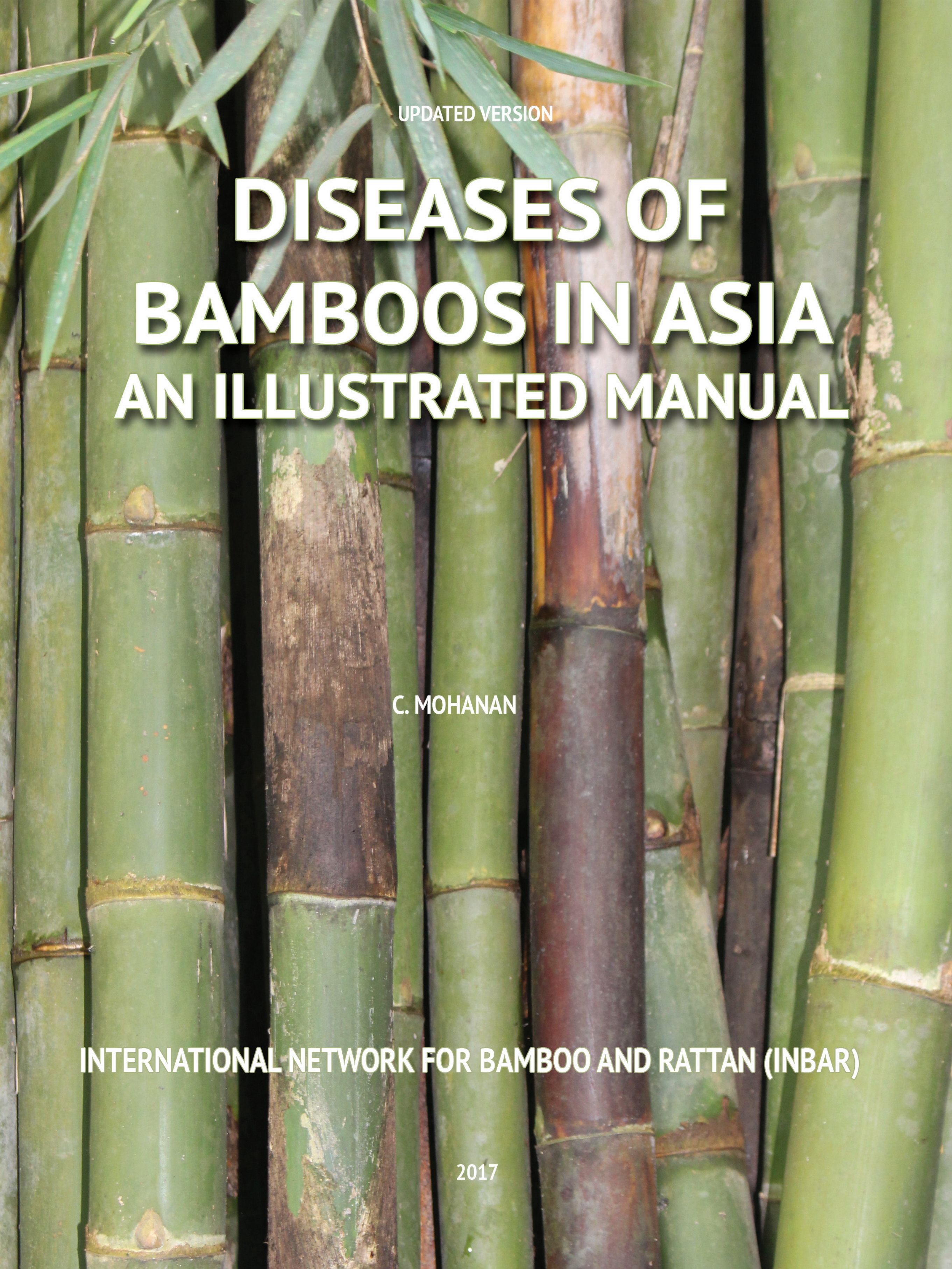


UPDATED VERSION

DISEASES OF BAMBOOS IN ASIA
AN ILLUSTRATED MANUAL

C. MOHANAN

INTERNATIONAL NETWORK FOR BAMBOO AND RATTAN (INBAR)

2017

UPDATED VERSION

DISEASES OF BAMBOOS IN ASIA: AN ILLUSTRATED MANUAL

C. MOHANAN

INTERNATIONAL NETWORK FOR BAMBOO AND RATTAN (INBAR)

2017

CREDIT PAGE

FOREWORD

ABOUT THE AUTHOR

Dr. C. Mohanan has served as Scientist and Head of Forest Health Division, Kerala Forest Research Institute (KFRI), Peechi, Kerala, India until his retirement in 2011 and continued his service as Scientist Emeritus. His major contributions are in the field of Tropical Forest Pathology - Disease surveys, Epidemiological and Disease management studies, Seed pathological studies - Biodiversity studies on plant pathogenic microorganisms, macrofungi, and mycorrhizae. He has published more than 150 research papers in National and International Journals and Proceedings. Also, he has authored and edited several Books, Handbooks and Proceedings. He has also handled research projects on bamboos and rattans sponsored by IDRC and INBAR. He has authored the earlier version of *Diseases of Bamboos in Asia: An Illustrated Manual* published by INBAR in 1997. Dr. Mohanan has also served as Editor and Chief Editor of *Journal of bamboo and Rattan*.

CONTENTS

EXECUTIVE SUMMARY

Bamboos are estimated to comprise more than 1670 species belonging to 125 genera globally. They are able to adapt a wide variety of ecosystems and climatic conditions. Bamboos cover a total of 37 million hectares worldwide with an average 4 per cent of the total forest area. Asia is the largest with 24 million hectares of bamboo growing area. Over the past 15 years, the area under bamboo stands in Asia has increased by 10 per cent due to large-scale planting of bamboos in China, and to a lesser extent in India. Bamboos form the backbone of the rural economy of many Asian countries. The bamboo resource base in this region is threatened by various biotic and abiotic factors, including pests and diseases. Available information on diseases and disorders of bamboos from different countries in Asia is assembled in this manual. A large portion of the information is from China, India, Japan and Taiwan-China, and only a limited number of records are available from other countries in the region.

About 195 species of bamboos belonging to 35 genera are found affected by various diseases and disorders. A total of 580 species of fungi belonging to 300 genera, five bacteria, two viruses, three phytoplasma and one bacterium-like organism have been reported to be associated with these diseases and disorders. Among the diseases recorded, only a few diseases are identified as serious ones, affecting culm production, stand productivity as well as local economy.

In bamboo nurseries, 13 diseases have been recorded from India, the Philippines, Thailand and China. Similar problems are likely to occur in other bamboo-growing countries in the region. Most of the diseases are common seedling diseases of other forestry species, with the exception of leaf striping and seedling stunting possibly caused by a virus. Among the nursery diseases, web blight caused by *Rhizoctonia solani* is a potentially serious disease that is widespread. *Kwelingia divina*, which causes leaf rust, and *Exserohilum* spp. and *Bipolaris* spp., which cause seedling foliage infection, are the other major diseases. In the warm-humid tropical climate, an occasional outbreak of any of these diseases is quite possible in bamboo nurseries. Most nursery diseases can usually be controlled by good nursery management practices or prophylactic fungicidal application.

Diseases that affect the rhizome, roots, culm, foliage, branches and minor branches, inflorescence, and seeds have been reported from bamboo stands. Decay and deterioration of culms in stands and storage, caused by an array of fungi, have also been noticed.

Among the diseases that affect bamboos in stands, the diseases affecting the emerging and growing culms are the most economically important ones, which are caused by about 26 fungi. A total of 8 *Fusarium* species have been reported as associated with the different diseases of culms. Culm rot caused by *Pterulicium xylogenum* is a newly emerged disease in India. Culm wilt caused by *Fusarium incarnatum* is another disease causing heavy damage to hybrid bamboo stands in China.

In bamboo stands, foliage diseases are most common, and about 245 species of fungi are known to be associated with such infections. Of these, 113 species cause major foliage infections and 132 species are associated with minor foliage infections. Most of the disease records are earlier reports from China, India, Japan and Taiwan-China; and there is a lack of more recent data on foliage diseases from Taiwan-China, China and Japan. Most foliage diseases are of minor significance; nonetheless, under conducive microclimates, flare-up of certain foliage diseases- such as leaf rust, leaf spot and leaf blight- are often reported. Diseases which are recognized as potentially serious include: culm blight caused by *Sarocladium oryzae* in village groves in Bangladesh and in the coastal belts of Odisha State, India; rot of emerging and growing culms caused by *Fusarium* spp.and *Pterulicium* sp.; witches'-broom caused by *Balansia* spp., *Aciculosporium* spp. in China, India, Japan and Taiwan-China; little leaf disease caused by Phytoplasma in the dry tracts of Southern India; culm mosaic caused by bamboo mosaic virus in Taiwan-China, China and India; and culm rust caused by *Steroestratum corticioides* and bamboo top blight of *Phyllostachys* spp. caused by *Ceratosphaeria phyllostachydis* in China.

Emerging culm rot, culm blight, culm rust, top blight, witches'-broom and culm mosaic are spreading fast in bamboo stands in different countries, and new outbreaks are common, adversely affecting bamboo industries as well as the rural economy as a whole. Disease management measures in practice in these countries have relied mainly on silvicultural measures and, to a lesser extent, on prophylactic treatment. However, etiology and epidemiology of these diseases are little investigated and disease management measures often prove inefficient. Hence, a concerted effort is required to develop appropriate measures to check further spread of the disease in stands, as well as to safeguard against the inadvertent introduction of the disease to new areas. Disease management strategies involving both short-term and long-term measures-including broadening the genetic base of bamboos, and the development and introduction of disease-resistant species/provenances-have to be made.

Biodeterioration and decay of culms in storage form an important problem. Natural durability of bamboo culms is very low. A large number of staining and decay fungi have been recorded on bamboos under storage in different countries. The severity of decay and deterioration depends on the duration of storage, the bamboo species, and environmental and storage conditions. Any appropriate storage technique devised to minimize the hazards must consider these aspects. Although effective preservative chemicals and treatment techniques for bamboos are available, more emphasis should be given to develop low-cost, easily available preservatives, and economically viable and environmentally friendly treatment methods.

In the earlier version of this book published by INBAR in 1997, a large number of potentially serious diseases posing threat to bamboos in different bamboo growing countries in the region have been described. As large-scale monoculture planting operations of bamboos in the region have been carried out rigorously for the past two decades, emergence of new diseases as well as flare up of existing minor or potentially serious diseases in epidemic proportions affecting bamboo culm production as well as stand productivity is anticipated. Hence, overall updation of information on diseases and disorders affecting bamboos in the region is attempted here.

1. INTRODUCTION

Bamboos are fast-growing, versatile plant species with multiple end-uses. For centuries, bamboos have been closely related to the agriculture, cottage industries, arts, culture, and day-to-day life of more than half of the world's population. About 2.5 billion people globally depend on bamboos for their survival and livelihood. The domestic and international trades in bamboo products amount to about US$ 60 billion (INBAR 2012, 2016; Phimmachanh et al. 2015). Recently, bamboos have also entered highly competitive markets in the form of pulp for paper and rayon, parquet, boards, plybamboo, charcoal, and as a canned vegetable. Till recently, bamboos were categorized as minor forest produce or even treated as weeds. With the alarming shrinkage of forest resources and the restrictions imposed on logging from natural stands, emphasis is being placed on raising fast-growing, multipurpose plant species to meet the ever-increasing demand for wood. Bamboo, the world's fastest growing and environment friendly giant grass, has now gained international reputation and priority, leading to its recognition as an important non-timber woody resource. During the past 15 to 20 years, bamboo has developed as an exceptionally valuable and often superior substitute for wood. Bamboo has tremendous potential for economic and environmental development. In the afforestation and reforestation programmes of many Asian countries, bamboo has assumed considerable importance to meet industrial and rural requirements, and also as a means to combat climate change through carbon sequestration, bioremediation for soil erosion and also to reverse land degradation.

Bamboos are estimated to comprise more than 1670 species in 125 genera belonging to three tribes: Arundinarieae (temperate woody bamboos), Bambuseae (tropical woody bamboos), and Olyreae (herbaceous bamboos) (INBAR 2017; Soreng et al. 2015,2017). They are able to adapt to a wide variety of ecosystems and climatic conditions. They have a wide range of distribution from tropics to the temperate zones and from sea level to elevations of 4 000 m. However, most bamboos occur in the warm-humid areas in the tropical and sub-tropical Asia, South America and Africa (Fig.1). Bamboo covers a total of 37 million hectares worldwide with an average 4 percent of the total forest areas (FAO 2007, 2010, 2014, 2015). Of the three continental regions of bamboo distribution, Asia is the largest with 24 million hectares of bamboo growing land (Hsiung 1991; Lobovikov et al. 2005). In Asia, the major bamboo growing countries are India (almost 11.4 million ha) and China (over 5.4 million ha), followed by Indonesia (2 million ha) and the Lao People's Democratic Republic (1.6 million ha). India accounts for roughly half the total area of bamboo reported for Asia and, together with China, approximately 70 percent. Over the past 15 years, the bamboo area in Asia has increased by 10 percent, primarily due to large-scale planting of bamboo in China and, to a lesser extent, in India (Hsiung, 1981,1991; Lobovikov et al. 2005; FAO 2007,2015).

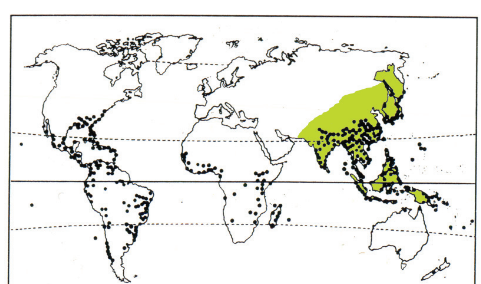


Fig.1 Geographical distribution of bamboos in the world

Table 1. Bamboos in Asian Countries

Country	Native species*	Native sp.**	Introduced sp.**	Area (1000 ha)**	% to forest cover**	Economically important bamboos
Bangladesh	18	33	4	83	9.5	*Bambusa balcooa, B. vulgaris, B. nutans, B. tulda, Dendrocalamus strictus, D. hamiltonii, Melocanna baccifera, Schyzostachyum dullooa*
Bhutan	21	-	-	-	-	*B. nutans, D. hamiltonii, Cephalostachyum* sp.
Cambodia	4			29	0.3	*D. giganteus, Cephalostachyum* sp., *Oxytenanthera* sp.
China	626	500	10	5444	2.8	*B. textilis, B. pervariabilis, B. blumeana, B. oldhamii, D. latiflorus, D. strictus, D. gigantus, Phyllostachys edulis,P. heterocycla* var. *pubescens P. makinoi, P. pubescens, P. glauca, P. flexuosa, P. nuda, P. bambusoides, P. tanaka*
India	102	119	25	11 361	16.8	*B. bambos, B. nutans, B. tulda, B. vulgaris, D. hamiltonii, D. strictus, Ochlandra travancorica, M. baccifera*
Indonesia	56	118	17	2081	2.4	*B. bambos, Gigantochloa apus, G. atter,G. verticllata*
Japan	84	139		154	0.6	*P. bambusoides, P. edulis, P. nigra, P. reticulata, P. pubescens, Pleioblastus simonii, P. hindsii*
Lao Peoples' Democratic Republic	13	-	-	1612	10.0	*G. albociliata, Cephalostachyum* sp., *Thyrsostachys* sp.
Malaysia	50	92	1	677	3.2	*G. levis, G. ligulata, C. scortechinii, G. wrayi, Thyrsostachys* sp.
Myanmar	75	97	-	859	2.7	*B. polymorpha, B. tulda, B. vulgaris, D. calostachys, D. giganteus, D. longispathus, D. membranaceus, Ochlandra scriptoria, Cephalostachyum pergracile, M. baccifera, M. bambusoides, T. siamensis*
Nepal	25	-	-	-	-	*Bambusa* sp., *D. hamiltonii, D. strictus,*
Pakistan	3	3	13	20	1.1	*B. tulda, D. strictus, D. hamiltonii*
Philippines	26	21	32	172	204	*B. blumeana, B. vulgaris, D. merrillianus, D. latiflorus, G. aspera, G. levis, Schizostachyum lima, S. lumampao*
Republic of Korea	2	5	46	6	0.1	*P. reticulata, Pleioblastus* sp
Sri Lanka	11	10	20	3	0.2	*O. stridula, D. giganteus, D. membranaceus, D. asper,D. strictus*
Thailand	36	-	-	261	1.8	*B. bambos, B. blumeana, B. longispiculata, B. nana, B. tulda, B. polymorpha, D. brandisii, D. hamiltonii, D. giganteus, D. membranaceus, D. strictus, C. pergracile, G. albociliata, G. haskarliana, G. longiapathus, G. nigrociliata, G. macrostachys, Oxytenanthera albociliata, O. nigrociliata, T. oliveri, T. siamensis,*
Vietnam	69	-	-	813	6.3	*B. bambos, B. tulda, P. bambusoides*
- Data not available, * Ohrenberger 1999; ** Lobovikov et al. 2005						

The economically important bamboos in Asia belong to relatively few species of the following genera: *Bambusa* Schreber, *Cephalostachyum* Munro, *Dendrocalamus* Nees, *Gigantochloa* Kurz ex Munro, *Melocanna* Trin., *Ochlandra* Benth., *Phyllostachys* Sieb. & Zucc., *Schizostachym* Nees and *Thyrsostachys* Gamble (Table 1). Data on native bamboo species provide an indicator of bamboo diversity in the countries and the world. The number of introduced species reveals the efforts of many countries to promote bamboo-based economic development. Introduced species include specimens in botanical gardens, trial plots, ornamental, private and public areas.

