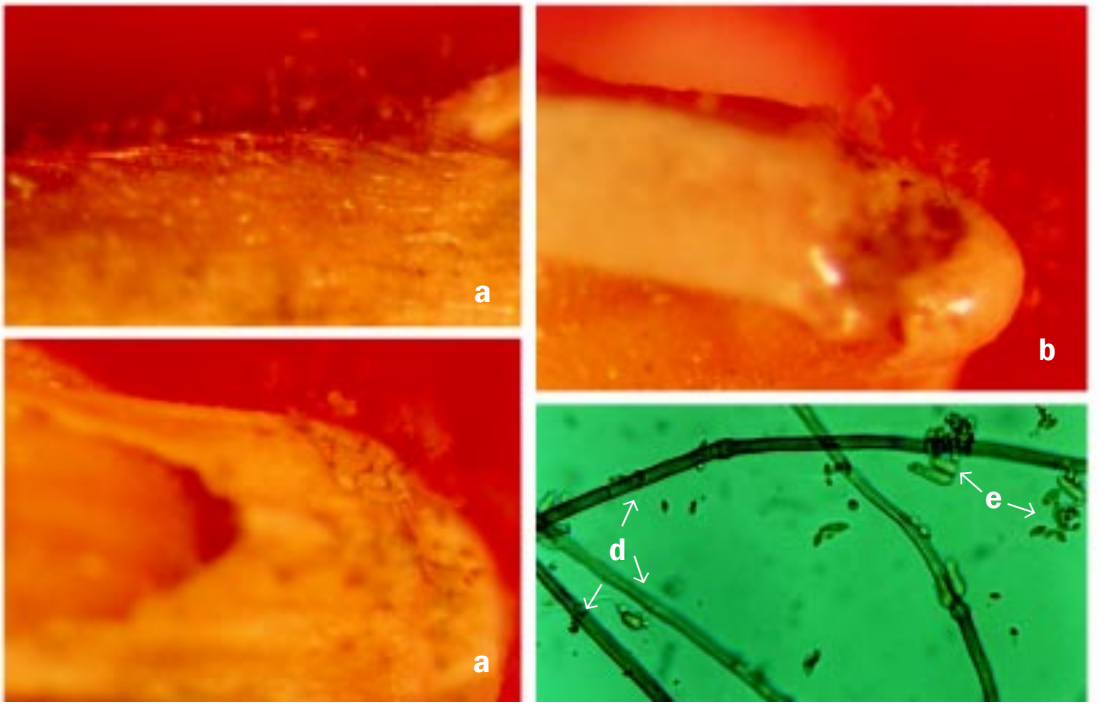

Fig. 71. Habit character of *Cladosporium* sp. on (a) embryonal area (10X) and sterile lemmas at (b) 40X and (c) 50X. Photomicrograph of *Cladosporium* sp. showing portion of (d) conidiophores and (e) conidia at 40X.

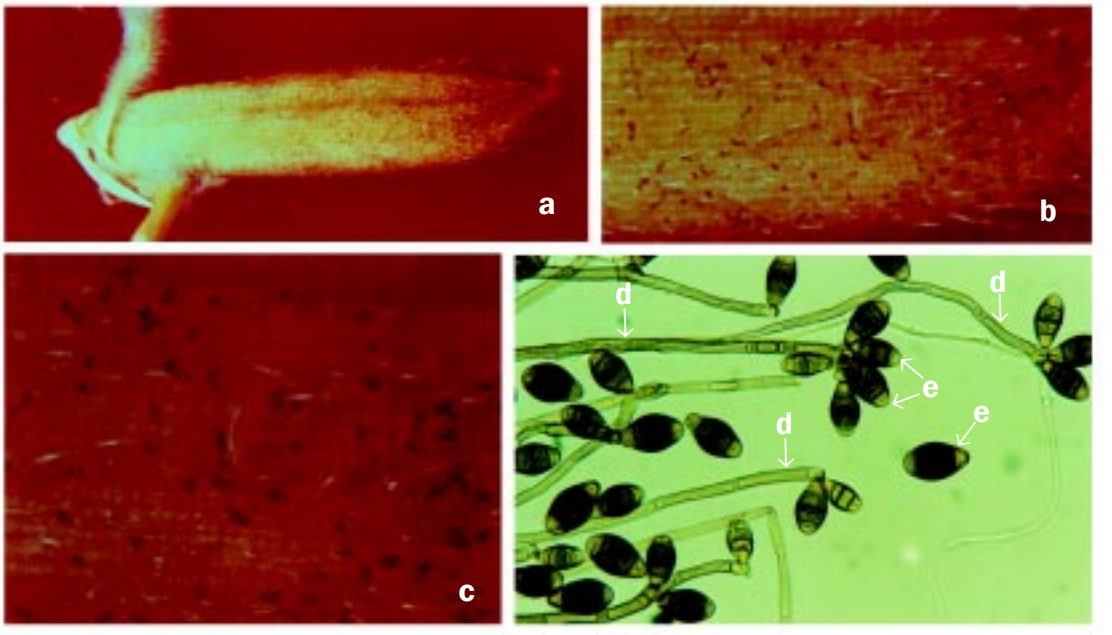

Fig. 72. Habit character of *Curvularia eragrostidis* (P. Henn.) Meyer on (a) whole seed (9X) and lemma at (b) 25X and (c) 50X. Photomicrograph of *C. eragrostidis* showing (d) conidiophore and (e) conidia at 40X.

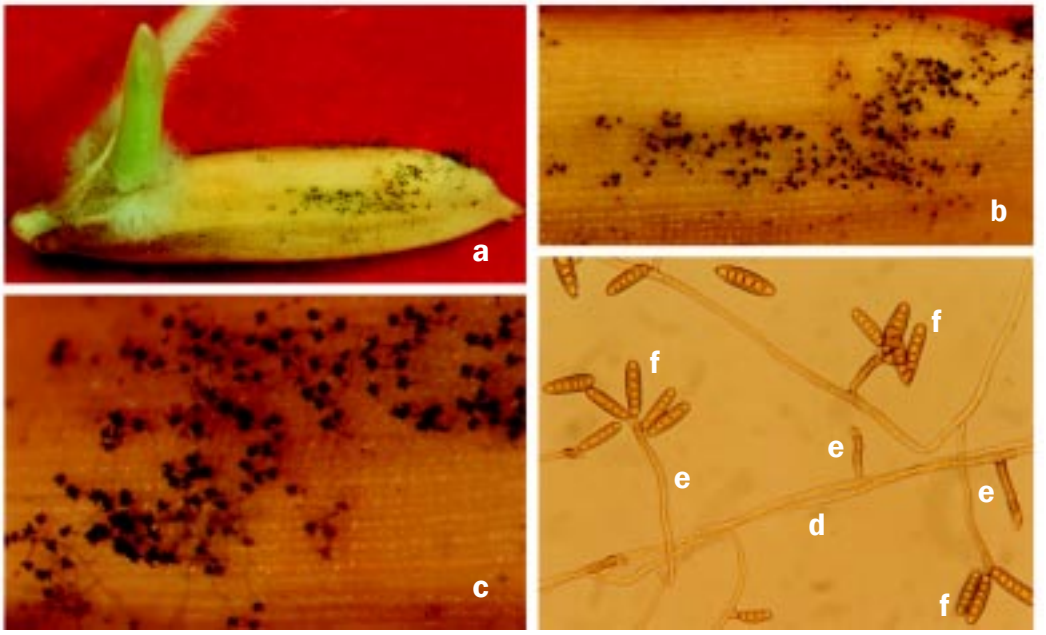

Fig. 73. Habit character of *Drechslera hawaiiensis* Subram. & Jain on (a) whole seed (9X) and lemma at (b) 25X and (c) 50X. Photomicrograph of *D. hawaiiensis* showing (d) mycelia, (e) conidiophores, and (f) conidia at 40X.

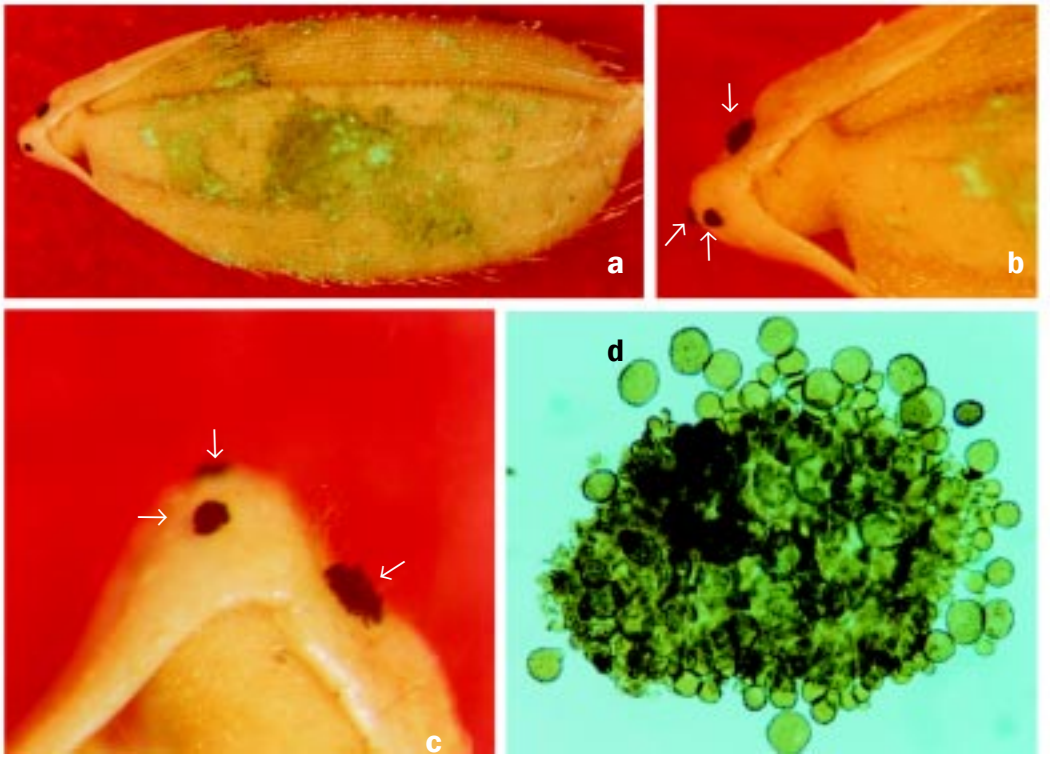

Fig. 74. Habit character of *Epicoccum purpurascens* Ehrenb. ex Schlect. on sterile lemmas showing sporodochia at (a) 10X, (b) 25X, and (c) 50X. Photomicrograph of *E. purpurascens* showing (d) golden brown conidia (40X).