China has the highest bamboo biodiversity in Asia, with over 500 species, followed by Japan, India, Indonesia, Myanmar and Malaysia, each with more than a hundred species (Table 1). There is some discrepancies in number of bamboo species reported by different authors (Table1) and it may be explained by gaps in taxonomical classification (Ohrenberger 1999; Bystriakova et al. 2003; Lobovikov 2005; Sungkaew et al. 2009; Clark 2012). Taxonomy of bamboo differs from the taxonomy of many other plants. Traditional plant classification relies mainly on floral characteristics. Bamboo blossoms at irregular cycles and the dynamics are not yet clearly understood. Taxonomists have developed an excellent and comprehensive knowledge of the variety of bamboo species worldwide. However, information on bamboo species diversity is still incomplete and contradictory. Recently, molecular phylogenetic data have been employed understanding the diversity of bamboos and a total of 1670 species of bamboos belonging to 125 genera have been reported (INBAR 2017; Soreng et al.2015,2017)

Even though, most bamboo resources grow naturally, greater emphasis has been given in recent years to the establishment of planted bamboos. In general, bamboo offers many opportunities because it serves both production and conservation purposes. In the last two to three decades, emergence of new bamboo processing technologies and greater opportunities have led to the over-exploitation of bamboo resources in some countries. These factors together with introduction of innovative micro-propagation technology and creation of awareness on ecological and economic values of bamboos have contributed to the development of bamboo stands on a large-scale in both private and forest sectors in many Asian countries. At present, approximately 30 percent of the total area of bamboo in Asia is planted (Lobovikov et al. 2005).

The productive potential of bamboo stands in most of the bamboo growing countries in Asia is affected by various biotic and abiotic factors. Bamboos are associated with a large number of bambusicolous fungi. More than 1,100 fungal species have been described and recorded on bamboos, which comprise about 630 Ascomycetes, 150 Basidiomycstes, and 330 mitosporic taxa (100 Coelomycetes and 230 Hyphomycetes) from the world (Hyde et al. 2002; Arjun et al. 2016). Among these, a large numbers are phytopathogens which cause diseases. A large number of diseases have been reported in bamboos from different countries in Asia.

Diseases have been reported on bamboo seedlings in nurseries and clumps in plantations, village groves, homesteads and natural stands. Deterioration and decay of culms during post-harvest storage and use have also been reported. However, the available information on diseases and disorder is widely scattered and often lacking in detail. It has been difficult to make any assessment on the present status of diseases as well as their impact upon bamboo cultivation and culm production in a particular country. Earlier, attempts to collate information on bamboo diseases were made by Boa (1987a), Mohanan and Liese (1990) and Mohanan (1997). This manual gathers information:

- To review existing knowledge of diseases and disorders of bamboos in Asia;
- To identify serious disease problems, if any, posing threats to the bamboo resource; and
- To identify gaps in knowledge as well as research needs on bamboo diseases/disorders and their management.

In the earlier version of this book published by INBAR in 1997, a large number of potentially serious diseases posing threat to bamboos in different bamboo growing countries in the region have been described. As large-scale monoculture planting operations of bamboos in the region have been carried out rigorously for the past two decades, emergence of new diseases as well as flare up of existing minor or potentially serious diseases in epidemic proportions affecting bamboo culm production as well as stand productivity is anticipated. Hence, overall updation of information on diseases and disorders affecting bamboos in the region is attempted here.

This manual presents available information on diseases in nurseries, plantations, village groves and natural stands, as well as on decay and deterioration of harvested culms. Available information on distribution of diseases, bamboo species affected, economic losses, associated pathogens, and remedial measures and corrective management practices for economically important diseases are furnished. Potential diseases of bamboos in Asia are also identified and described.

Sources and Nature of Information

Literature searches were carried out using the TREECD Database and by conventional library consultation. For updating the earlier version, CAB-Direct Database from 1995 to 2017 was searched and information collected and updated. Literature search was also made through a large number of E-Journals, which include: Annals of Forest Science, Annual Review of Ecology, Evolution and Systematics, Annual Review of Genetics, International Forestry Review, Journal of Tropical Forest Sciences, Journal of Phytopathology, Fungal Biology (Formerly Mycological Research), Forest Science, Annual Review of Plant Biology, Annual Review of Phytopathology, Annals of Forest Science, Biotropica, Blumea, Ecology, Environmental Conservation, Forest Ecology and Management, Tree Physiology, New Forests, Annual Review of Plant Biology (Formerly Annual Review of Plant Physiology and Molecular Biology). Attempts were also made to collect unpublished information by contacting concerned researchers and organizations in the region. Bamboo nurseries and stands in different localities in China, India, the Phlippines, Malaysia and Thailand were also visited, and first-hand information on diseases was gathered during the preparation of the first version published in 1997. Bamboo nurseries and Bambusetum at KFRI, Peechi, and Field Station at Palappilly, Thrissur, Kerala, India were also visited and information on diseases was collected. Field visits to bamboo natural stands in Thrissur and Nilambur Forest Division, Kerala State were also made and information collected and disease affected culms and foliage photographed. However, the present work is heavily dependent on earlier studies by the author (Mohanan, 1990; 1994a,b; Mohanan 2001,2008,2010,2011), Mohanan and Liese, 1990). Organizations and libraries consulted include: Bamboo Information Centre, India, Kerala Forest Research Institute (KFRI), Kerala, India; Indian Council of Forestry Research and Education (ICFRE), Dehra Dun, India; Tropical Forest Research Institute, Jabalpur, India; Institute of Rain and Moist Deciduous Forests, Jorhat, Assam, India; Assam Agricultural University, Jorhat, Assam, India; Botanical Garden, Culcutta, West Bengal, India; Indian Agricultural Research Institute (IARI), New Delhi, India; International Network for Bamboo and Rattan (INBAR), International Development Research Centre (IDRC), New Delhi, India; Forestry Research Support Programme for Asia-Pacific (FORSPA), Bangkok, Thailand; Bamboo Information Centre, China, Institute of Scientech Information, Chinese Academy of Forestry (CAF), Beijing, China; Nanjing Forestry University, Nanjing, China; Kasetsart University, Bangkok, Thailand; Royal Forest Department, Bangkok, Thailand; Forest Products Research and Development Institute (FPRDI), Los Banos, the Philippines; Ecosystem Research and Development Bureau (ERDB), Los Banos, the Philippines.

Greater part of the information collected is from China, India, Japan, and Taiwan-China. Only a limited number of disease records are available from Bangladesh, Indonesia, Hong Kong, Malaysia, Pakistan, the Philippines, Singapore, Sri Lanka, Thailand and Vietnam. Little or no information on bamboo disease is available from countries like Bhutan, Cambodia, Nepal and Papua New Guinea. Although there are numerous records of bamboo diseases from China, India and Japan, details on their etiology, symptoms, severity, economic importance, control measures, etc. are meagre. Many of the disease records from India are 70-100 years old.

Organization of Information

Information on bamboo diseases and disorders is arranged into six sections. The disease for which sufficient details are available are presented in Sections 3 and 4. Section 3 documents diseases affecting bamboo seedlings and planting stocks in nurseries. Section 4 documents information on diseases recorded in bamboo plantations, village groves and natural stands. In Section 5, information on post-harvest decay and deterioration of bamboo culms is presented. In Section 6, information on new findings and potentially serious diseases of bamboos is presented.

Diseases are arranged on the basis of the plant parts affected, with details on their distribution, incidence and severity, economic importance, bamboo species affected, symptoms, causal organism(s), etiology and disease management measures. Scientific names of hosts are given as they have appeared in the original reports, but when possible and unambiguous, the nomenclature has been corrected. Nomenclature of all the bambusicolous fungi recorded has been checked using Index Fungorum - Royal Botanic Garden, Kew - Database and Species Fungorum - CABI Database and corrections incorporated. Disease management measures suggested in the text are taken from the available literature. Where control measures were not available in the literature, the author has suggested possible remedial measures. Summary checklists of diseases, disorders/ decay/pathogens/ are provided in Appendices I,II and III. A glossary of technical terms, host and pathogen indices are also furnished.

2. IMPACT OF BAMBOO DISEASES ON THE ECONOMY

More than 190 species belonging to 33 genera of bamboos have been recorded as affected by various diseases and disorders. The relative importance of different diseases affecting bamboos in the region is difficult to assess because of the general lack of information accompanying the disease records. Similarly, lack of quantitative data on the extent of damage caused to the bamboo stands makes it onerous to evaluate the economic losses resulting from diseases. However, the overall impression is that the impact on economy is limited for most diseases.

A large number of foliage diseases - leaf spots, leaf blight, leaf rust, etc. - of bamboos have been recorded. In general, however, these cause comparatively less damage to bamboo stands than bamboo culm diseases.

Diseases affecting the emerging and growing culms are much more serious as they cause extensive damage to bamboo stands. Rot of emerging culms - reported on various bamboo species from Bangladesh, China, India, Pakistan, the Philippines and Thailand - appears to be one reason for the large-scale reduction in culm production in respective countries. In India, the disease is widespread in natural bamboo stands as well as in bamboo plantations in the southern States. Severe infection and large-scale mortality of emerging culms were recorded in bamboo stands in high-rainfall areas in Kerala and Karnataka States. About 34 per cent mortality of emerging culms was recorded in *Bambusa bambos* natural stands in different locations in Waynad Forest Division of Kerala during 1988-91. In bamboo plantations, mortality of emerging culms ranged from 5.5 per cent to 25.5 per cent during the same period. Usually, very high incidence of disease and mortality occurs in emerging culms of 15-30 cm height. Higher economic losses have been reported in unmanaged natural stands than in plantations Recently, 50-100% disease severity has been recorded on *Bambusa balcooa* and *Dendrocalamus asper* stands in Karnataka State. Recently, rot of emerging culms caused by *Pterulicium xylogenum*, an opportunist pathogen, has been recorded on different bamboo species from northern and north-eastern States in India. The disease is economically important as it severely affects the edible shoot production of *Melocanna baccifera*.

Rot of growing culms reported from China and India is another potentially serious disease affecting culm production. In India, the disease has been recorded in different species of bamboo grown in Kerala and Karnataka States, its incidence in different localities in Kerala State ranges from 3 per cent to 25 per cent during 1987-91. Young (2-4 years-old) clumps of *Bambusa bambos, Dendrocalamus longispathus* and *D. strictus* were found to be the worst affected. The disease lowers the quality as well as the quantity of the culms produced.

Bamboo blight, perhaps the most dreaded disease, has been reported as affecting village groves of *B. bambos, B. balcooa, B. tulda* and *B. vulgaris* throughout Bangladesh, and *B. nutans* in the coastal areas of Odisha State in India. In Bangladesh, the disease was first recorded in 1970 as a potentially serious problem of village bamboos. Losses from the disease have been highest in *B. vulgaris* and the Jawa/Kata Jali variety of *B. tulda*. From 3 per cent to 66 per cent clump infection has been reported in different localities such as Chittagong, Comilla, Dhaka and Rajshahi. Although the disease severely affects the bamboos in village groves and the village farmers in the affected areas experience considerable setbacks, the available data are not adequate to make an overall assessment of the economic losses or of the impact on culm production.

In India, large-scale mortality of *Bambusa nutans* owing to blight disease occurred in 1988 in the coastal areas of Ganjam, Puri and Cuttack in Odisha State, causing considerable damage to the village economy. Villagers in these areas earn Rs. 3000 to 5000 annually from sale of culms in their groves. The blight disease was so widespread and severe that it threatened to damage all the groves, each consisting of 50-100 clumps, within a period of 2-3 years. The blight disease soon reached an epidemic proportion, and about 55-67 per cent of the clumps in Cuttack and Puri districts were affected.

Culm brown rot is another disease that affects growing bamboo culms, mainly those of *Phyllostachys viridis, Phyllostachys glauca* and *P. viridis f. hauzeauana*. The disease was first recorded in 1974 in Nanjing, China, and at present it is widespread among *Phyllostachys* stands in Jangsu and Zhejiang Provinces. Disease incidence in different areas ranged from 9 per cent to 17 per cent during 1974-79, with an annual average of 10 per cent mortality. Recently, severe disease incidence has been recorded on *Phyllostachys glauca* stands in Nanjing, China affecting the culm production considerably.

Bamboo top blight (also known as withered tip disease or die-back or 'Moso tip blight'), which occurs in *Phyllostachys edulis, P. pubescens* and *P. heterocycla* stands in China, is another serious disease affecting the culm production and thereby the local economy. The disease affects the culms of current season, and is widespread in Jiangsu, Zhejiang, Anhui, Jiangxi, Fujian and Shanghai Provinces. Top blight caused large-scale mortality of bamboos in 1973. The resultant economic losses were reported to be very high in bamboo stands growing in drought-affected areas and in poor soils with poor growth.

Branch die-back disease is extensive in natural stands and plantations in Kerala State, India. Comparatively, the incidence of disease recorded was higher in young (2-3 year-old) *B. bambos* in plantations (14-67%) than in natural stands (2-37%) during 1987-91. The disease has been reported as adversely affecting the establishment of young clumps. A similar disease affecting *Phyllostachys* stands in Fujian Province, China has also been reported. However, economic losses resulting from it have not been assessed yet.