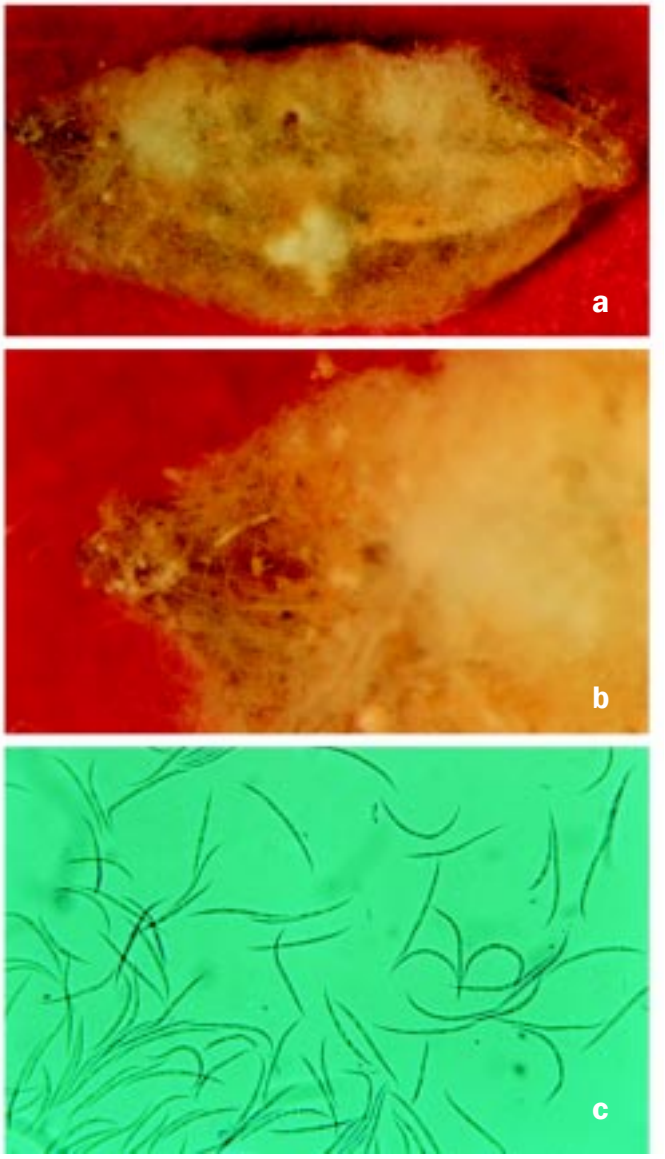

Fig. 75. Habit character of *Fusarium avenaceum* (Corda ex Fr.) Sacc. on whole seed at (a) 12X and (b) 40X showing white floccose aerial mycelia with pionnotal-like sporodochia. Photomicrograph of *F. avenaceum* showing (c) conidia (40X) stained with lactophenol blue.

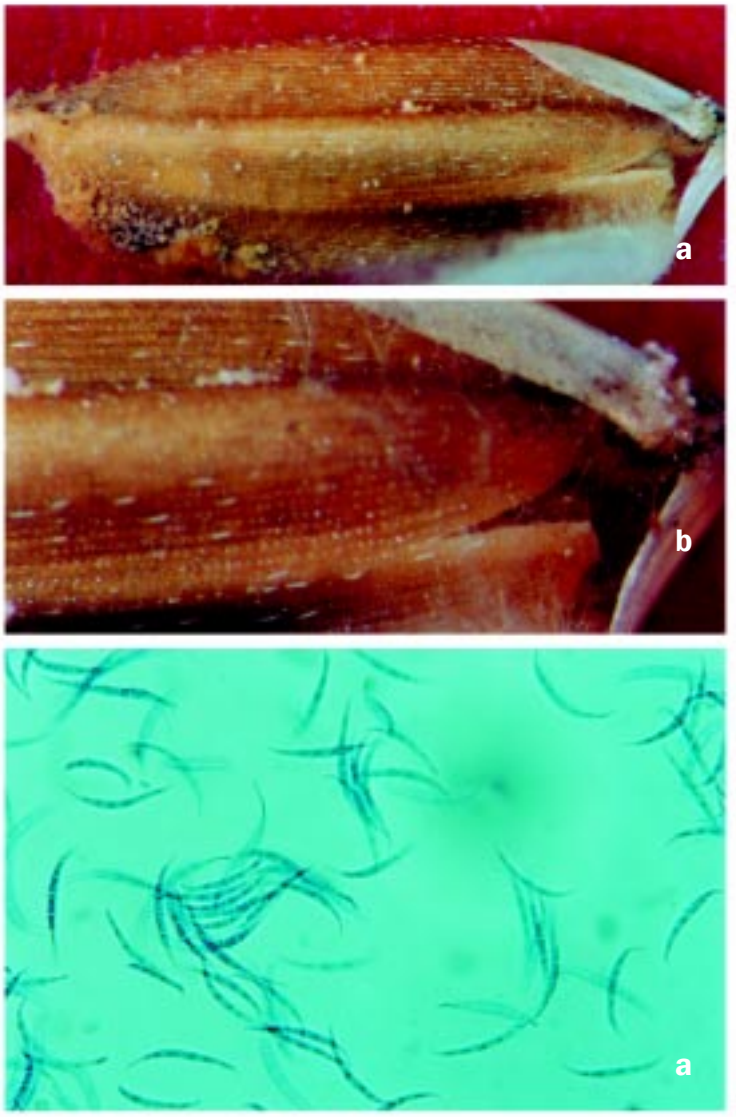

Fig. 76. Habit character of *Fusarium equiseti* (Corda) Sacc. showing light orange pionnotes on (a) whole seed (10X) and (b) sterile lemmas and palea and lemma (25X). Photomicrograph of *F. equiseti* showing (c) falcate conidia (40X) stained with lactophenol blue.

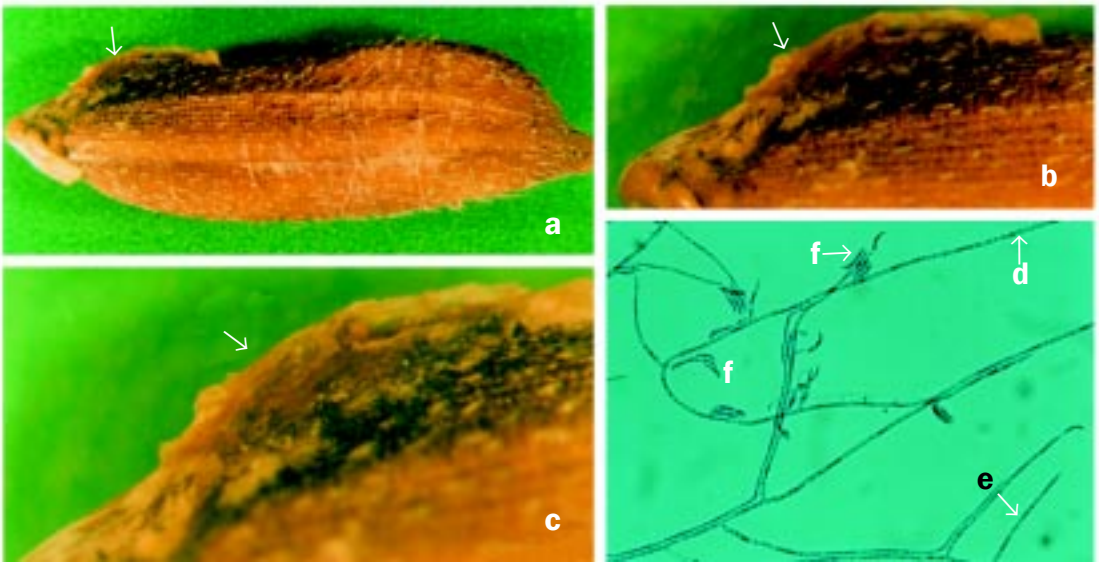

Fig. 77. Habit character of *Fusarium larvarum* Fuckel on embryonal area showing slimy yellowish pionnote at (a) 10X, (b) 18X, and (c) 35X. Photomicrograph of *F. larvarum* showing (d) mycelia, (e) conidiophore, and (f) conidia (40X) stained with lactophenol blue.

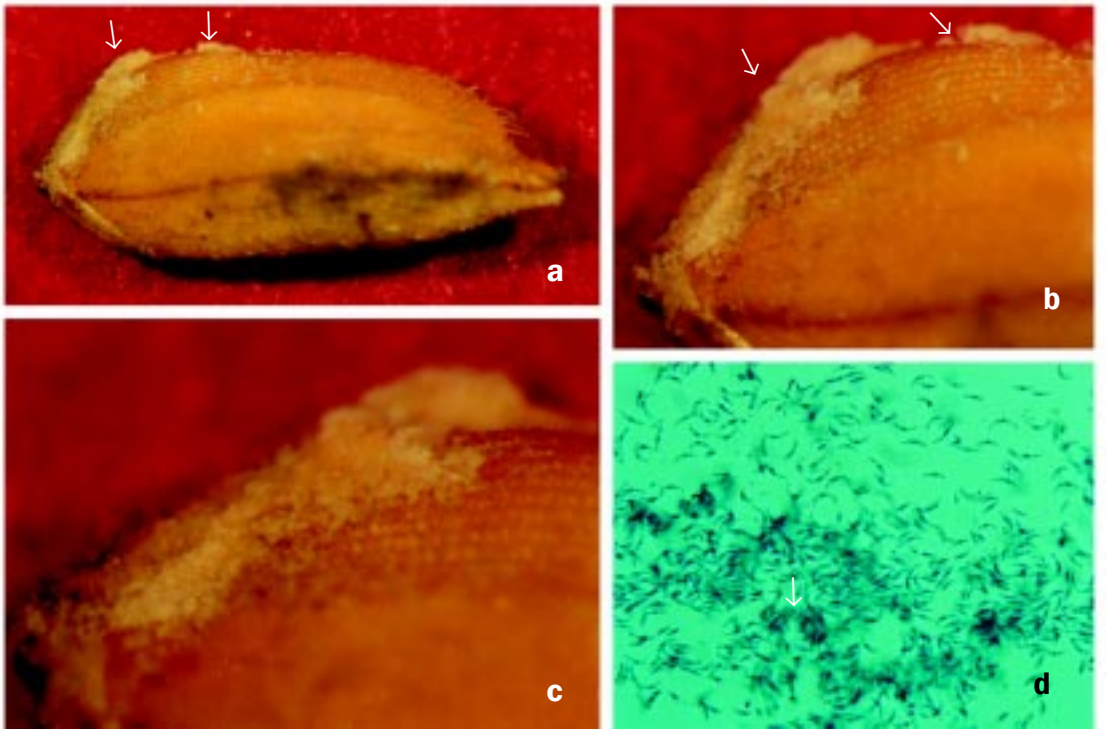

Fig. 78. Habit character of *Fusarium nivale* Ces. showing sporodochia on embryonal area at (a) 12X, (b) 25X, and (c) 40X. Photomicrograph of *F. nivale* showing (d) conidia (40X) stained with lactophenol blue.