Witches'- broom disease reported from China, India, Indonesia, Japan, Taiwan-China and Vietnam is considered a potentially serious disease that affects a large number of bamboo species in the genera *Phyllostachys, Ochlandra, Bambusa, Gigantochloa* and *Sasa*. In China, the disease is widespread in Zhejiang, Jiangsu and Hunan Provinces, causing 95 -100 per cent infection in *Phyllostachys* stands. Although, the disease causes malformation of the culms and affects culm production, data on economic losses are not available from any of the affected countries. Wiches'-broom caused by *Aciculosporium take* is the most destructive disease of bamboos in Japan. The disease is widespread in *Phyllostachys* and *Sasa* stands in the western Japan. Severe infection of about 93% has been recorded in *Phyllostachys bambusoides* communities in 17 Perfectures in the western Japan. In Kerala State, India, the disease is fairly extensive in areas where reed bamboos (*Ochlandra* species) grow, and 6% to15% disease incidence was recorded in different localities during 1988-92. Severe infection leads to the production of thin, wiry shoots. Even though, no assessment of economic losses is available, the extensive and systemic nature of the infection is expected to adversely affect culm production and stand productivity of reed bamboos in the near future.

Little leaf disease, caused by a *Phytoplasma* reported from Kerala, Karnataka, Tamil Nadu, Andhra Pradesh and Maharashtra States in India is another critical bamboo disease. Severe infection causes the emerging culms to be stunted and deformed , causing clumps to become bushy. In Kerala, very high incidence (90%) of the disease is reported in dry tracts and sandalwood reserves. A survey during 1988-92 recorded 6% to 12.5% increase in the disease occurrence over the four year period in different localities of the State. Economic losses caused by the disease are very high in dry tracts, where the farmers hardly get any culm from their groves.
Bamboo mosaic disease, caused by the Bamboo Mosaic virus (BaMV), has been reported as affecting the two major cultivated species in Taiwan-China - *Dendrocalamus latiflorus* and *Bambusa oldhamii*. Recently, the disease has been recorded on 13 species of bamboos with pachymorph rhizomes in Taiwan-China, China and India. The disease is widespread in bamboo growing areas in Taiwan-China, 70% to 82% disease incidence has been reported from different localities. The diseased shoots become hard in texture, their internal tissue gets discoloured, and their edible and canning quality declines markedly. The disease is reported to be spreading fast because of the large-scale use of vegetative propagules for raising plantations. As the disease affects industries based on the export of edible shoots as well as its canning, the economic losses resulting from the disease are very high.

Culm rust caused by *Stereostratum corticioides* affect more than 17 species of bamboos, however, it poses a major threat to *Phyllostachys glauca* and *P. meyeri* stands in Jiangsu, Hunan, Zhejiang and Anhui Provinces in China. The incidence of rust infection ranged from 30% to 90% in different Provinces, and the disease affects the production of edible shoots. Culm rust is reported as causing serious economic losses, and a major outbreak of the disease in Yangzhong County has destroyed about 200 ha of *P. glauca*. Recently, severe outbreak of the disease has been reported from Dequin County, Zhejiang Province, China affecting about 10 000 ha of bamboo forests.

Bamboo wilt causes by *Fusarium oxysporum* on hybrid bamboo, *Bamdusa Pervariadilix Grandis* Nin (*Bambusa pervariabilis* x *Dendrocalamopsis daii*), is a potentially serious disease affecting the hybrid bamboo stands in Guangxi and Sichuan Provinces in China. As the hybrid bamboo is presently cultivating on a large-scale in Giangxi and Sichuan Provinces in China for its culms for paper making and shoots for edible purposes, the wilt disease is posing severe challenge to both the industries and local economy.

Culm staining and die-back in *B. vulgaris* and *D. longispathus* stands, reported from Kerala State of India, acts as a limiting factor for the establishment of clumps in plantations, especially in high-rainfall areas. Although, 10 per cent to 98 per cent incidence was recorded during 1980-92, the disease has a patchy distribution and economic loss from it is negligible.

Microorganisms invade bamboo seeds during their different development stages in plant as well as after the seed fall. Seeds are also infected during storage and subsequent handling prior to sowing. Poor quality of seeds in terms of viability and vigour has been the cause of a high degree of failure in nurseries. Few of the seed-borne fungi are also capable of causing seedling diseases in nurseries. Considering the unusual long flowering and seeding cycle of bamboos, the seeds are so valuable and any losses owing to microbial deterioration is of great concern. Although, data on such losses are not available from any of the bamboo growing countries in the region, it is evident from some of the disease records that large quantities of bamboo seeds deteriorate at different stages by various microorganisms.

Large quantities of bamboo culms stored in forest depots, mill yards and other storage facilities are deteriorated and decayed by microorganisms. The onslaught on culms is mainly caused by fungi, which include those that cause soft-rot, staining, white-rot, and brown-rot. Bacterial degradation of culms also occurs, but is a slow process unlike that caused by fungi. Bamboos used for structural purposes in rural and tribal housing deteriorate within a couple of years, putting heavy pressure on the resource because of the frequent need for replacement. The natural durability of bamboo culms is low and varies from 1 to 36 months, depending on species and environmental conditions. During storage for up to 12 months, 20 - 25 per cent damage of culms has been reported in India. Decay and deterioration are major problems in bamboo culms stored for making pulp. Decay fungi affect the pulp yield by up to 25 per cent over a storage period of one year, and the pulp strength is reduced by 15-40 per cent. Although data on economic losses owing to culm decay and deterioration are not available, fungal attacks on culms, in general, increase pulping costs because of the increased alkali requirement and higher bleach consumption.

Apart from the infectious diseases, non-infectious diseases - which are caused by abiotic factors - also play a major role in limiting culm production. Severe damage caused by glazed frost has been reported from mainland China and Taiwan-China. About 3 800 ha of *P. pubescens* stands in Qianshan County of Anhui Province in China suffered destruction from glazed frost in 1988, causing losses worth 9 million yuan.

3. DISEASES IN BAMBOO NURSERIES

Bamboos, like many other forest species, are vulnerable to various nursery diseases. Nursery stocks raised in conventional seedbed nurseries as well as through vegetative propagation methods are equally susceptible to various pathogens. Usually, the nursery stocks have to be maintained for a considerable period of time (6 to 9 months) before planting out (Figs. 2-4).

Fig. 2a Bamboo seedbed nursery (Kerala, India)

Fig. 2b_ Bamboo nursery (KFRI Kerala, India)

Diseases affect the nursery stocks from the time the radicle emerges to the time of planting out, causing considerable damage depending on the prevailing microclimate in the nursery, bamboo species and the virulence of the pathogen. Diseases affecting the nursery stocks have been reported from India, the Philippines,Thailand and China. Altogether 13 nursery diseases, caused by 16 fungi and one virus, have been reported on bareroot, container-seedlings and vegetatively propagated planting stocks.

Damping-off

Damping-off is common in bamboo nurseries, causing considerable loss of seedlings. The disease affects seedlings during germination (pre-emergence damping-off) or after germination (post-emergence damping-off). While the seedling tissues are still succulent. Damping-off has been recorded in *Bambusa bambos*, (L.) Voss (= *Bambusa arundinacea* (Retz.) Willd.), *Dendrocalamus brandisii* (Munro) Kurz, *D. strictus* (Roxb.) Nees and *Thyrsosatchys siamensis* Gamble in seedbed nurseries in Kerala, India (Mohanan, 1994a,b). The disease was observed in nurseries where high sowing rates of 750 g to 3 kg seeds per standard seedbed (12 x 1 x 2.5 m) were used, and seedbeds were provided with dense shading and profuse watering. The disease severity ranged from low to severe, depending upon the local microclimatic conditions and the nursery cultural practices. A high incidence of disease, affecting 30 to 40% of the seedlings of *B. bambos*, was reported during 1990 in a nursery at Kulanjithodu (Ranni Forest Division), Kerala, India (Mohanan, 1994a). Damping-off has also been reported on *Phyllostachys pubescens, P. sulphurea* cv. *viridis, P. glauca, P. aureosulcata* and *P. bambusoides* in Zhejiang, Fujian, Hunan and Hubei Provinces in China (Zhang 2000).

Fig. 3 Bamboo container nursery at Kanchanburi, Thailand

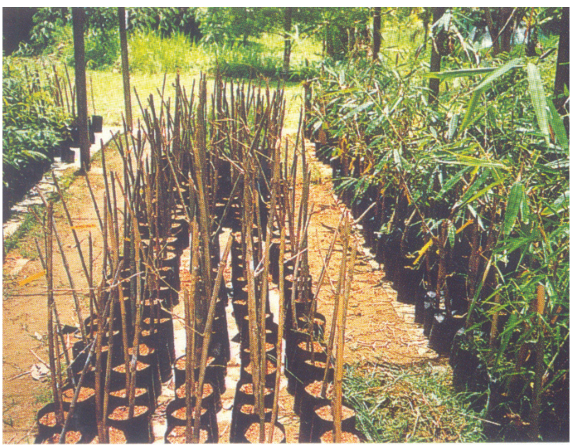


Fig. 4 Bamboo vegetative propagation nursery at Selangor, Malaysia

Fig. 4 Damped-off patches in *B. bambos* seedbed

SYMPTOMS

The disease occurs in patches in the seedbeds 7 to 12 days after sowing (Fig. 5). The seed decay and pre-emergence damping-off are characterized by the rotting of well-filled viable seeds and also the newly emerged radicle. Post-emergence damping-off is characterized by the development of water-soaked greyish brown lesions on the emerging plumule near the soil level. The lesions spread and become necrotic, resulting in the collapse of the plumule.

CAUSAL ORGANISMS

Rhizoctonia solani Kuhn state of *Thanatephorus cucumeris* (Frank) Donk; *Fusarium fujikuroi* Nirenberg (= *Fusarium moniliforme* Sheld.); and *F. oxysporum* Schltdl. (Mohanan, 1994a,b); *Rhizoctonia solani*, *Fusarium* spp., *Athelia rolfsii* (Curzi) C.C. Tu & Kimbr. (= *Sclerotium rolfsii* Curzi) (Zhang 2000).

ETIOLOGY

The seed or the emerging seedling tissue is infected either by spores or vegetative hyphae present in the soil or on the seeds. Infection of the host tissue results in the enzymatic degradation of the host cell wall and the death of host tissue. This appears as water-soaking, browning or shriveling of the stem tissue at soil level and collapse of the seedlings. Most damping-off fungi cause disease only at the seedling stage; as seedlings grow and the tissue becomes lignified, they become more resistant to infection. Factors influencing the severity of damping-off include soil moisture, temperature, soil pH, host vigour, host density and inoculum density. Conditions that favour damping-off by one fungus species may not be favourable for another fungus. Damping-off by *Rhizoctonia solani* is most severe at high moisture levels, which favour the mycelia growth, while *Fusarium* spp. grow best in dry soil. The seeds of species that germinate quickly and seedlings that grow fast possibly sustain less damage from damping-off as compared with slower emerging and slower growing species. However, in the case of bamboos, the seeds in general germinate quickly and the seedlings grow rapidly.

DISEASE MANAGEMENT

The best means to manage the damping-off is by preventing pathogenic fungi from entering the seedbed. Damping-off can be avoided by adopting proper nursery cultural practices. Excessive watering and dense shading should be avoided.Low sowing rate – 500 g seeds per standard seedbed – is preferable to prevent the build-up of conditions conducive to the spread of the pathogen (Mohanan, 1994a). Pre-sowing seed treatment (overnight soaking of bamboo seeds in water), which possibly reduces the spermoplane microflora, and subterranean exposure of the seeds prior to germination also help minimize the incidence of damping-off.

Seedbed soil solarization and seed dressing with fungicides – such as Thiram 75 WP (@ 2 g/kg), Captan 75 WP (@2g/kg) – and seed coating with spores of antagonistic fungi - such as *Trichoderma harzianum* Rifai and *T. viride* Pers. ex Fr. - are the other measures suggested to minimize the disease incidence (Mohanan 1994a,2001).

Seedling Spear Rot

Seedling spear rot has been observed in *Bambusa bambos* and *D. strictus* nurseries in Kerala, India (Mohanan, 1994a,b,2008). The disease was sporadic and its overall severity was low. However, in 1991, a disease outbreak was recorded in nurseries where seeds were sown densely (3 kg seeds per standard bed), and the seedbeds were covered with a thick layer (>0.5 cm) of soil and were insufficiently watered.

SYMPTOMS

Small irregular water-soaked lesions on emerging spear-like plumules appear near the soil level or at the pointed apical portion. The lesions coalesce and spread rapidly from the base to the apex or from the tip downwards, covering the entire plumule, which subsequently becomes necrotic. The infected plumules fail to grow further and dry up in due course. Disease occurs in patches in seedbeds within 2-5 days of emergence; the advanced stage of infection can easily be detected, because the patches of infected seedlings show a burnt-up appearance.

CAUSAL ORGANISM

Rhizoctonia solani Kuhn state of *Thanatephorus cucumeris* (Frank) Donk. (Mohanan, 1994a,b).

ETIOLOGY

Rhizoctonia solani Kuhn state of *Thanatephorus cucumeris* is a soil-borne pathogen which occurs as a collective species or a species complex made up of divergent populations. This fungus invades tissues of emerging plumules and arrests their further growth by gradual disintegration of the affected tissues. A longer period of subterranean exposure of the emerging plumule owing to a thick layer of soil over the broadcast seeds, along with high soil temperature and lack of sufficient moisture, are the possible factors enhancing infection by *R. solani*.

DISEASE MANAGEMENT

Symptom-wise, the disease appears to be an extension of damping-off, probably delayed by unfavourable soil conditions. The incidence of spear-rot can be minimized by proper nursery management practices, such as regulated watering of seedbeds and the adoption of good sowing techniques.

Seedling Wilt

Seedling wilt of bamboos has been observed in *Bambusa bambos* and *D. strictus* bareroot as well as container nurseries in Kerala (Mohanan 1994a,b). The disease affected seedlings that were 20-40-days old, and the disease severity recorded from most of the nurseries was low.

SYMPTOMS

Fig. 6 Seedling wilt of *B. bambos* caused by *R. solani;* note the development of epicormic roots

Initially, the infection occurs as water-soaked, greyish brown lesions on the seedling stem near ground level. The infection spreads upwards and causes lesions on leaf sheath, basal leaves and stem; the juvenile leaves are found almost free from infection. The infected areas on the stem become dark brown in colour and necrotic, which later coalesce and become constricted. Affected seedlings show symptoms of physiological wilting. Owing to loss of turgidity, the seedlings show rolling up of entire foliage from about 11 AM onwards, especially those which receive direct sunlight and less water. Bending and breaking up of the seedling stem occur at the constricted area and epicormic roots often develop from the lower portion of the cankered area. (Fig. 6).

CAUSAL ORGANISM

Rhizoctonia solani Kuhn state of *Thanatephorus cucumeris* (Frank) Donk. belonging to Anastomosis group AG2-2IV (Mohanan, 1994a).

Fig. 7 Diseased *B.bambos* seedlings with mycelaial webs of causal fungus

Fig. 8a A portion of the severely affected *B.bambos* seedbed

Fig. 8b Web blight *of D. asper* seedlings Palappilly, Thrissur, Kerala, India

ETIOLOGY

Rhizoctonia solani invade the root and stem tissues of seedlings and causes disintegration of the affected tissues; foliage is rarely affected. This indicates the specificity of the fungus on host tissues. Wilting is due to the partial breakdown of the conductive tissues of the seedlings. Specificity among the pathogen strains in the population, or even within the strain, has been reported to cause infection of aerial parts and underground tissues (Mohanan 2008).

DISEASE MANAGEMENT

Since seedling damage is usually low, control measures are seldom required. Drenching affected patches in the seedbeds with fungicide (Carboxin, 0.2% a.i.) can control the disease (Mohanan, 1994b).

Seedling Web Blight

Web blight of bamboo seedlings has been reported from India and the Philippines. In the Philippines, the disease has been reported as 'sheath blight' in *Bambusa blumeana* J.A. & J.H. Schultes seedlings in Iloilo (Dayan, 1988). In India, the disease was recorded in 23 seedbed nurseries in 15 localities in Kerala during 1987-1992 (Mohanan, 1994a,b,2008). The disease affected 20 to 30-day-old *Bambusa bambos, Dendrocalamus strictus, D. brandsii* and *Thyrsostachys siamensis* seedlings. Severity and spread of the infection largely depended on the local microclimatic conditions and the cultural practices adopted in the nursery. The overall disease severity index (DSI) ranged from 1.04 to 1.25 (max.4), and disease severity rating (DSR) was medium. Usually, the disease continues until the microclimatic conditions in the nursery are favourable for the growth and development of the fungus (90-120 days). Severe infection affects the availability of transplanting stocks. Recently, web blight has also been recorded on *Dendrocalamus asper* bareroot seedlings in a nursery at Palappilly, Thrissur, Kerala, India (Mohanan 2017 unpublished observation).

SYMPTOMS

Infection appears as water-soaked lesions on seedling stem near the soil level. Later, it spreads rapidly affecting the entire shoot, except one or two juvenile leaves. Infected stem and foliage become discoloured, greyish brown to dark brown, within 2-5 days of infection. Leaf necrosis is initiated either from the leaf tip and proceeding towards base of the leaf, or from the leaf margins towards midrib. The disease usually occurs in small patches of 5-10 seedlings in the seedbed, and the patches increase in size under favourable microclimatic conditions (Figs.7,8).

The infected patches in the seedbed merge and form large disease patches of up to 30 cm in diameter. Infected foliage shows shades of greyish brown, purplish grey and pastel green discolouration which later turn into necrotic areas. Complete necrosis often leads to withering of the foliage. Under high humidity, especially during the early morning hours, fungal mycelium, which arises from the soil, grows epiphytically over the affected seedlings. Yellowish brown sclerotia of the fungus develop on the decayed basal foliage and stem. The basidial stage of the fungus also appears on the basal part of the stem of the affected seedlings (Figs.9,10). The diseased seedlings are killed outright within 10-20 days of infection, leaving large circular to irregular patches of dried-up seedlings in the seedbeds.

Fig. 9 Sclerotia of *R. solani* on decaying seedling tissues

Fig. 10 Basidial stage of *R. solani* on the stem of diseased seedlings

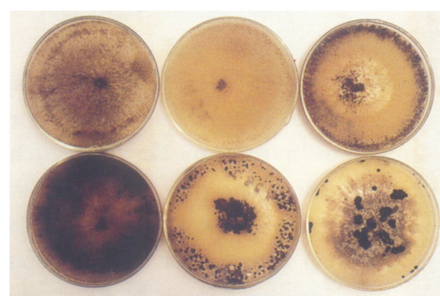


Fig. 11 *R. solani* bamboo isolates belonging to different anastomosis groups

CAUSAL ORGANISM

Rhizoctonia solani Kuhn state of *Thanatephorus cucumeris* (Frank) Donk. belonging to different Anastomosis groups – AG1-IA, AG1-IC, AG2-2IV (Fig.11) (Mohanan, 1994a).

ETIOLOGY

The fungus mycelium penetrates the seedling stem and leaf tissues. The infection spreads very rapidly within the seedlings through fast-growing mycelial strands. Spread of the disease between seedlings is mainly through physical contact of diseased foliage with healthy neighbouring seedlings. The fungus produce sclerotial as well as basidial stages which serve as inoculum for secondary infection. Heavy and incessant rain for a couple of days followed by overcast weather for 5-6 days form ideal conditions for the disease to become severe. Factors conducive to the incidence and spread of the disease are high density of seedlings, thick shading over the seedbeds and free water on seedlings.

DISEASE MANAGEMENT

Disease management measures suggested for the web blight of bamboo seedlings include sanitation, modification of nursery cultural practices, and use of fungicide (Mohanan, 1993a,1994a,b). Solarization of seedbeds and treatment of seed and seedbeds with antagonists like *Trichoderma harzianum* and *T. viride* are also recommended for reducing disease incidence (Mohanan, 1994a; 1995ab,2001). Sanitary measures recommended are disposal of leaf litter in the nursery and segregation of diseased seedlings soon after their detection to prevent the lateral spread of the disease. Regulation of shade over the nursery beds (no shade) and watering quantity (120 l per standard seedbed per day) and low seedling density (500 g seeds per standard seedbed) are suggested (Mohanan, 1995a; 2008). Application of fungicide (Carboxin 0.2% a.i.) after 7 and 21 days of seedling emergence is also recommended for controlling the disease (Mohanan, 1994a, 1995a,1996a).

Seedling Leaf Rust

Fig. 12 Severely affected 8-month-old *B. bambos* seedlings

Leaf rust of bamboo seedlings is widespread in nurseries in Kerala, India (Mohanan, 1990,1994a,b; 2008,2010). The disease has been recorded in 4 to 8 –month-old bareroot as well as container seedlings of *Bambusa bambos, Dendrocalamus brandisii, D. strictus, Pseudoxytenanthera ritcheyi* (Munro) Naithani, *Ochlandra travancorica* (Bedd.) Benth., *O. scriptoria* (Denst.)Fisch. and *Thyrsostachys siamensis*. Of these, *B. bambos* and *D. strictus* are the most susceptible species. The overall severity of infection was observed to be low; a severe rust infection was recorded during 1991 in 8-month-old *B. bambos* seedlings in a nursery in the northern part of Kerala which completely devastated seedlings in about 20% of the affected seedbeds (Fig.12). Leaf rust infection was also observed in *B. Bambos* and *B. blumeana* seedlings in a nursery at Kanchanaburi, Thailand (Mohanan 1995, unpublished observation). Recently, leaf rust infection was also recorded on *Dendrocalamus giganteus, D. asper, B. vulgaris*, and *B. balcooa* in a bamboo nursery at KFRI, Peechi, Thrissur, Kerala, India (Mohanan 2017 unpublished observation).

SYMPTOMS

Infection usually appears during August on mature leaves in the form of greyish brown minute flecks; usually, juvenile leaves are free from infection. The small flecks coalesce and form spindle-shaped dark brown pustules surrounded by a pale area. Mature leaves are more susceptible to infection than younger ones because density of uredinia is higher on the former. Uredinia, yellowish brown in colour, develop in the flecks on the lower surface of the leaves (Figs.13,14).

Development of uredinial sori occurs rarely on the upper surface of the leaves. In severe cases, the lower surface of the entire leaf lamina becomes covered with uredinia, imparting a yellowish brown colour. The rust infection continues until late May. Dark brown teliosori develop either in mature uredinial sori or separately on the adaxial surface in linear rows during January. Necrosis and withering of leaves occur from rust infection.

Fig. 13 a Leaf rust in *B. bambos* seedlings caused by *Kwelingia divina*

Fig. 13 b Leaf rust in *D. giganteus* seedlings caused by *Kwelingia divina*

CAUSAL ORGANISM

Kweilingia divina (Syd.) Buritica (=*Dasturella divina* (Syd.) Mundk. & Khes. (Mohanan, 1990,1994a,b, 2004,2005,2008,2010).

ETIOLOGY

Kweilingia divina (Syd.) Buritica is a heteroecious rust with uredinia and telia on bamboo, and pycnia and aecia on *Randia* spp. (= *Catunaragam*, Rubiaceae). Infection on *Randia* produces marked hypertrophy, and formation of witches'-broom following systemic invasion of the host. Aeciospores produced in chains from *Randia* infect bamboo leaves, causing leaf rust. The period of incubation ranges from 27 to 34 days. Urediospores produced on bamboo leaves spread the disease by secondary infection (Thirumalachar *et al*., 1947; Bakshi and Sujan Singh, 1967; Mohanan, 2010).

Fig. 14 Urediniospores of *Kwelingia divina*

DISEASE MANAGEMENT

Application of fungicide (Plantavax 0.01% a.i.) on rust affected seedbeds has been suggested to manage the disease (Mohanan, 1994a). Sulphur-based fungicides can also be employed (dusting).

Bipolaris Leaf Blight

Leaf blight affecting both young and mature leaves of 2 to 18-month-old seedlings, has been reported as widespread in bamboo nurseries in Kerala, India (Mohanan, 1990,1994a,b). The disease was recorded in bareroot and container seedlings of *Bambusa bambos, Dendrocalamus strictus, D. brandisii, D. membranaceus* Munro, *Phyllostachys pubescens* Mazel ex H. de Lehaie (=*P. heterocycla* var. *pubescens* (Mazel) Ohwi), *Thyrsostachys siamensis* and *Ochlandra wightii* Fisch. Disease severity, however, was low in all the nurseries. The infection appears in young seedlings during March-April and continues till planting out of seedlings.

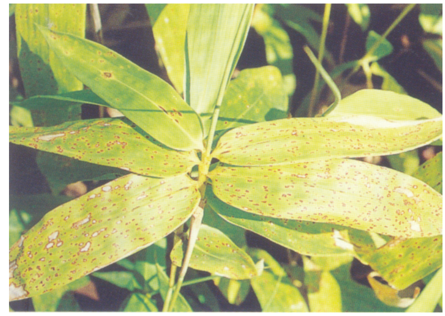


Fig. 15 *O. wightii* seedlings showing Bipolaris leaf infection

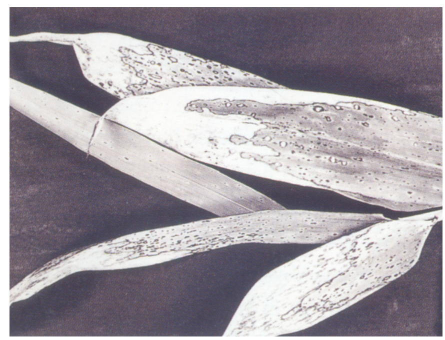


Fig. 16 Bipolaris leaf blight in *B. bambos*

SYMPTOMS

Minute, spindle-shaped, water-soaked lesions appear on both young and mature leaves, and later turn dark brown to dull violet, with greyish brown centres. Lesions coalesce and form large necrotic areas. Necrosis of leaf tissues starts from the leaf tip downwards or from the leaf margins towards the midrib. Usually, dark brown cross bands occur in the necrotic area (Figs.15,16).

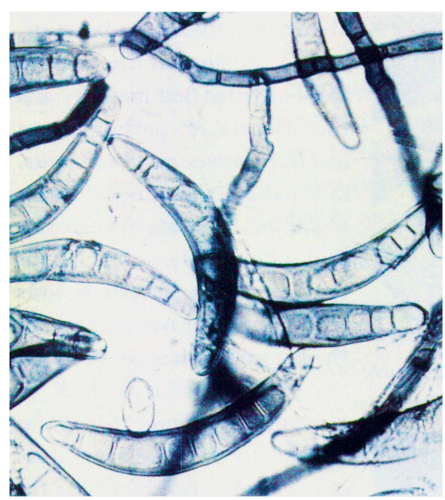


Fig. 17 Conidiophores and conidia of *Bipolaris maydis*

The colour of the lesions, spread, etc. vary depending on the bamboo species affected, leaf maturity and the associated pathogen. In *Dendrocalamus membranaceus*, *D. brandisii, D. strictus, Ochlandra wightii* and *Thyrsostachys siamensis* seedlings, Bipolaris leaf blight produces dark brown lesions with greyish brown centres. In *Phyllostachys pubescens* seedlings, the blight produces dark to blackish brown linear to irregular lesions on both young and mature leaves. Under high humidity, the lesions spread rapidly to the entire surface of the leaf lamina, and sporulation of the fungus occurs as dark grayish black mass in the necrotic tissues on the lower surface of leaf.

CAUSAL ORGANISMS

Three species of *Bipolaris* act as causal agents of the leaf blight: *Bipolaris maydis* (Nisikado & Miyake) Shoem. anamorph of *Cochliobolus heterostrophus* (Drech.) Drech. on *Dendrocalamus, Ochlandra* and *Thyrsostachys*; *B. urochloae* (Putterill) Shoem. on *Phyllostachys*; and *Bipolaris bambusae* Mohan. on *B. bambos* (Mohanan, 1994a,b, 1995d) (Figs.17,18).

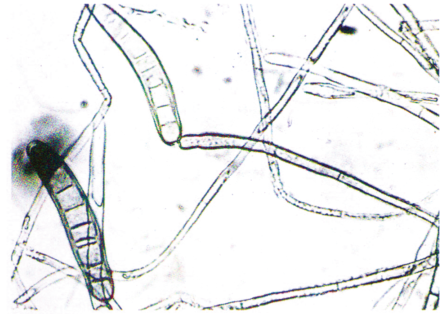


Fig. 18 Conidiophores and conidia of *Bipolaris urochloae*

ETIOLOGY

Fungal spores germinate on the leaf surface, and the infection hyphae enter the host through stomata, infecting epidermal and mesophyll cells. Proliferation of the fungus results in rupture of infected cells. The fungi thrive well under damp conditions, especially when cool nights alternate with hot days; the spores produced in the affected tissues are dispersed by water splash or in damp air currents.

DISEASE MANAGEMENT

Foliar drenching with Carbendazim (0.1% a.i.) is effective in controlling the disease (Mohanan, 1994a,b).

Exserohilum Leaf Spot

Leaf spot disease has been reported in 2 to 8-month-old bareroot and container seedlings of *Bambusa bambos, Dendrocalamus strictus* and *Phyllostachys pubescens* in India (Bhat et al., 1989; Harsh et al.,1989; Mohanan, 1990, 1994a,b,1997). Average disease incidence in *B. bambos* nursery in Karnataka State has been recorded as 39%, while in *B.bambos*, *P. pubescens* and *D. strictus* nurseries in Kerala State, the infection varied from low (18%) to severe (76%) and caused defoliation (Mohanan, 1994a,1997,2008).

SYMPTOMS

Minute greyish brown, water-soaked lesions appear on mature leaves. Lesions are longitudinally distributed over the leaf lamina and measure 2-4 x 1-2 mm. Under warm-humid conditions, the individual lesions coalesce to form large spindle-shaped to irregular reddish to dark brown lesions with grayish white centres and dark to chocolate brown margins. (Fig. 19). The diseased areas become necrotic and often give a blighted appearance; under high humidity, sporulation of the fungus occurs as greyish black spore mass on the adaxial surface of the necrotic lesions. Severe infection leads to spread of lesions to the entire leaf lamina, followed by withering of affected leaves and premature defoliation.

CAUSAL ORGANISM

Two species of *Exserohilum* have been reported as the causal agents: *Exserohilum rostratum* (Drech.) Leonard & Suggs (= *Exserohilum halodes* (Drech.) Leonard & Suggs); *Exserohilum holmii* (Luttr.) Arx. anamorph of *Setosphaeria holmii* (Luttr.) Leonard & Suggs;

Fig. 19 Exserohilum leaf spot in *D. strictus*

ETIOLOGY

The pathogen enters the host through stomata and infects epidermal and mesophyll tissues. Proliferation of fungal tissues results in rupture of the infected cells. The fungi thrive well under warm-humid conditions. The conidia produced in the necrotic tissues on the lower leaf surface serve as the inoculums for secondary infection.

Fig. 20 Conidiophores and conidia of *Exserohilum rostratum*

DISEASE MANAGEMENT

Since the pathogen causes withering and premature defoliation only under conducive microclimatic conditions, the disease may not pose problems in raising bamboo seedlings. Foliar drenching with fungicides Carbendazim (0.1% a.i.) or Mancozeb (0.2% a.i.) is suggested for checking the infection (Mohanan, 1994a,b).