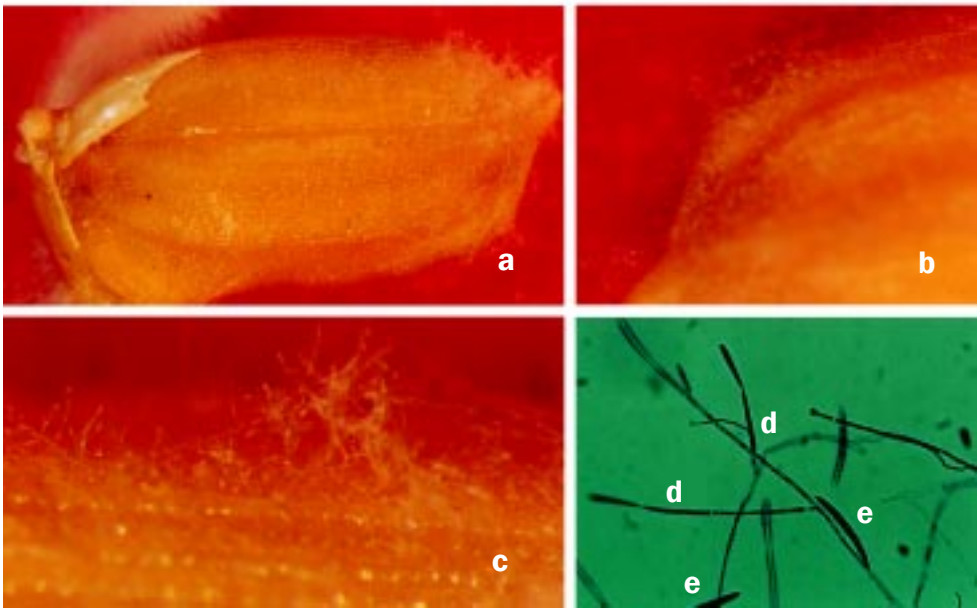

Fig. 79. Habit character of *Fusarium semitectum* Berk. & Rav. on (a) whole seed (10X), (b) awn portion (25X), and (c) lemma (50X). Photomicrograph of *F. semitectum* showing (d) conidiophores and (e) macroconidia at 40X and stained with lactophenol blue.

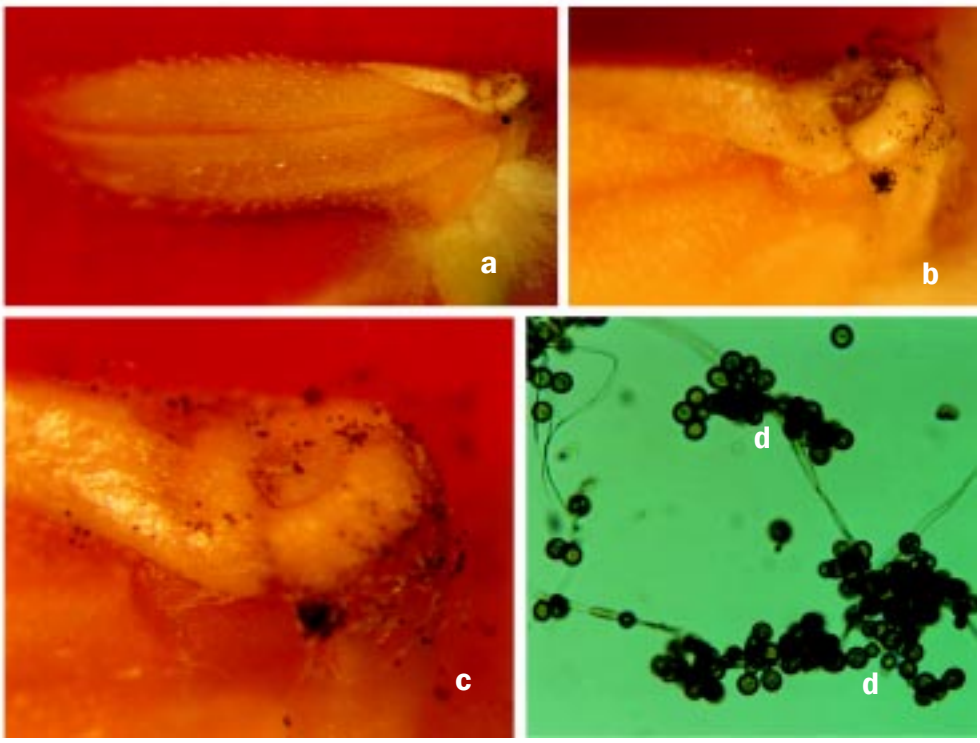

Fig. 80. Habit character of *Gilmaniella humicola* Barron on sterile lemmas at (a) 9X, (b) 25X, and (c) 50X. Photomicrograph of *G. humicola* showing (d) conidia at 40X.

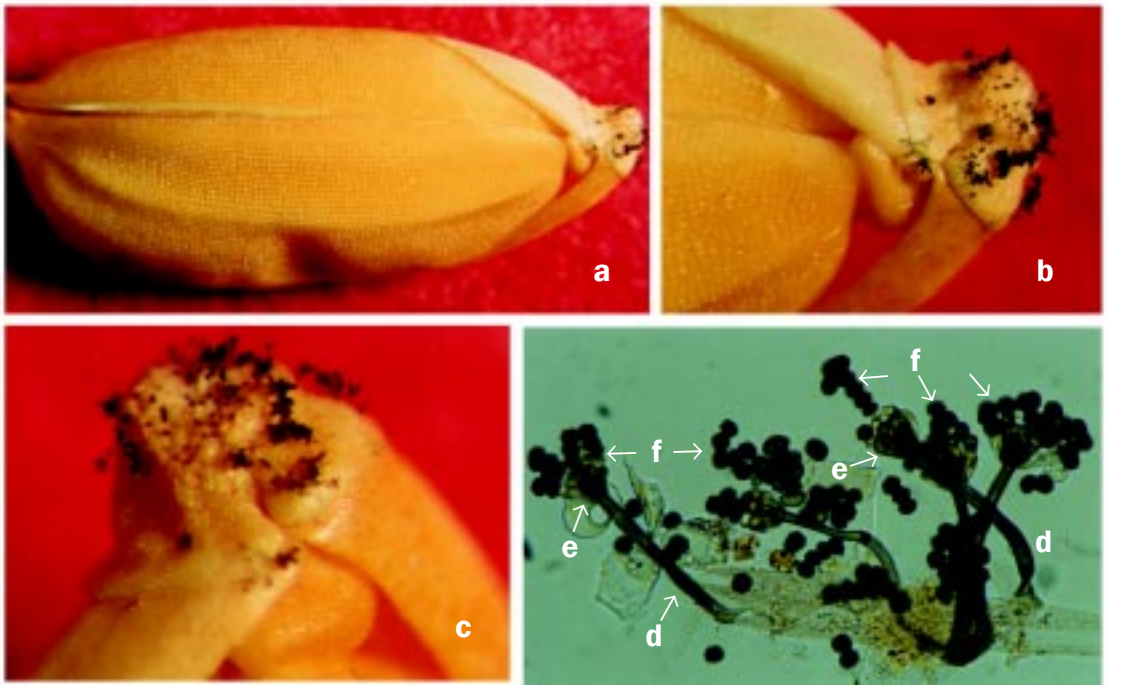

Fig. 81. Habit character of *Memmoniella* sp. on sterile lemmas at (a) 10X, (b) 25X, and (c) 40X. Photomicrograph of *Memmoniella* sp. showing (d) conidiophores, (e) phialides, and (f) conidia at 40X.

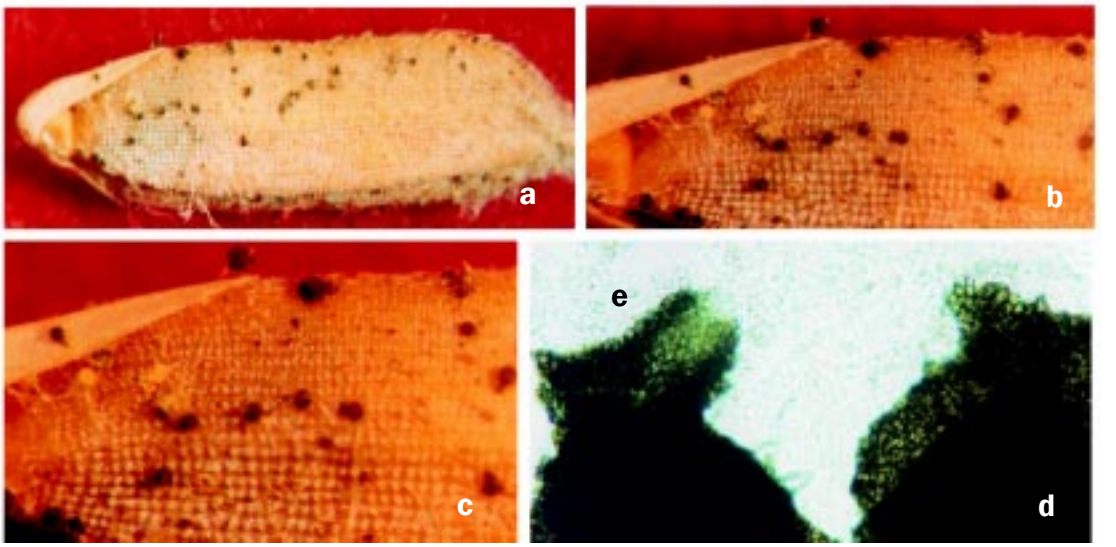

Fig. 82. Habit character of *Microascus cirrosus* showing dark, globose, ostiolate, with cylindrical neck ascoma on (a) whole seed (8X) and lemma and sterile lemmas at (b) 19X and (c) 40X. Photomicrograph of *M. cirrosus* showing (d) portion of ascoma and (e) mature ascopores at 40X.