Dactylaria Leaf Spot

Dactylaria leaf spot is widespread in bamboo nurseries in Kerala, India. The disease was recorded in 1 to 10-month-old bareroot and container seedlings of *Bambusa bambos* and *Dendrocalamus strictus* in most nurseries raised during 1987-92, and seedlings of *D. brandisii, Thyrsostachys siamensis* and *Ochlandra wightii* during 1991-92 (Mohanan, 1994b). *B. bambos* and *D. strictus* were the most susceptible species but disease incidence was generally low.

SYMPTOMS

Minute, water-soaked lesions occur near the leaf tips. They coalesce and spread to form large circular to irregular greyish brown areas with greyish white centres and dark brown margins

(Fig. 21). Withering of leaf tips occurs in severe infection. Under high humidity, the causal fungus sporulates on the necrotic leaf spots (Fig. 22).

Fig. 21 Dactylaria leaf spot in *B. bambos* seedlings

CAUSAL ORGANISM

Dactylaria bambusina Mohan (Mohanan, 1994b,1995d).

ETIOLOGY

The fungus enters the host through stomata and infects epidermal and mesophyll tissues. Proliferation of fungal hyphae results in rupture of the infected cells. The fungus thrives well under warm-humid conditions. Conidia produced on the conidiophores in the necrotic tissues serve as the inoculum for secondary infection.

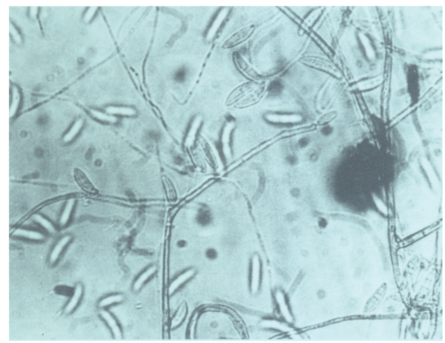


Fig. 22 Conidiophores and conidia of *Dactylaria bambusina*

DISEASE MANAGEMENT

Since damage is usually slight, control measure is seldom required. Removal of infected fallen leaves from the seedbeds or containers may help to limit the potential inoculums.

Colletotrichum Leaf Spot

Colletotrichum leaf spot was recorded in 15-day-old to 10-month-old bareroot and container seedlings of *Bambusa bambos* and *Dendrocalamus strictus* in bamboo nurseries in Kerala, India, during 1988-92 (Mohanan, 1994a,b). Disease severity was low in all nurseries. Colletotrichum leaf spots were often observed intermixed with other leaf infections such as those caused by *Dactylaria bambusiana, Bipolaris maydis* and *Bipolaris bambusae.* Colletotrichum leaf spot has also been recorded on *Phyllostachys pubescens, Phyllostachys* spp., *Bambusa vulgaris* seedlings in Zhejiang and Guangdong Provinces in China (Zhang 2000). The disease was also observed in *B. bambos* and *B. blumeana* seedlings in a nursery at Kanchanaburi, Thailand (Mohanan, 1995, unpublished observation). Recently, the disease has been recorded in *B. bambos, B. balcooa,* and *D. asper* seedlings in bamboo nurseries at Peechi and Palappilly, Thrissur, Kerala State, India (Mohanan 2017 unpublished observation)

SYMPTOMS

Minute, water-soaked lesions on the upper surface of mature leaves, and later spread to form large reddish brown areas, linear to irregular in shape, often concentrated either at the leaf base or at the margins and tips (Fig. 23). The discoloured areas later become necrotic. Merging of

Fig. 23 Leaf spot of *B. bambos* seedlings caused by *C. gloeosporioides*

lesions with those caused by other leaf infecting fungi sometimes occurs. Infection also appears on leaf sheaths and petioles of bamboo seedlings.

CAUSAL ORGANISM

Colletotrichum gloeosporioides (Penz.) Penz.& Sacc. and its teleomorph *Glomerella cingulata* (Stonem.) Spauld. & Schrenk (Mohanan, 1994a,b); *Colletotrichum septorioides* Sacc. (Zhang 2000) are the causal organisms.

ETIOLOGY

The pathogen enters the host through stomata as well as by direct penetration through the epidermis. Proliferation of hyphae results in rupture of infected cells. The fungus produces acervuli and ascocarps in the necrotic tissues. Damp, humid conditions favour the spread of the fungus in the infected tissues as well as the production of spores. Splashed water or air-borne conidia and ascospores serve as inoculum for secondary infection.

DISEASE MANAGEMENT

Since this leaf spot is not very damaging, disease management measures are seldom required. Foliar spray with fungicides - Mancozeb (0.1% a.i.) or Carbendazim (0.1% a.i.) - can reduce the incidence and spread of the disease.

Curvularia Leaf spot

Curvularia leaf spot has been recorded in 1 to 2-month-old seedlings of *Bambusa bambos* in bareroot nurseries and *B. vulgaris* Schrad. ex Wendl., *Dendrocalamus longispathus* Kurz., *Thyrsostachys oliveri* Gamble and *Ochlandra scriptoria* in vegetative propagation nurseries in Kerala, India (Mohanan, 1994a,b). Disease severity was observed to be low in *B. bambos, T.oliveri* and *O. scriptoria*. Severe infection was recorded only in vegetatively propagated shoots of *D. longispathus*.

Fig. 24 *B. vulgaris* shoot affected with *C. pallescens*

SYMPTOMS

Water-soaked lesions with yellow haloes appear on young and mature leaves. The lesions coalesce and form circular to irregular greyish black spots with dark yellow haloes. The lesions develop near the leaf tips and margins, and later coalesce to form large necrotic areas. The affected leaf tips roll in and dry up (Fig. 24).

CAUSAL ORGANISM

Curvularia pallescens Boed., anamorph of *Cochliobolus pallescens* (Tsuda & Veyama) Sivan. (Mohanan, 1994a,b) is the causal agent.

ETIOLOGY

Curvularia pallescens is a weak pathogen and it enters the host tissues through stomata or injury. Proliferation of hyphae occurs within the cell and intercellular spaces, causing rupture of the infected cells. The fungus thrives well in damp conditions and produces conidia in the affected necrotic tissues as inoculum for further spread of the disease.

DISEASE MANAGEMENT

As the leaf spot is of minor significance, management measures are seldom warranted. Foliar spray of Mancozeb (0.1% a.i.) can reduce the spread of infection.

Seedling Leaf Tip Blight

Seedling leaf tip blight has been reported in 1 to 3-month-old bareroot and container seedlings of *Bambusa bambos* and *Dendrocalamus strictus* in nurseries in Kerala, India. The disease was observed during the hot, dry period (April-May) in nurseries affected by water scarcity.

SYMPTOMS

Minute, greyish brown, linear to spindle-shaped lesions appear near the margin and tip of both young and mature leaves. The lesions coalesce and cause necrosis of the affected tissues (Fig. 25). Infection spreads downwards under warm-humid conditions. Severe infection leads to tip blight and withering of leaves.

Fig. 25 Leaf tip blight of *B. bamoos* seedlings caused by *A. alternata*

CAUSAL ORGANISM

Alternaria alternata (Fr.) Keissler (Mohanan, 1994a,b).

ETIOLOGY

Alternaria alternata is a weak pathogen which enters the seedling leaf tissues through stomata or injury. The fungal hyphae proliferate in the affected cells and the infected cells rupture. Under warm-humid conditions, the fungus produces conidia in the necrotic tissues which serve as the source of secondary infection.

DISEASE MANAGEMENT

As seedlings denied adequate water are the ones usually affected by the disease, proper nursery management practices can prevent the disease incidence.

Seedling Rhizome Rot

Seedling rhizome rot was recorded in 10 to 18-month-old container seedlings of *Bambusa bambos* in Kerala, India during 1987-89 (Mohanan, 1994a,b). The disease was observed during May-June and 4-5% seedling mortality was recorded.

SYMPTOMS

The above-ground symptoms of the disease manifest as general wilting of seedlings, rolling up of juvenile foliage, yellowing of more mature leaves and finally premature defoliation. The affected seedling shows dark yellowish brown discolouration and decay of the growing portion of the rhizome, especially around the rhizome buds. Usually, the fleshy rhizome buds become discoloured and decayed, and later the infection spreads to the entire rhizome of the seedling (Fig. 26). The diseased seedling is killed outright.

Fig. 26 Rhizome rot in 18 month-old *B. bamoos* seedlings caused by *R. hibisci*

CAUSAL ORGANISM

Rhizostilbella hibisci (Pat.) Seifert state of *Nectria mauritiicola* (Henn.) Seifert & Samuels (Fig. 27) (Mohanan, 1990, 1994a,b,2008).

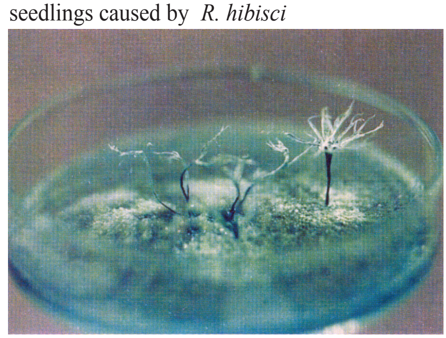


Fig. 27 Petri dish culture of *R. hibisci*

ETIOLOGY

The fungus is a soil-borne wound parasite, which enters the rhizome tissues through mechanical injuries caused to roots and rhizomes during transplanting in containers. The fungus proliferates on the roots and the fleshy rhizome buds as well as on other tissues. Factors favourable for the incidence of disease are mechanical wounds on roots and rhizome, and water-logging in the containers.

DISEASE MANAGEMENT

Since the rhizome rot is uncommon in bamboo nurseries, it is of minor significance. The disease can be managed by adopting good nursery management practices and also proper care during transplanting the seedlings from seedbeds to containers to avoid injuries to the seedling rhizome and roots.

Seedling Leaf striping and Stunting

The disease was recorded in 4 to 14-month-old container and bareroot seedlings of *Bambusa bambos* during 1990-91 in Kerala, India (Mohanan, 1994a,b,2008). The disease incidence was low in all nurseries surveyed. In a nursery at Kothamangalam Forest Division, about 6% of planting stocks were detected as carrying the infection and all the affected seedlings had to be discarded.

SYMPTOMS

Pale yellowish to greenish stripes occur on both young and mature leaves. Striping of leaves also occurs in the new shoots developed from the rhizome (Fig. 28). Often the individual stripes merge together and the leaves become greenish white and leathery. Affected seedlings show stunted growth, and their stem becomes thin, wiry, fragile, pendulous and easily breakable. The disease shows the systemic nature of infection. New shoots developed also show similar disease symptoms

Fig. 28 *B. bamoos* container seedlings affected with leaf striping and stunting

CAUSAL ORGANISM

The pathogen is suspected to be a virus (Mohanan, 1994a,b).

ETIOLOGY

The etiology of bamboo seedling leaf striping and stunting disease has not been studied. Usually, the virus that cause leaf striping, seedling stunting and leaf mosaic diseases are transmitted mechanically, through seeds or vegetative propagules. The incidence of disease in both bareroot and container nursery shows the possibility of seed transmission of the causal agent. Vectors like insects and nematodes may also play a role in the incidence and spread of the infection.

DISEASE MANAGEMENT

Since, the disease is systemic and the rhizome of the affected seedlings produces only diseased shoots, the diseased seedlings should be destroyed.

4. DISEASES IN BAMBOO STANDS

Bamboos in plantations, village groves and natural stands (Fig.29) are vulnerable to various diseases at different stages of growth. A large number of diseases affecting the roots, rhizomes, culms, branches and minor branches, foliage, culm sheaths and inflorescences have been reported from various countries in the region, viz. Japan (Hino 1958, 1961; Hashimoto et al. 2005, 2008, 2011), China (Ding et al. 2000, 2001; Dong et al. 2001; Liu et al. 2001; Xu et al. 2006, 2007; Xie et al. 2006; Zhang 2000; Zhou et al. 2011), Taiwan-China (Hsieh 1984,1987, Lo et al. 1966; Lin et al 1977,1979,1993), India (Shukla et al. 1988; Gupta et al. 1990; Mohanan 1997, 2004,2008,2011; Mohanan and Liese 1990; Jamaluddin et al. 1996, 1999; Sharada et al. 2013; Bengyella et al. 2015), Bangladesh (Boa 1987a,b; Boa and Brady, 1987; Boa and Rahman 1983), Malaysia (Overeem 1926; Azmy and Maziah 1990), the Philippines (Dayan 1988; Caasi et al. 1999), Thailand (Chalermpongse et al. 1984; Liu et al. 2011), Pakistan (Khan 1960, 1961), Myanmar (Hansen 1963), Vietnam (Mao 1993). However, many such reports lack information on disease symptoms, etiology, severity of disease and its relative economic importance. More than 580 fungi, five bacteria, and three phytoplasmas, one bacteria-like organism and two viruses have been reported to be associated with various diseases and disorders of bamboo stands in Asia (Appendices I, II). The diseases and disorders, on which some descriptive information is available, are arranged on the basis of plant parts affected.

Fig. 29 *B. bamoos* natural stands in Kerala, India

Diseases of Culms and Foliage

The woody stems arising from woody root stocks or rhizomes are called culms. A young shoot is a new growth of the distal end a pachymorph rhizome or of a lateral bud of a leptomorph rhizome. The buds on rhizome nodes enlarge and tender shoots emerge as pointed cones, completely covered with imbricate sheaths. Since, there is no terminal bud in a culm, growth is achieved by the elongation of internodes. The lowest internode near the ground expands first, and the top-most one last. The newly emerged tender shoots or culms (20-30 cm high) are covered by sheaths and no internode is seen outside. The new culms grow rapidly and reach their full height within 60-90 days depending on the species, clump vigour, and edaphic and microclimatic conditions.

A bamboo culm is divided by horizontal partitions (nodes). Most culms have cylindrical and hollow internodes. Branches develop while the culm is still growing or after the culm reaches its full height. Foliage develops later. Newly emerging and growing supple culms are generally susceptible to diseases. Diseases that affect culms include: rot of emerging and growing culm, culm brown rot, culm purple blotch, culm base rot, bamboo blight, bamboo top blight, branch die-back, witches-broom, little leaf, thread blight, mosaic, wilt, rust, smut, sooty stripe, culm stain and necrosis of culm internodes.

Foliage diseases include: foliage blight, leaf rust, leaf spot and culm sheath spot. Usually, foliage diseases reduce the photosynthetic area of the foliage and impair food manufacturing capacity. Quite a large number of fungi have been reported as associated with these diseases, but only a few foliage diseases have been recorded as potentially serious. Many of the foliage diseases are economically insignificant. Leaf spots caused by various fungi have been reported in different species of bamboos. However, only a few leaf spot diseases are treated specifically while others are described as miscellaneous leaf spots.

Rot of Emerging Culm

This disease has been reported in various bamboo species in Bangladesh (Banik 1984; Boa and Rahman 1987), in India (Mohanan 1990, 1993b, 1994a,b,1995a,b, 2008) and in Pakistan (Sheikh et al. 1978). It has been recorded in *Bambusa bambos, B. tulda Roxb., B, vulgaris,* and B. *balcooa* Roxb. in village groves in Bangladesh. Rot of emerging culms was also observed in different species of bamboos in China, the Philippines and Thailand (Mohanan 1995, unpublished observation). In Pakistan, large-scale mortality of emerging shoots in *Dendrocalamus strictus* stands has been reported. In Kerala and Karnataka States, India, the disease has been recorded on *B. balcooa, B. bambos, B. polymorpha* Munro*, B. vulgaris, D. longispathus* Kurz*, D. strictus, Ochlandra travancorica, O. scriptoria* and *Thyrsostachys oliveri* stands. The disease is widespread in Kerala, with the incidence and mortality of affected culms varying from locality to locality depending upon the microclimate and the bamboo species. Severe infection and mortality of emerging culm were recorded in bamboo stands situated in low-lying, high-rainfall areas. Among the bamboo species, the highest percent mortality of emerging culms (34%) was recorded in *B. bambos* natural stands in northern parts of Kerala. The lowest percent disease incidence (3.5-4.5%) and culm mortality were recorded in *Thyrsostachys oliveri* plantations (Mohanan 1994b, 2008). Recently, the disease has also been recorded in Karnataka State, India on *B. balcooa* and *D. asper* with a disease severity ranges from 50% to 100% (Sharada et al. 2013).

SYMPTOMS

Greyish brown lesions surrounded by dark brown margins occur on the outermost culm sheath of the emerging culms (15-20 cm in height), near the soil level. The emerging culm at this stage is completely covered by sheaths. Lesions also develop on the tips and margins of culm sheaths. These lesions spread rapidly, become necrotic and entirely cover outer culm sheaths. Since, at this stage, the culm sheaths are telescopically arranged tightly one over the other, the infection spreads very fast from the outermost sheath which is in contact with the soil, to the inner sheaths. As the tissues of emerging shoots are very tender and succulent, the infection spreads rapidly, and the tissues become discoloured, decay and give off a strong smell of molasses (Figs. 30-32). Usually, severe infection and mortality occur at this phase of growth, which is normally slow.

The disease spreads to the entire culm, hindering its further development and causing total decay (Fig.33).

CAUSAL ORGANISMS

Fusarium fujikuroi Nirenberg (= *Fusarium moniliforme* var. *intermedium* Neish & Legget) was the pathogen associated with the culm disease in India (Mohanan 1994a,b, 2008). *Fusarium fujikuroi* (= *F. verticillioides*) and *Fusarium oxysporum* Schltdl. were associated with *B. balcooa* and *D. asper* (Sharada et al. 2013). No causal agent was detected from the rotting culms in Bangladesh (Banik 1984). *Rhizoctonia* sp. was reported as the associated fungus of *D.strictus* in Pakisthan (Sheikh et al. 1978) and *Ochlandra* spp. in India (Mohanan 1990; 2002).

Fig.30 *Rot of emerging culms of B. bamoos* caused by *Fusarium fugikuroi*

Fig.31 *Rot of emerging culms of D. longispathus*

Fig.32 Rot of internodal tissues of *B. bamboos*

ETIOLOGY

The fungus enters the host tissue through injury caused either mechanically during culm emergence through hard soil or by the mining insects and wild animals like monkeys, porcupines and squirrels. The fungal hyphae proliferate in the infected succulent tissues and spread towards the innermost undifferentiated culm tissue. Browning and rot occur in the outermost four to seven culm sheaths and undifferentiated internodal tissue. The discolouration also spreads from the shoot tip downwards. However, this type of infection does not spread to the inner tissues, but causes browning and necrosis on the margins and tips of two to three outer culm sheaths. In many cases, apical portions of sheaths remain free from discolouration. Factors favouring the infection include heavy rainfall during and after the emergence of culms, water logging around the clump, mining insect activity and poor stand management.

DISEASE MANAGEMENT

Rot of emerging culms is a disease that adversely affects the culm production in bamboo stands in high-rainfall areas in Kerala and Karnataka States in India (Mohanan

1996). Cultural control measures, such as removal of debris around the clumps before the onset of monsoon, light burning of the debris over the ground, loosening the soil around the clump before culm emergence, and pruning and removal of the branches from the basal part of culms during March-April, are suggested. To avoid mechanical damage to the emerging culms by cattle and wild animals, clump tending and clump cleaning operations are recommended only in well-protected stands (Mohanan 1995a,1996, 1997). Biocontrol experiments using different species of *Trichoderma* and leaf and bark extracts of *Cleistanthus collinus* and *Prosopis juliflora* were screened against *Fusarium oxysporum* and *F. fujikuroi* and promising results obtained (Sharada et al. 2013).

Fig.33 Diseased and dead emerging culms of *B. bamboos.* Note the sporulation of the fungus

Rot of Growing Culms

Rot of growing bamboo culms has been reported in bamboo plantations and natural stands in Kerala, India (Mohanan 1990, 1992, 1994a,b,1997), and in *Phyllostachys pubescens* stands in China (Anonymous 1982). In India, the disease has been recorded on *Bambusa balcooa*, *B. bambos, B. polymorpha, Dendrocalamus brandisii, D longtispathus, D. strictus* and *Thyrsostachys oliveri* stands in Kerala. In bamboo plantations and natural stands in various localities in the State, the disease incidence varied from 3% to 25% during 1987-91. High incidence of disease was recorded in young (2 to 3-year-old) plantations; *B. bambos, B. polymorpha* and *D.strictus* were severely affected and adversely affect the culm production and stand productivity (Mohanan 1996). Recently, the disease has been recorded on *B. balcooa* and *D. asper* stands in Karnataka (Sharada et al. 2013).

Fig.34 Rot of growing clums of *D. strictus* caused by *F. equseti*

SYMPTOMS

Water-soaked, greyish brown, spindle-shaped lesions usually occur at the base of culm sheaths where they are attached to the nodes. Injury on culm sheaths and culm at the nodal region, made by the sap sucking insect *Purohitha cervina* Distant (Fulgoridae), predisposes the plant to fungal infection. Sap oozes out from the pin-prick wounds made by the insect, and infection develops in and around these wounds. The lesions coalesce and spread to form dark greyish brown, irregular, necrotic areas with dark brown margins; the infection often spreads to the entire culm sheath and to the tissues (branch buds, culm node and internodal tissues) beneath the culm sheath. Since young culms are tender and succulent and grow rapidly, rot of the affected tissues progresses from one internode to another at a fast rate. Severely infected culms cease to grow, become shrivelled and decayed, and fall off (Figs. 34-36).

Fig.35 Severely affected *T. oliveri* culms

In many instances, diseased culms fall off before they complete their elongation phase. Medium to severe infection causes various culm deformities, including shrivelling and necrosis of internodes, twisting and bending of culms owing to severe necrosis on one side, partial development of branches, and breaking of culm at the point of infection. Infected culm sheaths become closely attached to the internodes and do not fall off even at the time of branch development. Infection on branch buds hinders the development of normal branches from the nodes.

Fig.36 Rot of growing culm of *B. bambos*

CAUSAL ORGANISMS

Fusarium equiseti (Corda) Sacc. (Mohanan 1994a,b, 2008); *Fusarium fujikuroi* Nirenberg (= *Fusarium moniliforme* Sheldon) (Anonymous 1982); *Fusarium oxysporum* affecting *B. balcooa* and *F. fujikuroi* affecting *Dendrocalamus asper* (Sharada et al. 2013) are the causal organisms reported.

ETIOLOGY

The fungus enters the host tissue through wounds on the culm and culm sheaths made by the sap sucking insect *Purohitha cervina*. Since bamboo culms lack terminal growth and all culm internodes are arranged telescopically one above the other, wounds made by the insect on the outermost culm sheath also affect a few inner culm sheaths and unexpanded culm internodes. Infection spreads to the succulent tissues of the expanding internodes and causes necrosis of affected tissues. The causal fungus sporulates profusely on the necrotic tissues of culm internodes and sheaths. Build-up of the insect population at the culm elongation phase and the subsequent mechanical dispersal of fungal spores were found responsible for the spread of the disease on the individual culm, and among culms and clumps.

DISEASE MANAGEMENT

Since the incidence and severity of disease can be correlated with the heavy build-up of sap sucking insect (*Purohitha cervina*) population in plantations and natural stands during the culm elongation phase, disease management measures against should be directed towards checking such build-up of insect population. Secondary spread of the infection can be controlled by applying the fungicides Carbendazim (0.2% a.i.) or Mancozeb (0.2% a.i), or the insecticide Monocrotophos (0.05% a.i.).

Pterulicium Culm Rot

Emerging culm rot caused by *Pterulicium xylogenum* has been recorded on *Bambusa vulgaris* var. *waminii*, *Dendrocalamus giganteus* and *Gigantochloa* sp. from bambusetum and botanical garden of Forest Research Institute, Dehradun, India during June 2000 (Harsh et al. 2000). Among the bamboo species, the highest percent mortality of emerging culms (45%) was recorded in *B. vulgaris* var. *waminii* followed by 36% culm mortality in *Gigantochloa* sp. Recently, the disease has also been recorded on edible shoots of *Melocanna baccifera* from Tripura, India (Sandeep, 2010). The disease was also recorded on *Dendrocalamus giganteus* (Fig. 37 a,b), *B. pallida, D. longispicula, D. asper, B. tulda* in bambusetum of Kerala Forest Research Institute Field Station at Palappilly, Thrissur, Kerala (Mohanan 2017 unpublished observation). Culms produced during May-June were usually found not affected by the disease. Whereas, culms emerging during late August were found severely affected and killed (Mohanan, 2017 unpublished observation).

Fig.37 a Rot of emerging culm of *D. giganteus* at KFRI Bambusetum, India

Fig.37 b Rot of emerging culm of *D. giganteus* at KFRI Bambusetum, India

SYMPTOMS

Profuse white mycelial growth occurs at the base of clumps over leaf litter at the start of rainy season. Soon, circular to fan-shaped white mycelial patches (subiculum) developed over the culm sheath. Necrotic lesions also appeared on the affected culms. Needle-shaped white to dirty-white, branched fruiting bodies are produced from the subiculum with a disc-like attachment at the base from the affected culm surface. Curling of internodes and shortening of nodes resulting into deformity were the prominent features of the disease. Mortality of the culms started with drying of the culms from tip downwards. Emerging young supple culms are affected and killed by the pathogen. The curling of tips of emerging shoots occur at later stages of growth arresting their further development suggested that the infection is carried along with the growing tips. The fungal mycelium was observed growing inside the pith cavities of affected culms. The fungal mycelium traversing the tissue of the culm and degradation of fibre wall were apparent in the microscopic sections.

CAUSAL ORGANISM

Pterulicium xylogenum (Berk. & Broome) Corner was the pathogen associated with the culm disease. *P. xylogenum* (= *Clavaria xylogena* Berk. & Broome), is basically a saprotroph, which occurs under favourable conditions, has acted as necrotrophic parasite. The fungus has earlier been reported on dead bamboo culms, dead leaf sheaths and trunks of various palms from Sri Lanka , Malaysia, the Philippines (Corner, 1950) and on rotting bamboo culms from China (Zhishu et al. 1985). Earlier, *Clavaria* sp., *C. zollingeri* and *C. vermicularius* have also been recorded on decaying forest litter including bamboos (Mohanan, 1997,2011).

ETIOLOGY

The fungus occurs in the decaying litter as saprotroph and the fungal hyphae proliferate in the infected succulent culm tissues. Fruit bodies of the fungus occur on the affected culms and possible aerial spread of the disease is suggested through airborne spores. The spread of fungus on leaf litter at the base of culms can be considered as a means of its survival and lateral spread. The old infected culms also acted in similar way during the favourable season. The disease is favoured by relative humidity (69-88%) and temperature (mean 21-28^{0}C). Factors favouring for the infection and spread include heavy rainfall during and after the emergence of culms.

DISEASE MANAGEMENT

Pterulicium culm rot is a disease that adversely affects the culm production in different species of bamboos. The causal fungus reported is an opportunist pathogen which survives in bamboo litter saprophytically. Hence, disease management measures suggested include cleaning the litter from the base of clumps before the onset of monsoon (Mohanan, 2017). The disease can be managed by spraying and drenching with a mixture of fungicide, Copper oxychloride and Carbendazim (0.05% (a.i.) (Harsh et al. 2000).

Culm Brown Rot

This disease has been reported on *Phyllostachys viridis* (Young) McCl. and *P.viridis f. hauzeauana* (McCl.) Chu et Chao (= *P. sulphurea* (Carr.) A. et C. Riv. cvs. *viridis* and *houzeau*) (Lan 1980), *Phyllostachys aureosulcata* (Zhang 2000), and *Phyllostachys glauca* stands in China (Zhou et al. 2011). The disease was first recorded in 1974 in *Phyllostachys* stands in Nanjing, China, and at present it is widespread in Jiangsu and Zhejiang Provinces Zhang, 2000; Zhou et al. 2011). Incidence of disease and mortality of culms in different localities ranged from 9% to 17% during 1974-79, with an average annual culm mortality of 10%. Recently, severe infection was recorded on *Phyllostachys glauca* stands in Nanjing, China (Zhou et al. 2011).

SYMPTOMS

Pale yellow spots appear on the lower part of the culm. The spots spread vertically and the upward extension is fast, forming violet-brown to black-brown streaks along the culm. Later, infection spreads all over the basal part of the culm, leading to shrivelling and death of the affected culm (Fig.38). Infection develops in early May, streaks form in July and by the end of October, the affected culm starts shrivelling and dies.

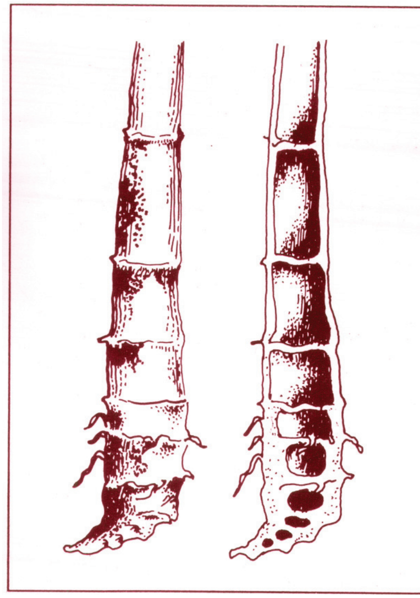


Fig.38 *P. Viridis* culms affected by brown rot (Source : Lan 1980)

CAUSAL ORGANISM

Fusarium solani (Mart.) Sacc. (Lan 1980; Hsiung 1981) and *Fusarium equiseti* (Corda) Sacc. were the pathogens associated with the disease (Zhou et al. 2011).

ETIOLOGY

The fungus invades the host tissue through wounds. Optimum temperature for fungal spore germination and hyphal growth is recorded as 25-28^{0}C. Artificial inoculation trials showed *P. pubescens, P. bambusoides, P. glauca, P. praecox, P. nuda, P. angusta, P. nigra, P. nigra 'henonis'*, and *Brachystchyum densiflorum* are highly susceptible to the disease (Zhang 2000).

DISEASE MANAGEMENT

Although this disease appears to be an important one and widespread in Jiangsu and Zhejiang Provinces, no control measure has so far been suggested.

Culm Base Rot

The disease, also known as 'Moso bamboo foot rot' or 'Moso basal culm rot' has been reported on *Phyllostachys pubescens* in Jiangsu, Zhejiang, Anhui, Henan, Hebei, and Sichuan Provinces of China (Chen 1982; Xia 1988; Zhang 1989, 2000) and Fujian Province, China (Zhang et al. 1999). The disease was first recorded in Zhejiang in 1973 and then in Jiangsu, Anhui Provinces in 1976. The disease is also known as 'Moso basal culm disease'. The disease occurs mainly in low-lying, water-logged areas and attacks newly sprouted bamboo culms. Disease incidence and degree of damage were closely related to the amount of precipitation during the period of shoot emergence. The disease affects the bamboo culm production in Zhejiang and Jiangsu Provinces in China (Zhang 2000).

SYMPTOMS

Browning and necrosis of the culm tissue occur at the base of the culms, later resulting in rot of the basal part of the growing and developed culms. Culm withering and dying occurs in severe cases. Profuse sporulation of the associated fungi on the affected necrotic tissues was observed (Xia 1988).