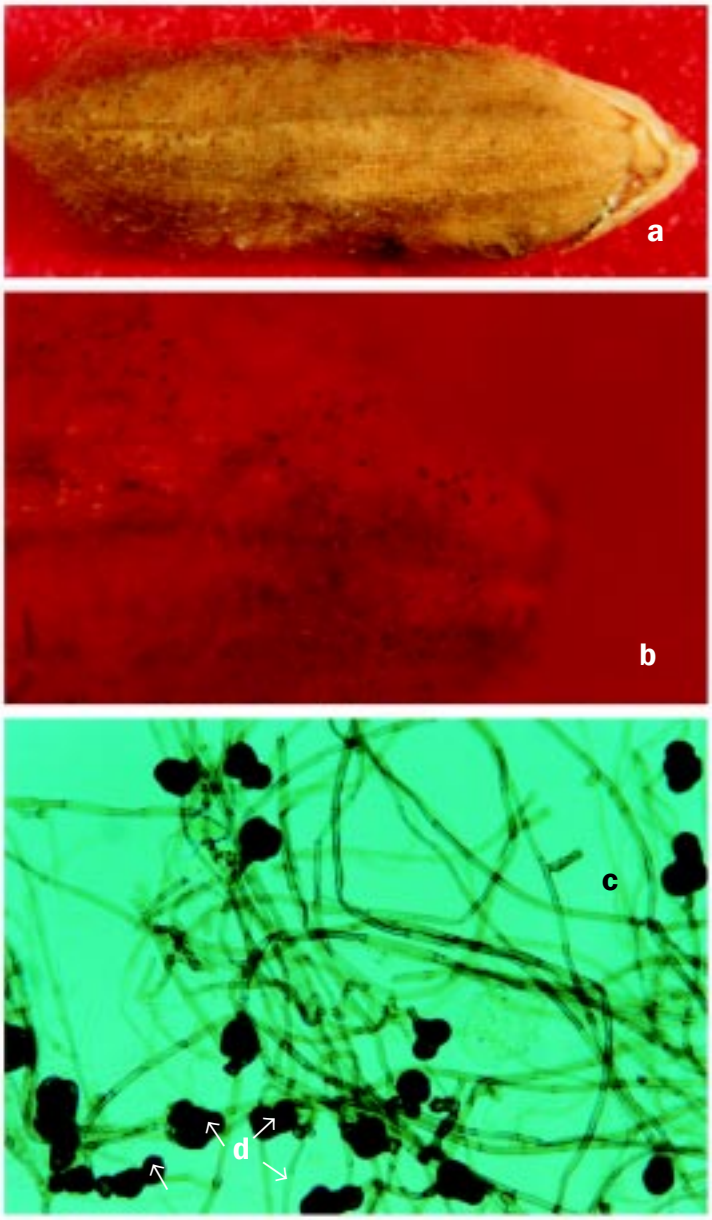

Fig. 83. Habit character of *Monodictys putredinis* (Wallr.) Hughes showing blackish brown aerial mycelia and almost black conidia on whole seed at (a) 10X and (b) 50X. Photomicrograph of *M. putredinis* showing (c) conidiophore and (d) conidia at 40X.

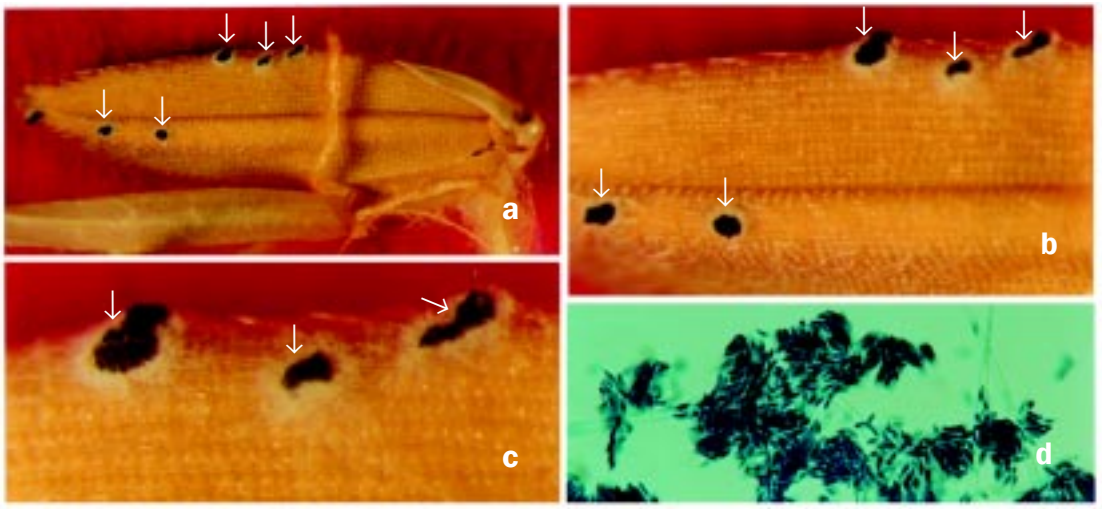

Fig. 84. Habit character of *Myrothecium* sp. on palea and lemma at (a) 10X, (b) 25X, and (c) 50X showing cushion-like sporodochia with marginal hyaline setae. Photomicrograph of *Myrothecium* sp. showing (d) elongately ovoid conidia (40X) stained with lactophenol blue.

Fig. 85. Habit character of *Nakataea sigmoidea* Hara on sterile lemmas and pedicel at (a) 8X and (b) 50X. Photomicrograph of *N. sigmoidea* showing (c) conidiophore and (d) conidia at 40X.

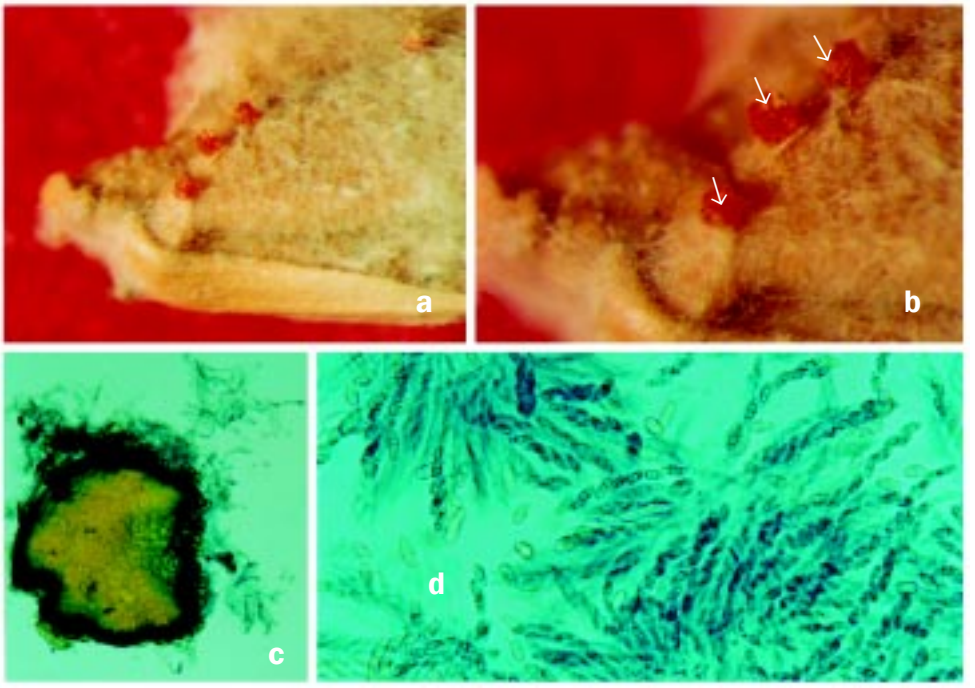

Fig. 86. Habit character of *Nectria haematococca* Berk. & Broome showing superficial, red-orange, globose ascoma at (a) 20X and (b) 40X. Photomicrograph of *N. haematococca* showing (c) cross section of ascoma (10X) and (d) ascopores (40X) stained with lactophenol blue.

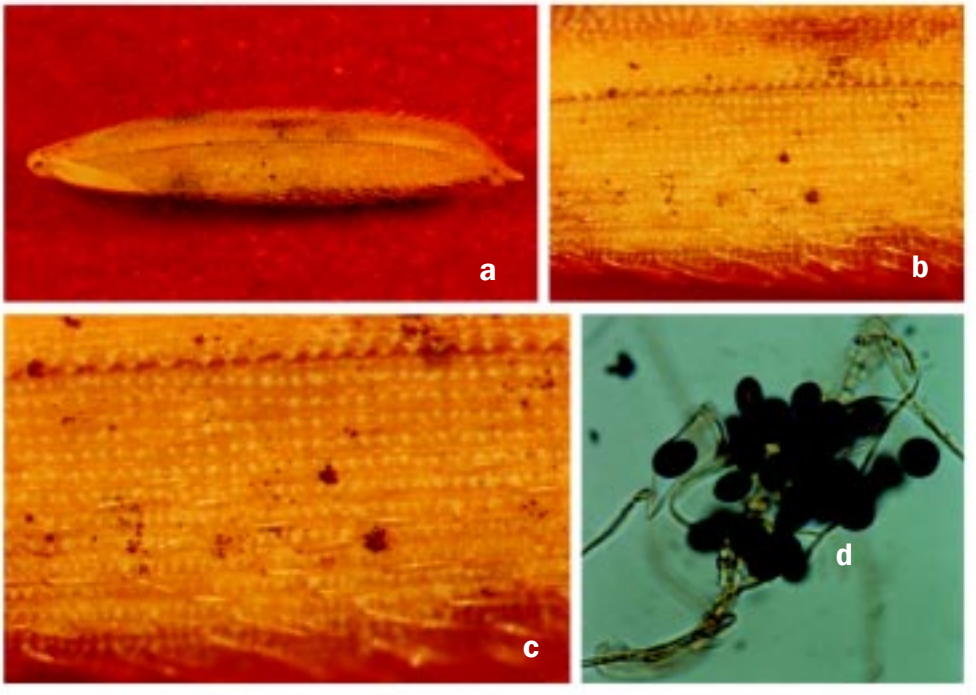

Fig. 87. Habit character of *Papularia sphaerosperma* (Pers.) Hohnel. showing minute, black, round conidia at (a) 8X, (b) 25X, and (c) 50X. Photomicrograph of *P. sphaerosperma* showing (d) conidia (63X).