CAUSAL ORGANISMS

Arthrinium phaeospermum (Corda) M.B. Ellis (Zhang 2000). Earlier, different microorganisms - *Alternaria alternata* (Fr.) Keissler (= *Alternaria* tenuis Nees), *Arthrinium* sp. and two unidentified fungi (Xia 1988), *Fusarium oxysporum*, *Fusarium fujikuroi (= F. moniliforme*) - were also recorded as associated with the culm base rot (Chen 1982; Zhang 1989).

ETIOLOGY

Etiology of the disease has not been well studied. Infection occurs for about half a month during sprouting. High precipitation during shoot emergence favours the development of infection as well as spread of the disease. Optimum temperature for the fungal pathogens are 24 to 28^{0}C. Severe infection and damage occur in high rainfall areas (Zhang 2000)

DISEASE MANAGEMENT

The disease management measures recommended are to make bamboo stand more healthy and vigorous, beside good drainage and soil sterilization (Zhang 2000). Application of fungicides - Bayleton (Triadimefon) 20% emulsion, Kitazin 40% emulsion or Thiophanate methyl 70% wettable powder – on affected culms is suggested for disease control (Zhang 1989). Field tests with systemic fungicides, in Fujian Province, China revealed 90% control of the disease by spraying Thiophnate-methyl, 87% control by Triademefon and 81% by spraying Kitazine (iprobenfos). Cultivating and selecting large strong bamboo shoots to enable rapid growth to 2 m in height before the initial infection occurs helped to avoid infection. Peeling off the basilar sheath of bamboo shoots also reduced disease development. Integrated use of these control methods enabled up to 93% disease control during 1994 (Zhang et al. 1999).

Culm Purple Blotch

The disease has been reported on *Phyllostachys viridis* (= *P. sulphurea*) in Zhejiang Province, China (Anonymous 1987; Chen 1989; Yu and Chen 1990). Recently, the disease has been recorded on *Phyllostachys pubescens, P. viridis P. dulcis* and *P. praecox* in the north-western part of Zhejiang (Zhang 2000). The disease usually occurs during April-May, and has been recorded on 2 to 3-year-old bamboos, causing death of the affected culms. In dense bamboo stands in mountain foothills, under high temperature and precipitation, very high incidence of the disease has been recorded.

SYMPTOMS

Pale yellow mottled spots and stripes occur on the basal part of the culm, and later spread around the culm. The colour of the spots changes to purple brown, with dark shades of colour on basal part of the culm. The leaves of the diseased culms turn yellow and fall off prematurely; the minor branches wither and die; and finally, the severely infected culms die during the same year, while the moderately infected ones die within 2-3 years.

CAUSAL ORGANISM

Fusarium stilboides Woolen (Yu and Chen 1990).

ETIOLOGY

The causal fungus is soil-borne. It infects through wounds on roots, rhizomes and basal parts of culms during the rainy season. Warm-humid conditions, high precipitation, and water accumulation around the culms favour the incidence and spread of the disease. During July-August, when the ambient temperature becomes high, the disease disappears rapidly.

DISEASE MANAGEMENT

Silvicultural measures suggested to manage the disease include: timely culm tending, thickening of the soil around the clump and intermediate digging of bamboo shoots. In winter, along with tending, application of limestone powder (dusting) on the floor around the clumps and covering with a thin layer (10 cm) of soil are recommended (Yu and Chen 1990).

Bamboo Blight

Bamboo blight has been reported in Bangladesh and in India. The disease has been recorded as affecting the village groves of *Bambusa bambos*, *B. balcooa, B. tulda* and *B. vulgaris* throughout Bangladesh (Gibson 1975; Rahman 1978, 1988; Boa and Rahman 1987). The disease was first recorded in 1970 by Rahman and Zethner (1971) as a potentially serious problem of village bamboos in Bangladesh. Disease losses have been recorded as greatest in *B. vulgaris*, followed by *B. balcooa* and the Jawa/kata Jali variety of *B. tulda*. Death of the whole affected culmp within 3-4 years of infection has been recorded in *B.vulgaris*. The disease was studied in detail and about 3-66% infection of clumps in different localities-Chittagong, Dhaka, Comilla and Rajshahi-was reported. However, quantitative data assembled are not sufficient to make an overall assessment of the disease's impact on culm production. There has been no new outbreak of the disease since 1981.

Recently, bamboo blight has also been recorded in *Bambusa nutans* Wallich in the coastal belts of Odisha State, India (Gupta et al. 1990; Jamaluddin et al. 1992; Mohanan 1995b; Jamaluddin and Gupta 1996). An average of 94% infection has been recorded in *B.nutans* clumps in Puri, Cuttack, Baleshwar and Ganjam Districts in Odisha State (Mohanan 2008). Bamboo blight occurs mostly in well established older clumps, aged more than 8-10 years. Culms which survive the first growing season remain healthy and the spread of the disease between clumps of bamboo is slow.

Fig.39 *B. nutans* culms showing initial symptoms

SYMPTOMS

The disease results in a sequential die-back of culms in their first season of growth. Symptoms appear when culms are nearing full growth or shortly after this. The initial symptoms of blight are premature death of culm sheaths and partial collapse of the fragile apical regions (Fig.39). Later, wet rotten patches develop on the internodes, often associated with insect damage. These necrotic patches spread rapidly in the succulent internodes and eventually become confluent. At the same time, symptoms begin to develop in the lower, more fibrous internodes, and spread slowly downwards, resulting in die-back (Figs. 40-42). Epicormic branches from the nodes of the infected culms develop occasionally which also become affected by the disease in due course.

Fig.40 Diseased *B. nutans* culms with epicormic shoots from the nodes

CAUSAL ORGANISMS

Sarocladium oryzae (Sawada) W. Gams & D. Hawks has been reported as the principal fungus associated with bamboo blight in Bangladesh (Boa and Brady 1987; Rahman 1988) and in India (Gupta et al. 1990). *Paraconiothyrium fuckelii* (Sacc.) Verkley & Gruyter (= *Coniothyrium fuckelii* Sacc.), *Fusarium* spp., *Sarocladium strictum* (W. Gams.) Summerb. (= *Acremonium strictum* W. Gams, *Pteroconium* sp., *Arthrinium* sp. were the other fungi recorded as associated with bamboo blight (Rahman 1978; Rahman and Khisha 1983; Boa and Rahman 1983).

Fig.41 *B. nutans* culms in advanced stage of disease

Fig.42 *Blight affected B. nutans* clumps in a village grove at Cuttack, Odisha, India

ETIOLOGY

Etilogy of the disease is still poorly understood. Various fungal organisms have been found associated with blighted culms. However, pathogenic connection between a fungus, or a group of fungi, and the blight disease has not been adequately demonstrated (Boa 1987b).

However, *Sarocladium oryzae* is considered to be the principal fungus associated with bamboo blight. The fungus perennates in the affected culms, bamboo debris or in paddy which act as the source of inoculum. The fungus gets inside the rhizome system before blight is established (Boa and Rahman 1987). The spores of *S. oryzae* germinate easily in water within a few hours and infect new culms or culm sheaths (Jamaluddin et al. 1992; Jamaluddin and Gupta, 1996). Water accumulation in debris, weeds or shrubs around the culms enhances the susceptibility of the culms to infection. In India, development of the disease is related to climatic conditions of the area. High humidity owing to canal irrigation and high temperatures during monsoon favour infection. Poor stand management, conducive climatic and soil factors, and insect attack are responsible for the development of the disease (Boa and Rahman 1987). Mining insects are suspected to help in spreading the disease. The spread of infection from one area to another is rather slow.

DISEASE MANAGEMENT

Silvicultural measures recommended for controlling the disease include: cutting and removing blighted bamboo culms, burning the debris of clumps *in situ* and addition of new soil to clumps. Light surface fire (controlled burning) before the onset of monsoon is suggested for reducing the inoculum potential of the pathogen in the debris or in the top few centimetres of soil. Weeds and bushes around the clump should be removed as these act as retainers of moisture, which is considered favourable for causing infection (Jamaluddin and Gupta 1996). Offsets for planting out should not be taken from blighted clumps. Soil or debris from infected clumps or nearby areas should not be transferred to healthy clumps. Application of Carbendazim combined with Mancozeb (Carbendazim 0.15%

a.i. + Mancozeb 0.3% a.i.) or with Fytolan (Carbendazim 0.25% a.i.+ Fytolan 0.3% a.i.) is recommnded. Drenching the soil around the bamboo clumps with Copper oxychloride and Mancozeb is also desirable to check the disease (Rahman 1988). Selection of planting stock from disease-free clumps has also found helpful in reducing the infection (Jamaluddin and Gupta 1996).

BambooTop Blight

The disease, also called 'withered tip disease', 'Moso tip blight' and 'die-back-, has been reported in *Phyllostachys pubescens, P. heterocycla* and *P. edulis* in China (Shi et al. 1979; Deng and Yu 1980; Zhang 1982; Liu and Pan 1983; Yu 1981, 1986; Lin 1988; Xu et al. 1989; Lin and Qju 1993; Zhang and Ou 1993; Ou and Zhang 1993a,b; Zhang 2000; Lin 2001; Ye et al. 2001). The disease is widespread in Jiangsu, Zhejiang, Anhui, Jiangxi, Fujian and Shanghai Provinces, causing heavy damages to the bamboo groves. During 1973, a severe disease incidence affecting more than 40 million new bamboo culms has been recorded. Peak incidence of disease occurs in July-September. Bamboo groves located in drought affected areas, at forest borders, on hill tops and on poor soils with poor growth have been seriously damaged. The disease has been studied in detail and a disease prediction model has been generated for forecasting the infection (Ou and Zhang 1993a). The disease distribution pattern over time is that of a polyetic epidemic disease (monocyclic disease) and the disease index increases more often 2.5 to 3.4 times in accordance with the logistic model; the spatial distribution pattern of the causal agent obeys the law of aggregation distribution, with an obvious infection centre and the disease spreading repeatedly from that centre to a distance of about 5-10 m (Ou and Zhang 1993b). After the disease outbreak in 1970s, no large-scale occurrence of the disease has been recorded for more than ten years in China. Recently, the disease occurred sporadically in Zhejiang, Fuji, and Jiangxi Provinces (Zhang 2000).

SYMPTOMS

The disease affects mainly new culms of the current season. Infection causes browning and necrosis of the culm and branch internodes, and subsequent withering of branches, minor branches and whole culms. Accordingly, depending on the plant parts affected and the degree or damage caused, the symptoms manifest as branch withering (branch blight), minor branch withering (tip blight) and plant withering (culm blight) (Fig.43). Lightly infected groves belong to branch-withered type, while heavily infected groves suffer from all three infection types. The causal fungus produces its fructifications on the necrotic tissues. Severe infection occurs during August-September and subsides after October. Dieback of the affected culms occurs from infection in successive years.

Fig.43 Top blight of *Phyllostachys* sp. caused by *C. phyllostachydis* (Source : Anon. 1982)

CAUSAL ORGANISM

Ceratosphaeria phyllostachydis Zhang (Zhang 1982; Xu et al. 1989).

ETIOLOGY

Fungal spores, extruded from the perithecia of diseased bamboo tissues, are disseminated by wind or rain splashes. The spores germinate on the host surface and invade the tissues during May through natural openings or wounds at the branch fork of new shoots. The latent period of infection is about 30-90 days. High atmospheric humidity and temperatures in the range of 22-25^{0}C are favourable for the fast spread of the infection. The infection spreads and causes necrosis, followed by the withering of affected plant parts. Recently, production of toxin in the affected tissues by the causal fungus and its role in symptom development was confirmed (Ye et al. 2001). The hyphal structures of the fungus overwinter in the infected tissues and can be alive for 3-5 years. The fructifications of the pathogen are produced in the infected tissues during April. Factors responsible for the high incidence and severity of the disease include fast spread of the pathogen, poor resistance of the bamboos against the disease and conducive environment for the development of the disease.

DISEASE MANAGEMENT

Silvicultural measures suggested for disease management include: cutting and removal of infected branches and culms in order to reduce the inoculum, clearing miscellaneous trees nearby and tending young bamboos to eradicate alternate hosts of the pathogen. Adoption of cultural measures in bamboo groves reduced the disease incidence from 70% to 20% (Xu et al. 1989). Quarantine measures suggested include preventing the transport of diseased bamboos out of the infected area. Application of fungicides-Carbendazim (0.05% a.i.), Thiophanate methyl (0.02% a.i.) or Bordeaux mixture (1:100) - during May June is also desirable. The fungicidal spray should be given 2-3 times successively once every 10 days. Recently, integrated disease management measures, including hoeing herbage, loosening the soil, N and P fertilizer application, disrupting the infective cycle by cutting old bamboos, and digging up bamboo shoots during spring and winter, were suggested (Zhang, 2000; Lin 2001).

Branch Die-back

Branch die-back has been reported in bamboo natural stands and plantations in Kerala, India (Mohanan 1994a,b; 2002). The disease was widespread in *Bambusa bambos*, *B.vulgaris* and *Dendrocalamus strictus* plantations and *B. bambos* natural stands; percent disease incidence was higher in plantations (14-67%) than in natural stands (2-37%). In plantations, culms produced by 2 to 3-year-old clumps were severely affected. The disease was recorded during September-October; severe infection occurred during January, causing die-back of branches and culm tips, and premature defoliation. A similar disease in *Phyllostachys* sp., causing foliage blight and branch die-back, has also been reported from Fujian Province, China (Kuai 1987).

SYMPTOMS

Infection occurs on branches and top three to five internodes of young culm in the form of small, greyish magenta, linear lesions which later develop into necrotic streaks. Foliage infection appears as pale yellowish, linear lesions which later develop into necrotic streaks (Fig.44). They later spread to the entire leaf lamina, resulting in leaf necrosis, withering and premature defoliation. The necrotic streaks on branches and culm internodes coalesce to form large streaks; the affected branches and often the entire length of apical three to five culm internodes become discoloured. As the leaves of infected branches wither and defoliate prematurely, discolouration and necrosis on the branches and culm tip become very prominent. Infection spreads from branches to culm nodes, and from there downwards to internodes. Under high humidity, the causal fungus sporulates on the infected necrotic areas of culm internodes and branches. Infection causes premature defoliation and die-back of branches and culm tip (Fig. 45).

Fig.44 Branch die-back in *B. bambos*

Fig.45 Branch necrosis and premature defoliation in *B. bambos*

CAUSAL ORGANISMS

Fusarium pallidoroseum (Cooke) Sacc. (Mohanan 1994a,b,1997,2008) and *Fusarium* sp. (Kuai 1987).

ETIOLOGY

Fusarium pallidoroseum is an air-borne pathogen, and the conidia dispersed by wind serve as the primary soure of inoculum. The fungus invades the host tissue through natural openings like stomata and lenticels, or through wounds; the fungus proliferates in the leaf and stem tissues and causes necrosis of the invaded tissues. Under warm-humid conditions, the fungus sporulates on the affected tissues and these conidia serve as the source of secondary infection. In young plantations, infection in successive years may affect culm vigour and production.

DISEASE MANAGEMENT

Aerial application of the fungicide Mancozeb (0.2% a.i.) is suggested for controlling the disease in young bamboo stands.