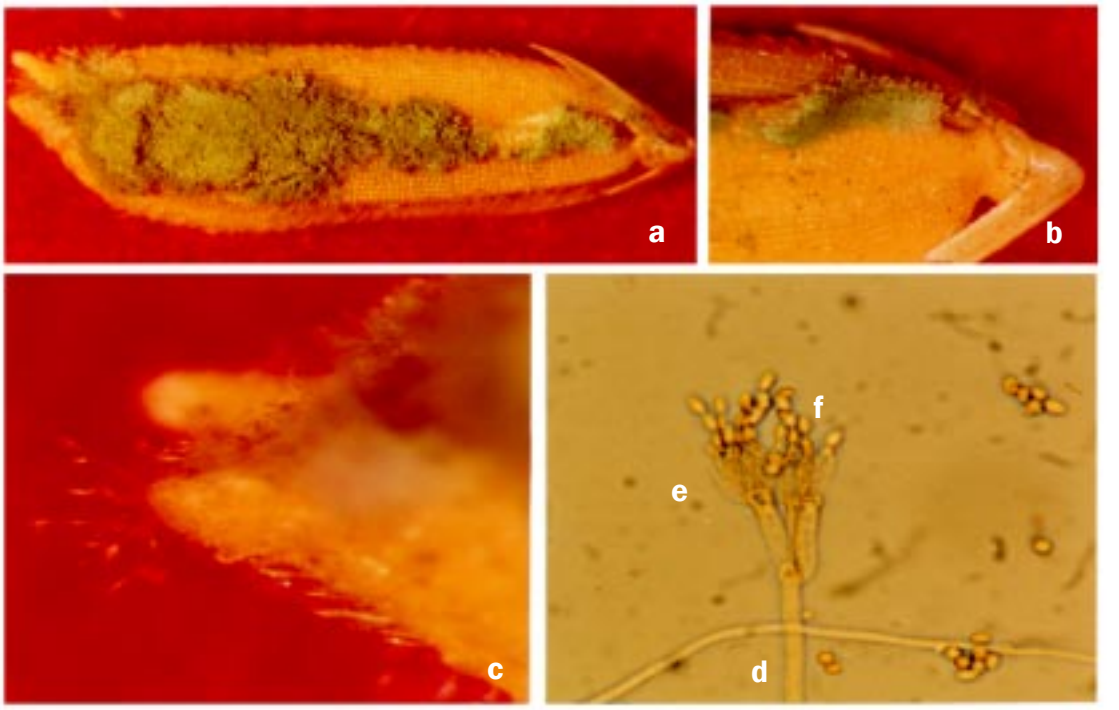

Fig. 88. Habit character of *Penicillium* sp. on (a) whole seed (10X), (b) sterile lemmas and lemma (18X), and (c) awn (50X). Photomicrograph of *Penicillium* sp. showing (d) branched conidiophore, (e) phialides, and (f) conidia at OIO.

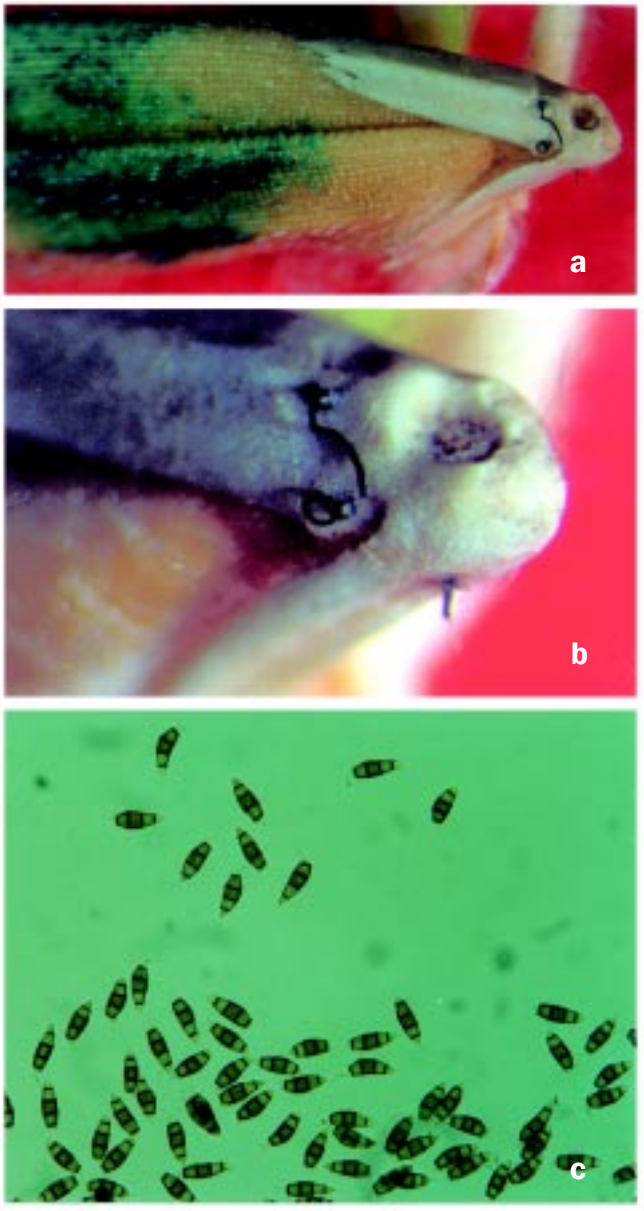

Fig. 89. Habit character of *Pestalotia* sp. showing subepidermal acervuli with conidial mass on sterile lemmas at (a) 12X and (b) 30X. Photomicrograph of *Pestalotia* sp. showing (c) septated conidia with 2–3 hyaline appendages (40X).

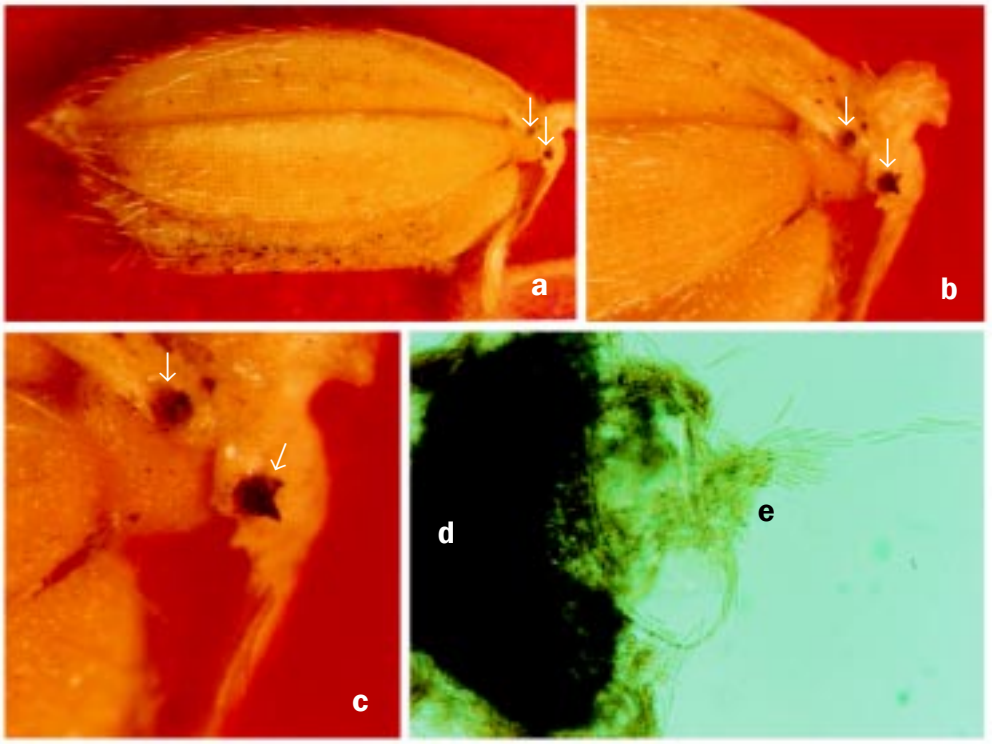

Fig. 90. Habit character of *Phaeoseptoria* sp. on sterile lemmas at (a) 10X, (b) 25X, and (c) 50X. Photomicrograph of *Phaeoseptoria* sp. showing (d) portion of pycnidia and (e) conidia at 40X.

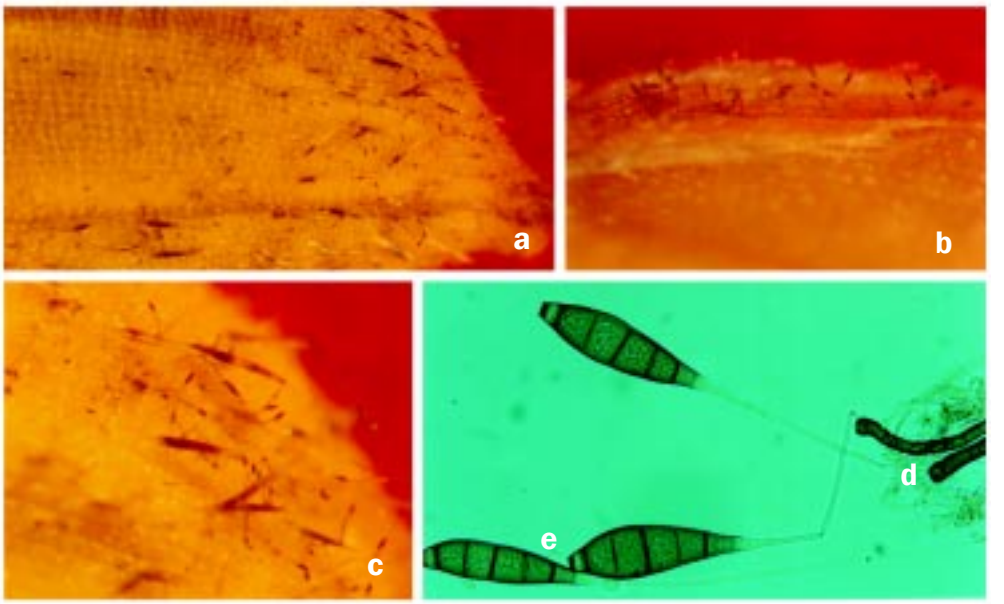

Fig. 91. Habit character of *Phaeotrichoconis crotalariae* (Salam & Rao) Subram. on (a) palea and lemma (25X), (b) sterile lemmas (40X), and (c) awn area (40X). Photomicrograph of *P. crotalriae* showing (d) portion of conidiophore (40X) and (e) conidia with large dark brown scar at the base (40X).

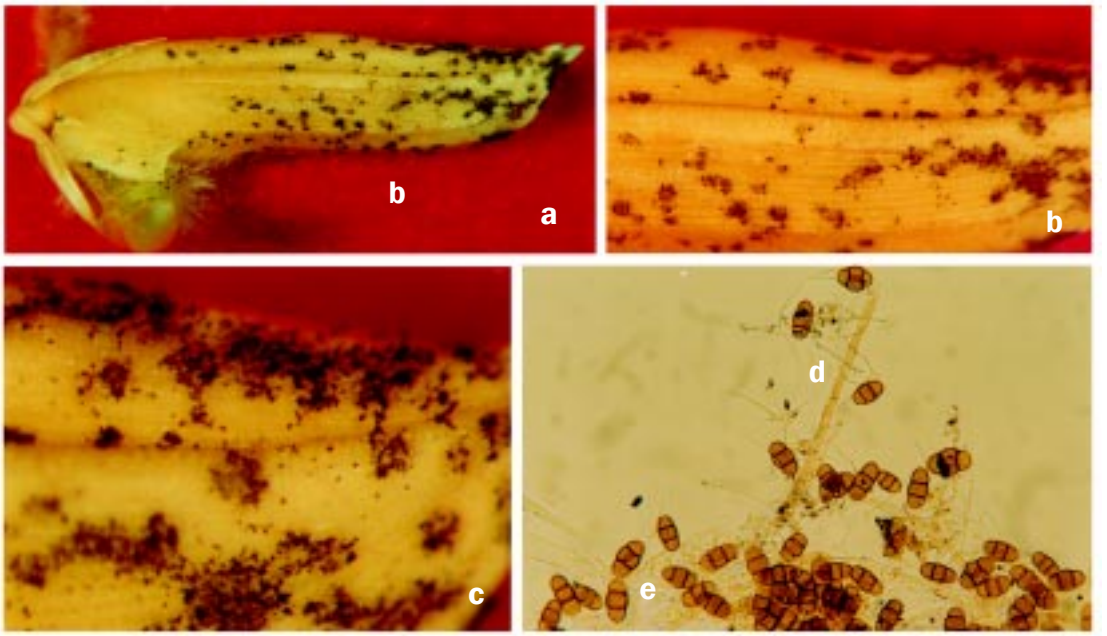

Fig. 92. Habit character of *Pithomyces* sp. on (a) whole seed (9X) and palea and lemma at (b) 18X and (c) 40X. Photomicrograph of *Pithomyces* sp. showing (d) mycelia and (e) conidia at 40X.

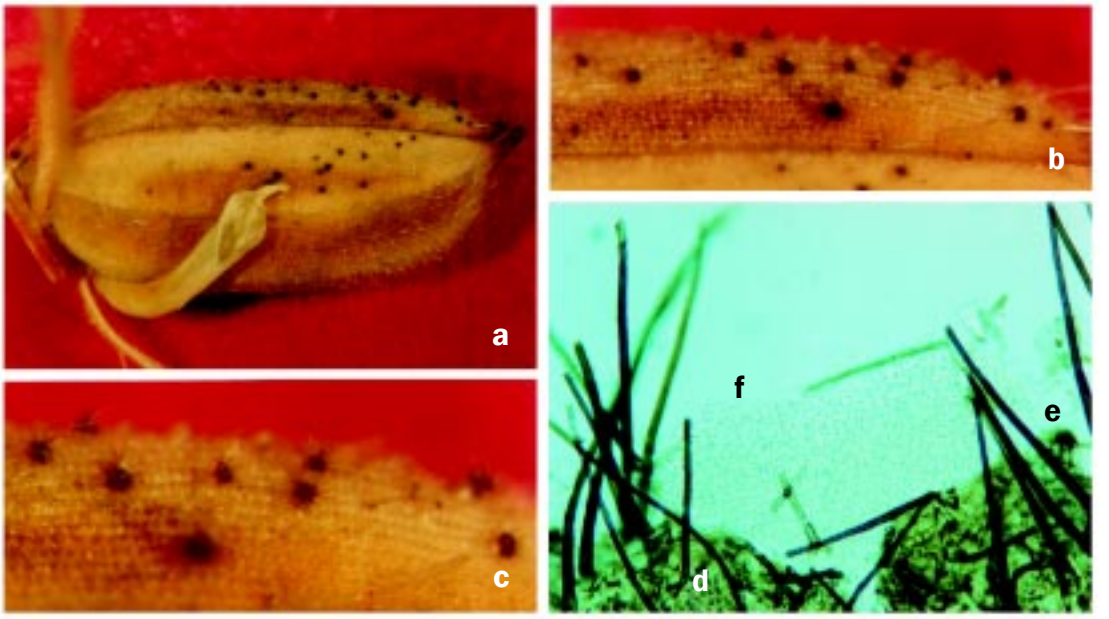

Fig. 93. Habit character of *Pyrenochaeta* sp. showing dark and globose pycnidia with bristles on (a) whole seed (9X) and palea at (b) 25X and 40X. Photomicrograph of *Pyrenochaeta* sp. showing portion of (d) pycnidia, (e) bristles, and (f) 1-celled conidia at 40X.

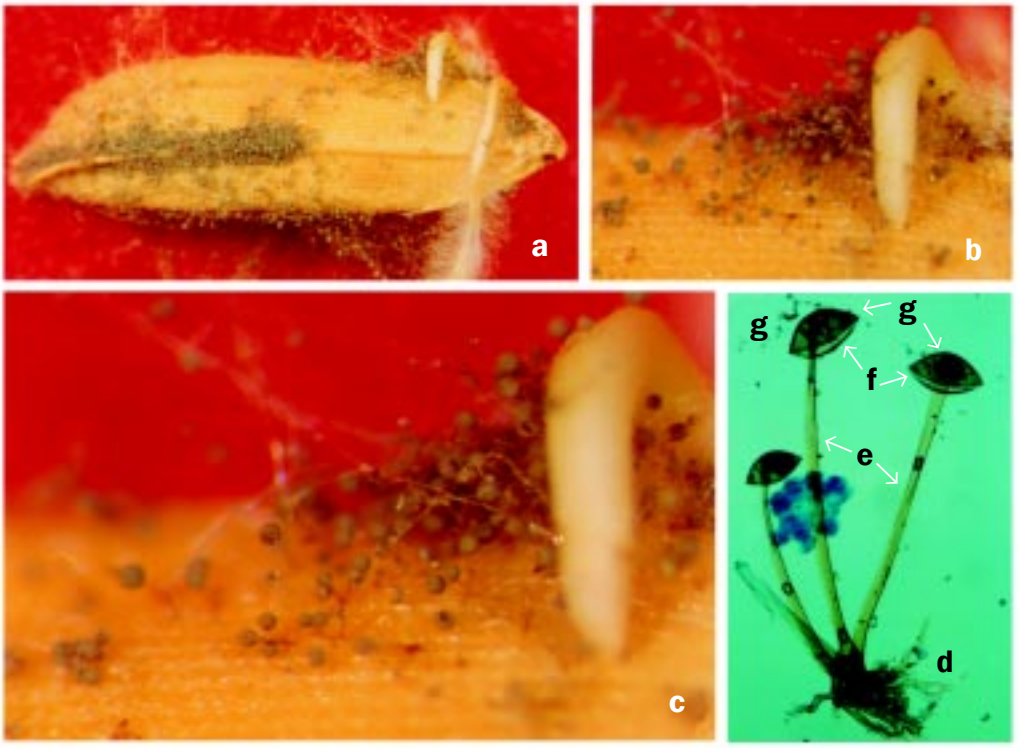

Fig. 94. Habit character of *Rhizopus* sp. showing gray sporangia on (a) whole seed (9X), (b) lemma (25X), and (c) embryonal area (40X). Photomicrograph of *Rhizopus* sp. showing (d) rhizoids, (e) sporangiophores, (f) sporangium, and (g) sporangiospores (10X).

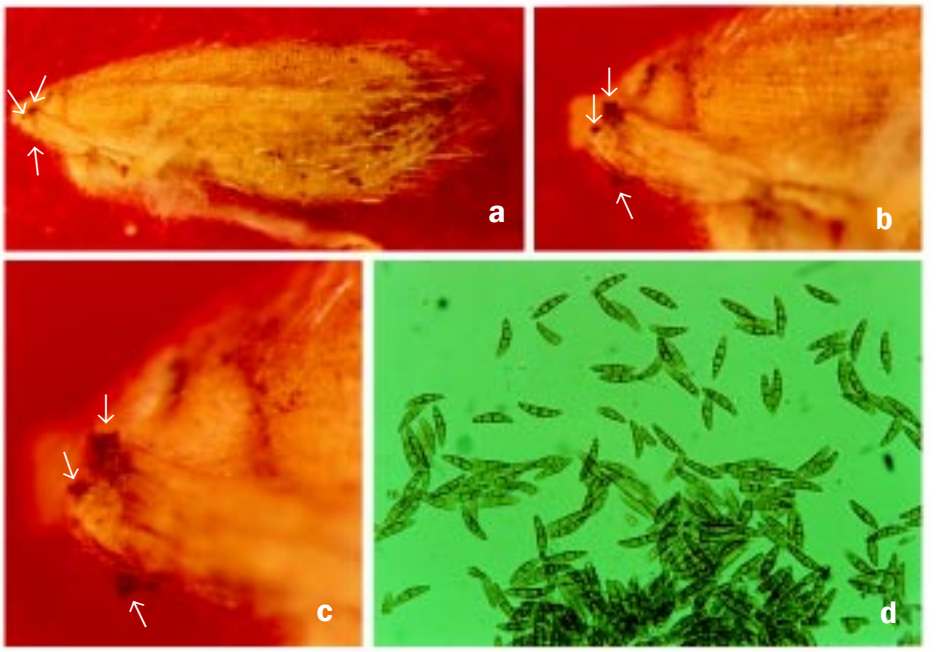

Fig. 95. Habit character of *Septogloeum* sp. on sterile lemmas at (a) 10X, (b) 25X, and (c) 50X. Photomicrograph of *Septogloeum* sp. showing (d) conidia at 40X.

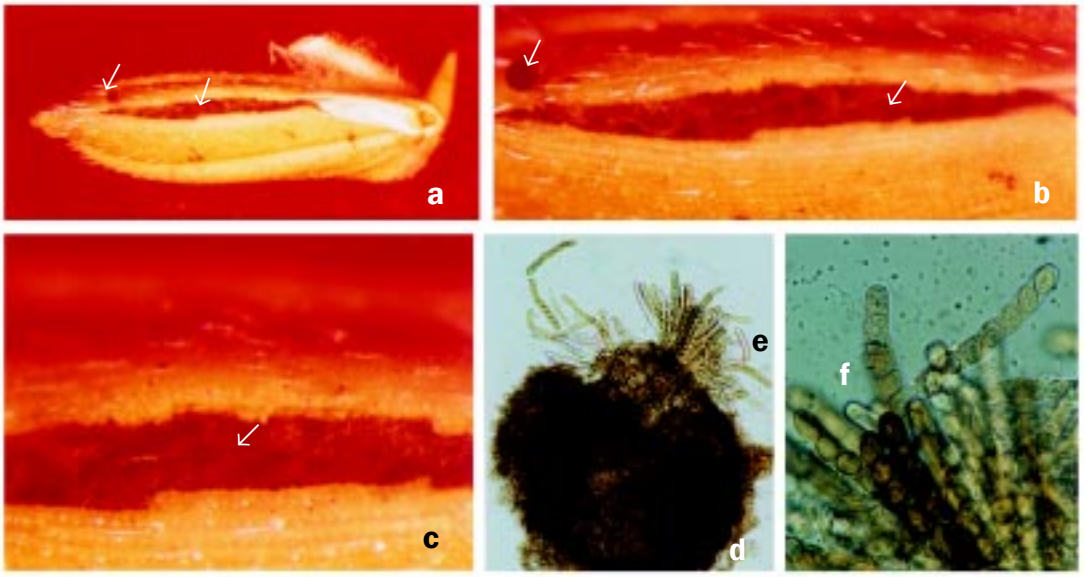

Fig. 96. Habit character of *Sordaria fimicola* (Roberge ex Desmaz.) Ces. at (a) 9X, (b) 25X, and (c) 50X. Photomicrograph of *S. fimicola* showing (d) perithecium and (e) ascus with ascospores at 10X. (f) Ascus with ascospores at 40X.

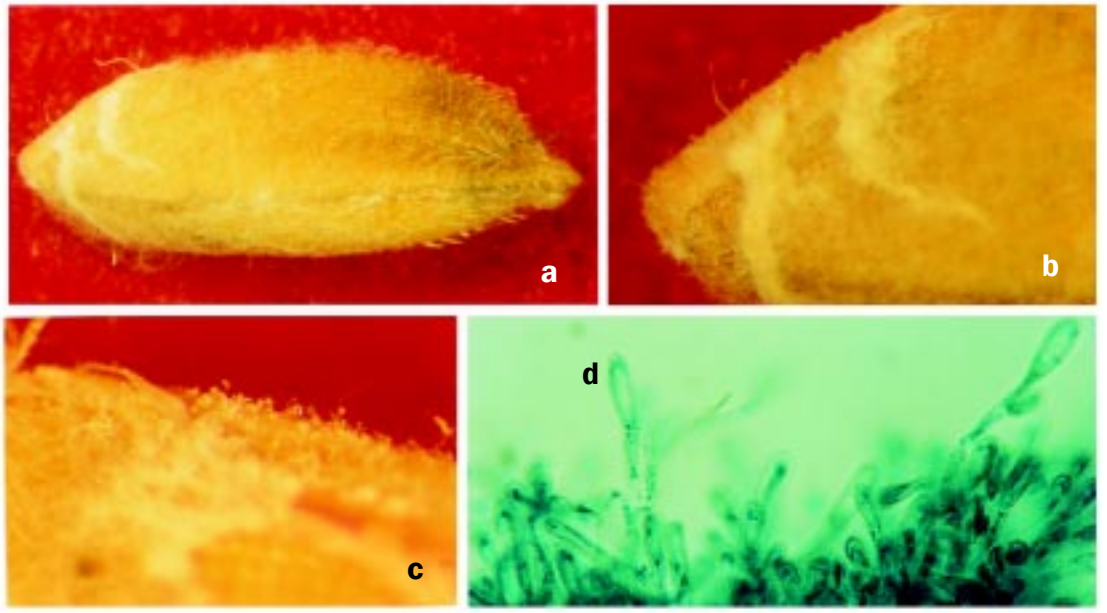

Fig. 97. Habit character of *Spinulospora puccinii phila* Deighton on (a) whole seed (10X), (b) sterile lemma area (25X), and (c) embryonal side (50X). Photomicrograph of *S. puccinii phila* showing (d) bulbils (40X).

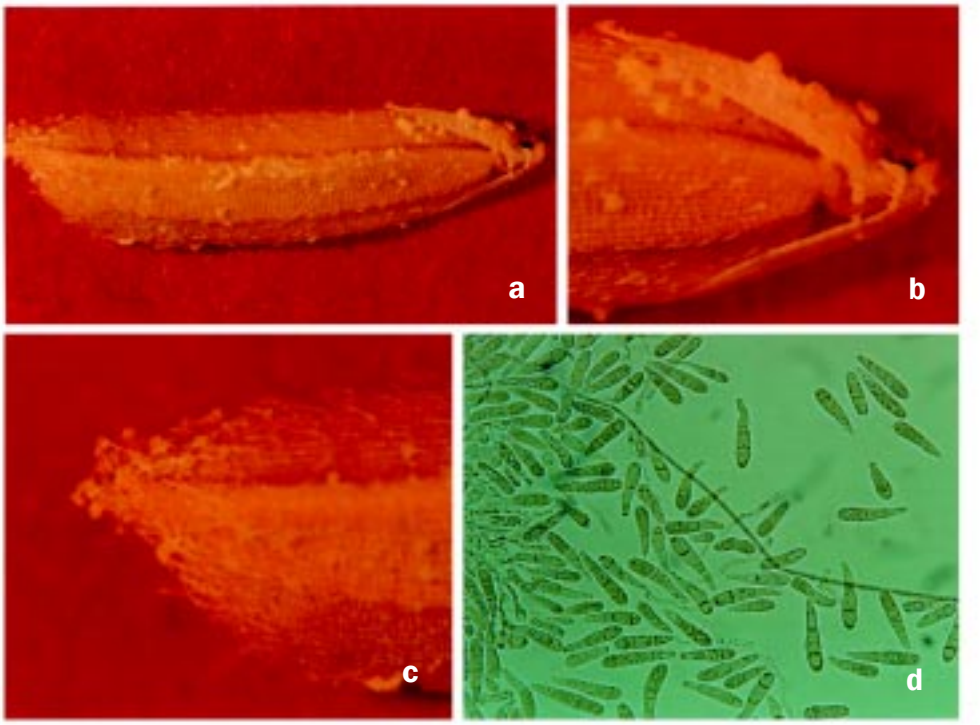

Fig. 98. Habit character of *Sterigmatobotrys macrocarpa* (Corda) Hughes on (a) whole seed (10X), (b) portion of sterile lemmas (40X), and (c) awn portion (40X). Photomicrograph of *S. macrocarpa* showing (d) conidia at 40X.

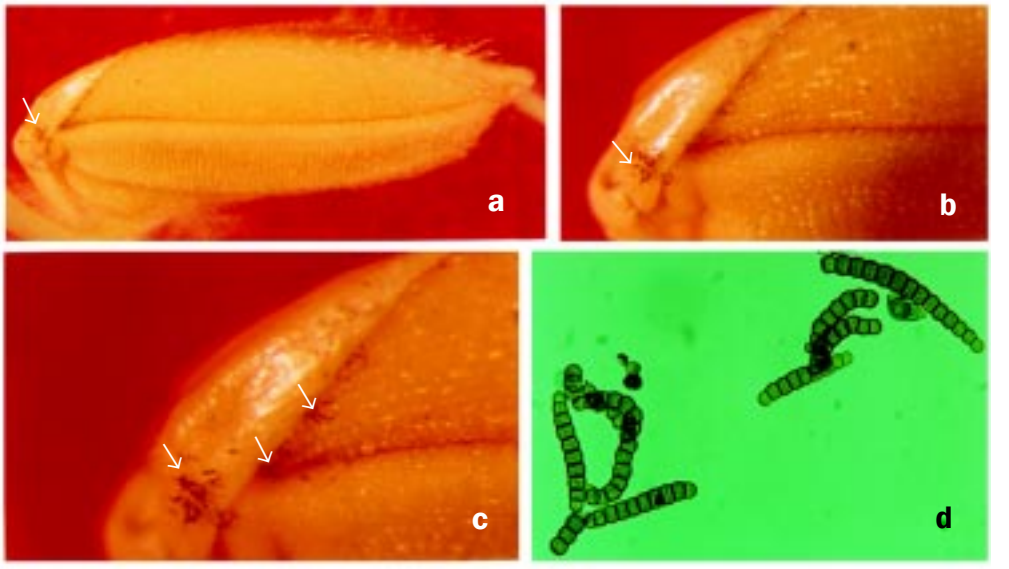

Fig. 99. Habit character of *Taeniolina* sp. on sterile lemmas at (a) 12X, (b) 25X, and (c) 40X. Photomicrograph of *Taeniolina* sp. showing (d) multiseptate conidia (40X).

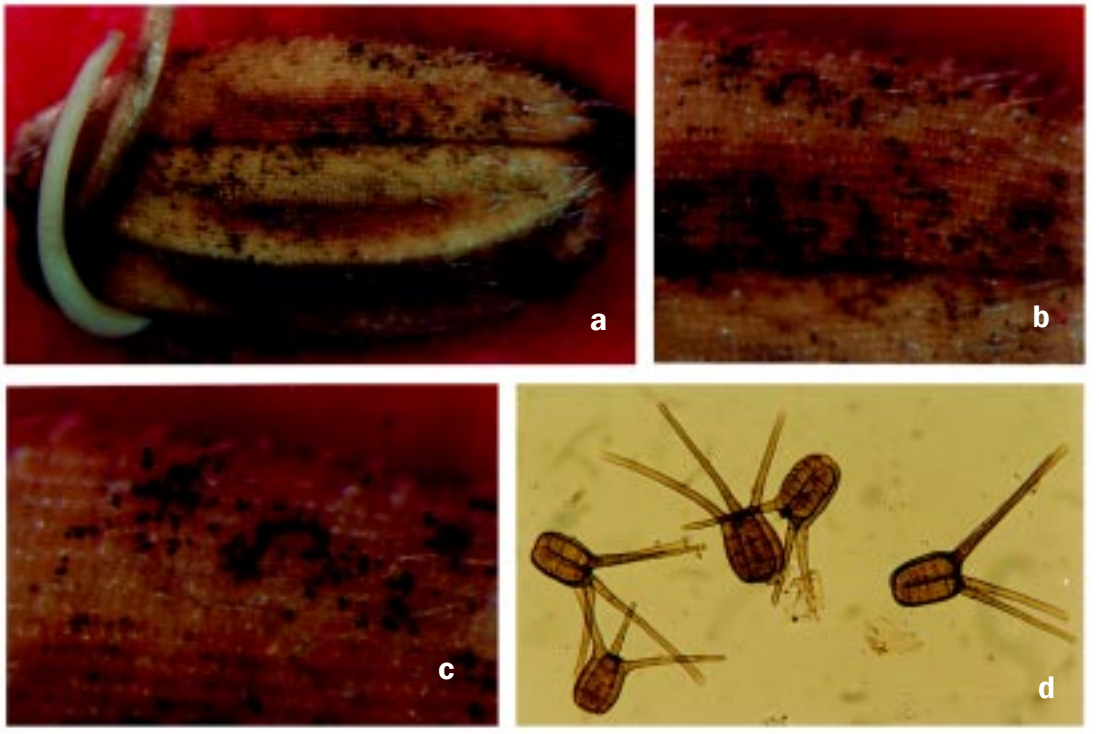

Fig. 100. Habit character of *Tetraploa aristata* Berk. & Br. on (a) whole seed (12X), (b) palea and lemma (25X), and (c) palea (50X). Photomicrograph of *T. aristata* showing (d) conidia with septate appendages (40X).

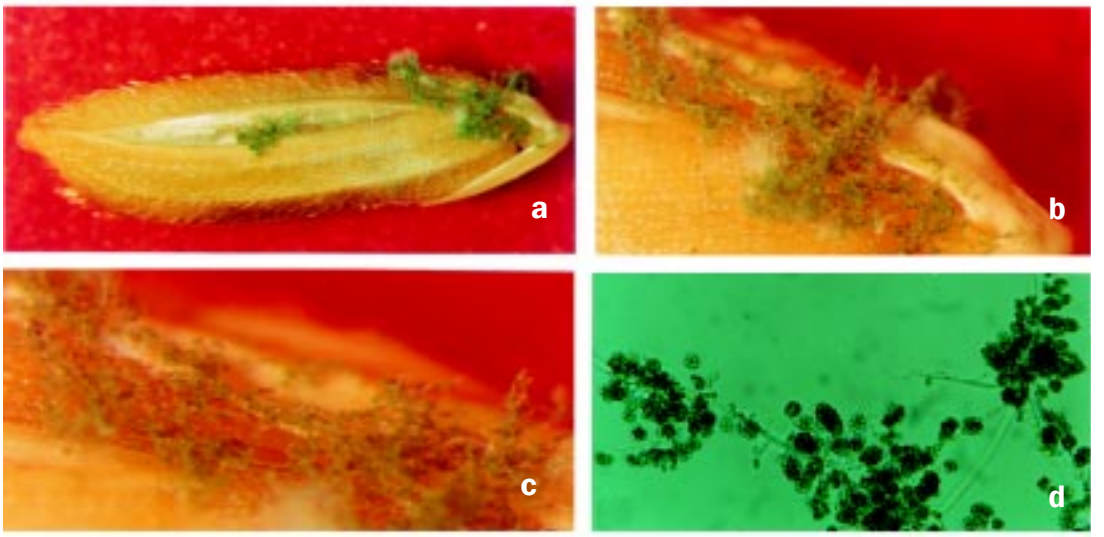

Fig. 101. Habit character of *Trichoderma* sp. on sterile lemma and palea and lemma at (a) 10X, (b) 25X, and (c) 40X. Photomicrograph of *Trichoderma* sp. showing (d) conidia borne in small terminal clusters (40X).

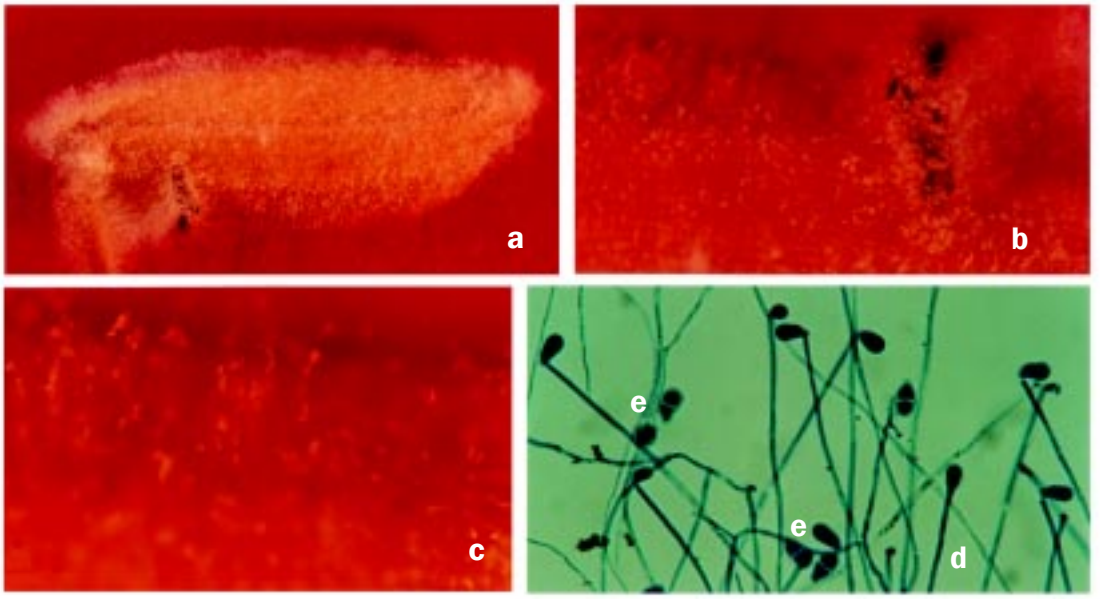

Fig. 102. Habit character of *Trichothecium* sp. on (a) whole seed (9X), (b) embryonal area (25X), and (c) lemma (50X). Photomicrograph of *Trichothecium* sp. showing (d) conidiophore and (e) conidia at 40X and stained with lactophenol blue.

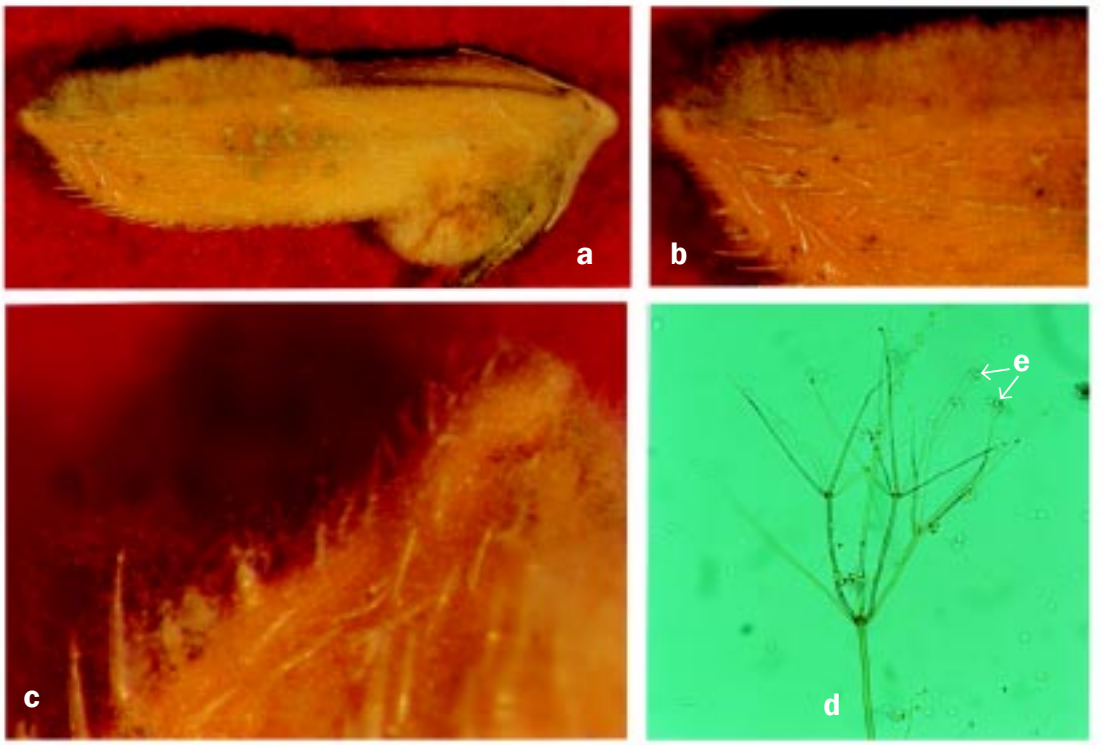

Fig. 103. Habit character of *Tritirachium* sp. on (a) whole seed (10X), (b) palea and lemma (18X), and (c) awn (50X). Photomicrograph of *Tritirachium* sp. showing (d) branched conidiophore and (e) conidia at 40X.

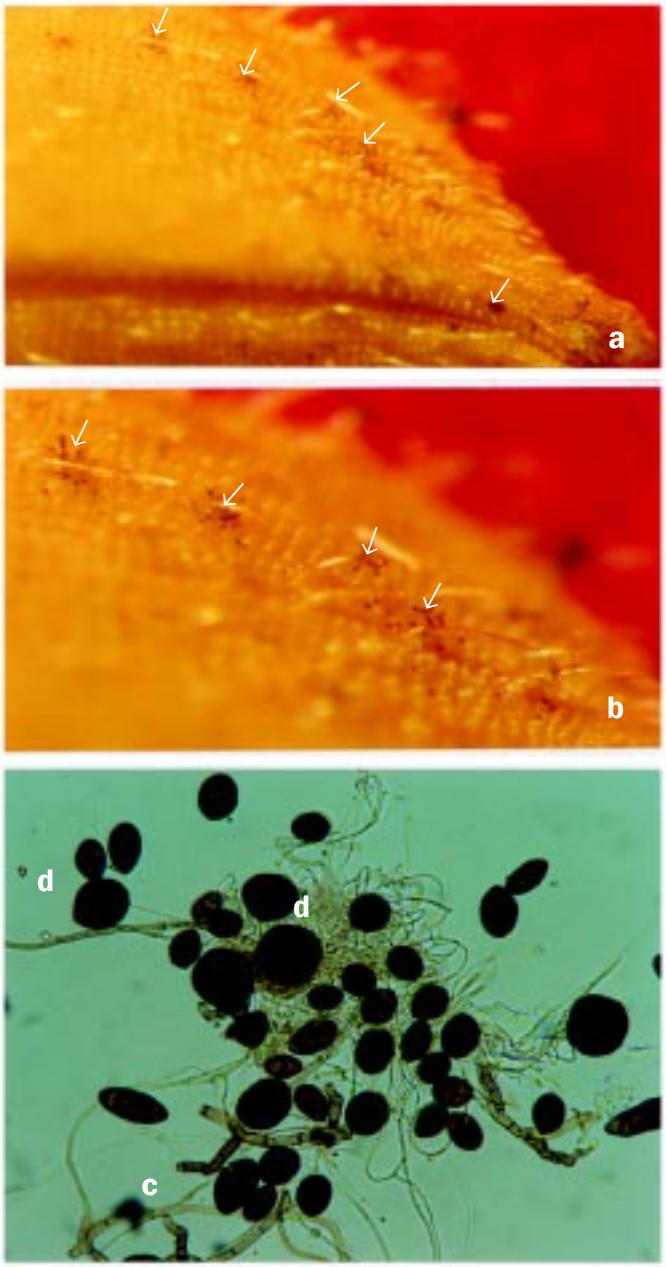

Fig. 104. Habit character of *Ulocladium botrytis* Preuss. at (a) 30X and (b) 50X. Photomicrograph of *U. botrytis* showing (c) conidiophores and (d) conidia at 40X.

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