Witches'-broom

Witches'-broom disease has been reported on different species of bamboos in China, India, Indonesia, Japan, Taiwan-China and Vietnam. Witches'-broom disease is caused by fungi like *Aciculosporium take, Heteroepichloe bambusae, Heteroepichloe sasae*, *Epichloe bambusae* etc. Earlier, the disease caused by *Aciculosporium take* was recorded on a cultivar of *Phyllostachys viridis, P. glauca* McCl. and other *Phyllostachys* species in China (Lin and Wu 1987; Zhu and Huang 1988, 1992; Zhu 1989a,b). Recently, the disease has become more and more harmful to the bamboo production, especially in Zhejiang, Jiangsu, Anhui, Hunan, Sichuang, Hubei, Guangdong, Shanxi, Henan, and Guizhou Provinces in China causing 95-100% infection in *Phyllostachys viridis, P. glauca, P. praecox, P. heteroclada, P. aurosulcata, P. incarnate, P. nuda* and *Semiarundinaria fastuosa* (Zhang 2000). Witches'-broom disease caused by *Heteroepichloae bambusae* has been recorded on *Phyllostachys pubescens*, *P. dulcis, P. nidularia*, and *Bambusa* spp. in Zhejiang, Jiangsu, Guizhou Provinces in China (Zhang 2000). Recently, the disease has also been recorded on *Phyllostachys pubescens/heterocycla/edulis, P. praecox* Chu et Chao, *P. nuda* McCl., *P. aurea* Carr. ex A. & C. *Riv., P. arcana* McCl., *P. nidularia* Munro and *Bambusa multiplex* (Lour.) Raeusch. ex Schultes in Nanjing and Yixing in China (Mohanan 1995, unpublished observation).

Witches'-broom, caused by *Aciculosporium take* is the most destructive of bamboo diseases in Japan (Tanaka 2003, 2009, 2010; Hashimoto et al. 2008; 2010). In Japan, the disease has been recorded on *Phyllostachys bambusoides* Sieb. et Zucc. *P. nigra var. henonis* Stapf. ex Rendle*, Sasa borealis* var. *purpurascens, S. kurilensis* (Rupr.) Makino et Shibata, *S. paniculata* Makino et Shibata, *S. tectoria* Makino ex Koidz and *S. veitchii var*. *tyugokensis* (Makino) Muroi (Shinohara 1965; Nozu and Yamamoto 1972; Nonaka 1989; Zhu 1989). Recently, disease survey conducted in *Phyllostachys* stands in western Japan revealed that in 17 Prefectures, 93% of *P. bambusoides* communities had the disease, and that in 10 of the Prefectures, several *P. bambusoides* communities were severely damaged. The disease survey indicated that the number of *P. bambusoides* communities affected by witches'-broom may increase in the near future throughout western Japan (Hashimoto et al. 2008). Witches'-broom disease has also been recorded on *Gigantochloa levis* in Quezon and Laguna in the Philippines (Lit et al. 1999).

Fig.46 *P. viridis* culms affected with witches' - broom in Nanjing, China

In India, witches'broom disease has been recorded on *Ochlandra travancorica*, *O. travancorica* var. *hirsuta, O. scriptoria* and O. *ebracteata* Raizada et Chatterji in the southern states (Mohanan 1990, 1994a,b, 1997,2004, 2008). The causal fungus is *Linearistroma* *lineare* (Rehm.) Diehl. (= *Balansia linearis*). In southern India, witches'-broom is widespread in reed bamboo areas, and about 6-15% disease incidence was recorded during 1988-92 (Mohanan 1994b; 2004, 2008). The infection was also observed on a grass, *Pennisetum polystachyon* (L.) Schultes, growing in the vicinity of the affected bamboos.

Fig.47 Diseased *O. travancorica* clump by *L. linearis,* Kerala , India

The disease has been reported on *Gigantochloa* apus Kurz, *Gigantochloa atter* (Hassk.) Kurz and *Gigantochloa robusta* Kurz (= *G. verticillata* Munro) from Indonesia. Witches'-broom has also been recorded in *Phyllostachys aurea, P. bambusoides, P. lithophila* Hayata, *P. makinoi* Hayata, *P. nigra var. henonis*, *P. pubescens*, *P. lithocarpa, P. nuda, Bambusa multiplex, B. oldhamii* and *B. dolichoclada* in Taiwan-China (Chen 1970, 1971; Kao and Leu 1976; Lin et al. 1981). In Vietnam, the disease has been observed in *B. nutans, Dendrocalamus membranaceus, Gigantochloa atter* and *G. robusta* (Mao 1993, 1996).

Fig.48 Witches'-broom of *O. travancorica* clump caused by *L. linearis,* Kerala , India

SYMPTOMS

Numerous highly shortened shoots develop at the nodes of mature bamboo culms. These abnormal shoots do not develop into normal branches and produce only highly reduced shoots successively from their nodes. The culm sheaths which cover the internodes also become shortened in size and become boat-shaped, often with a prominent ligule. The internodes show purplish pink discolouration with reduced pale green foliage. Successive development of a large number of thin shoots in tuft from the nodes of the infected culms give rise to the characteristic appearance of witches'-broom (Fig. 46).

New shoots emerging from the rhizome during the growing season also show pronounced brooming symptoms. From an infected rhizome, a large number (often ranging from 30 to 800+) of abnormal, greatly shortened shoots are developed. The shoots grow only up to 10-50 cm in height, showing typical symptoms of the disease (Figs. 47-49). Shining black fungal fructifications develop on the affected shoots after 5-6 months of infection (Figs. 50-52). Often, one or two normal culms also develop from the infected rhizome and give rise to apparently healthy branches and foliage. Possibly owing to these apparently healthy culms, the diseased clump is not killed outright.

CAUSAL ORGANISMS

Fungi associatged with the witches'-broom include: *Balansia take* (Miyake) Hara (Zhu 1989a,b); *Linearistroma lineare* (Rehm.) Diehl (= *Balansia linearis* (Rehm.) Diehl (Mohanan 1994a,b; 2004); *B. take* and a bacteria-like organism (Lin and Wu 1987); *Aciculosporium take* Miyake (= conidial state of *Balansia take); Loculistroma bambusae* (Chen 1971; Shinohara 1965; Nozu and Yamamoto 1972; Kao and Leu 1976); *Aciculosporium sasicola* Oguchi; Heteroe*pichloe bambusae* (Pat.) E. Tanaka, C. Tanaka, Gafur & Tsuda (= *Epichloe bambusae* Pat.); *Heteroepichloae sasae* (Hara) E. Tanaka, C. Tanaka, Gafur & Tsuda (= *Epichloae sasae* Hara (Zhu 1989; Oguchi 2001; Tanaka et al. 2002). *Phaeosphaeria bambusae* (Yang and Wu 2011). *Aciculosporium sasicola* Oguchi (anamorph *Albomyces sasicola*), is also recently recorded. A phytoplasma was also detected on the diseased tissues (Zhu and Huang 1992).

Fig.49 Witches'-broom of *P. praecox* by *B. take,* Nanjing, China

Fig.50 Witches'-broom of *P. viridis* by *B. take,* Nanjing, China

ETIOLOGY

Aciculosporium take causes continuous shoot growth but maintains normal leaf-arrangement and branching patterns in the host plant, which eventually resulting in witches'-broom disease of bamboo. Endophytic mycelia of *A. take* is predominantly distributed in the intercellular spaces of the shoot apical meristem of the host. Endophytic hyphae in meristematic tissues, which may produce auxin, are responsible for continuous primordium initiation within the shoot apex. In the case of *Heteroepichloë sasae* another witches' broom pathogen, does not cause continuous shoot growth and *H. sasae* mycelia were distributed superficially, even on shoot apical meristems. These observations suggest that when their stromata develop, endophytic *A. take* destroys shoot apical meristem and epiphytic *H. sasae* chokes the shoot apex of the host. Stromata formation consequently causes lateral bud outgrowth because of release from apical dominance. This process repeats and eventually results in the witches' broom symptoms (Tanaka, 2010). A reduction in endogenous indole-3-acetic acid in the twigs of the diseased bamboo has also been reported (Tanaka et al. 2003) and suggested that the symptoms (bushy appearance) may be induced by reduction in auxin levels. However, Tanaka (2009) reported that *Aciculosporium take* grows endophytically, particularly in the shoot apical meristem of the host. The location of *A. take* hyphae suggested that the mechanism of symptom development can be explained by the action of exogenous fungal auxin, which continuously induces primordium initiation within the host (Tanaka 2009). Spread of disease is mainly through rain drop transmission (Tanaka et al. 2002).

In the case of witches'-broom of *Ochlandra* spp. caused by *Linearistroma lineare*, macroconidia and ascospores produced in large quantity in the affected host tissues are suspected to be sources of infection in reed bamboo natural stands; rhizomorphs, which overwinters on the affected bamboo shoots, also serve as an infection source (Mohanan 1997; 2004,2008). The spores germinate on culm internodes and penetrate the host tissue. A shining white fungal mycelial weft appears on the infected shoot, culm sheaths and foliage. The distal end of the abnormal shoot, as well as the shoot developed immediately from each node of the abnormal shoot, become modified into structures bearing fungal fructification. White, powdery fungal stroma develop at the base of the nodes and spread to the proximal end, later developing into greyish white to pale yellow, uniformly raised ascomata. The ascomatal stroma extend from the base of the nodes to the distal end, except for 1-2 cm at the terminal portion. As the development of the fructification progresses, the whole structure turns shining brown or greyish brown, with a white basal portion. At this stage, the shoot portion bearing the developing fungal fructification becomes free from the culm sheath and forms an inwards curved, sickle-shaped structure. The fructification further matures and turns shining black in colour. Development of the fructification starts during September-October and usually matures during January-February. After the discharge of the ascospores, the fructification degenerates during May-June. As new shoots are produced successively from the infected abnormal shoots, the disease spreads to the new shoots. The fungus also produces long, hair-like, black rhizomorphs on the affected withered shoots, foliage and culm sheaths during the dry period. Infection now spreads to the rhizomes and infected rhizomes give rise to a large number of slender wiry-shoots. The pathogen overwinters in infected shoots (Mohanan 2004, 2008).

Fig.51 Ascocarps of *L.linearis* developed on the affected shoots of *O. travancorica*

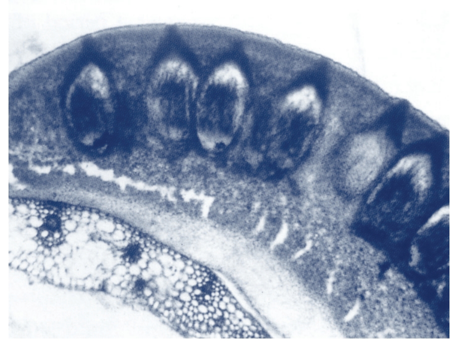


Fig.52 Cross section of ascocarp of *L.linearis*

DISEASE MANAGEMENT

Silvicultural measures, such as pruning and removal of infected minor branches, have been suggested by Zhu and Huang (1988) and achieved a control effect of 92% in China. Fungicides, and antibiotics such as tetracycline and oxytetracycline, have also been screened against

Aciculosporium take in China. Clearing infected branches plus spraying with Carbendazim or Triazolone dust achieved 99% disease control. Spraying with Carbendazim and Triazolone three times at 7-day intervals has a control effect of 100% (Lou et al. 2001). Improving the ventilation in the stands, cutting old and weak culms, and clearing diseased clumps and burning them outside the forest have been suggested for disease management in *Phyllostachys* stands in Japan and in reed bamboos in India (Nonaka 1989; Zhang 2000; Mohanan 1994a,b; 2004).

Phytoplasma Disease

Little Leaf Disease

Little leaf disease, also refered as 'witches'-broom disease of bamboo has been reported on *Dendrocalamus strictus* clumps in natural stands in Kerala, Karnataka, Tamil Nadu and Andhra Pradesh from India (Mohanan 1990, 1994a,b,c, 1995b,c,2008). In Kerala, very high incidence (90%) of the disease was recorded in dry tracts and sandal reserves (Mohanan 1994a,b, 2008). *Dendrocalamus strictus* had earlier been reported as a collateral host of sandal spike caused by phytoplasama (Nayar and Ananthapadmanabha 1977). Clump-to-clump spread of infection was found to be slow and an increase of 2-13% disease incidence over a period of four years was observed in different areas in the Kerala State (Mohanan 2008). A similar disease has also been recorded in *Bambusa multiplex* stands in Kanchanburi, Thailand (Mohanan 1997, unpublished observation). Recently, Phytoplasma disease has been recorded on *Dendrocalamus strictus* in five geographically different locations in Maharashtra State, India (Yadav etal. 2016). Recently, disease caused by Phytoplasma belonging to '*Candidatus Phytoplasma asteris*' has been reported on *Phyllostachys nigra* var. *henonis* from Yeoungyang, Korea (Jung et al. 2006). The presence of phytoplasma was confirmed by amplification of a 1.8-kb DNA fragment using a primer pair specific for the region containing a 16S rRNA gene and an intergenic spacer region between the 16S and 23S rRNA genes. Comparison of the 16S rRNA gene sequences showed that the causal phytoplasma belongs to "*Candidatus Phytoplasma asteris*," and shared the highest degree of similarity with the sequence of the onion yellows (OY) isolate in Japan (Jung et al. 2006).

Earlier, large-scale malformation in *Dendrocalamus strictus* has been reported from Ranchi Forest Division, Bihar State, India. The deformed culms developed witches'-broom on the nodes. Out of the 1498 culms in 124 clumps observed, 655 (43.7%) were affected with witches'-broom symptoms. Two types of the disease were recorded. Deformity in a large number of the affected culms was due to certain physiogenic factors that kill the tip of the shoots without causing major die-back. Only 37 culms (2.4%) showed the brooming symptoms characteristic of that caused by fungi, insects, viruses, phytoplasma, mites, etc. However, no causal agents could be detected from the affected tissues (Bakshi et al. 1972).

SYMPTOMS

The disease is characterized by the development of numerous, highly reduced, abnormal bushy shoots from the nodes of newly emerged culms and culm branches. Foliage develops from these shoots, showing prominent size reduction and needle-like appearance. Profuse development of such abnormal shoots from each node of the developing culm and their subsequent growth give rise to a massive bushy structure around each node. The disease also affects culm elongation; infected culms show stunted growth, and curve inwards mainly from the weight of the abnormal bushy shoots at the nodes. Healthy looking, straight-growing culms are also produced from low to moderately infected clumps. In this case, development of abnormal shoots occurs from the culm branch nodes (Figs. 53, 54). Even though culm growth is completed within six months of emergence, the abnormal shoots continue to develop from culm nodes and branches nodes year after year, and form a massive structure of highly reduced and branched nodal shoots (Fig. 55). In severely affected clumps, all the culms produced from the rhizome in a growing season become infected. The whole clump becomes bushy with only a few diseased and highly deformed culms.

Fig.53 *D. strictus* shoots affected with little leaf disease, Kerala, India

Fig.54 *B. multiplex* shoots affected with little leaf disease, Kanchanaburi, Thailand

Fig.55 Development of abnormal bushy shoots in *D.strictus*, Kerala, India

CAUSAL ORGANISM

Phytoplasma aurantifolia ((16SrII Group) has been identified as the causal organism associated with *Dendrocalamus strictus* in Maharashtra, India (Yadav et al. 2016). '*Candidatus Phytoplasma asteris'* has been identified on *Phyllostachys nigra* var. *henonis* from Korea (Jung et al. 2006).

Association of a *Phytoplasma* (mycoplasma-like organism) with the diseased tissue was proved by Dienes' staining (Fig. 56), fluorescence microscopy using aniline blue staining (Fig. 57), electron microscopy (Fig. 58) and tetracline hydrochloride therapy (Mohanan 1994a,b,c). Attempts to culture *Phytoplasma* associated with bamboo little leaf were unsuccessful (Mohanan 1994c)

.

ETIOLOGY

Etiology of little lead disease of bamboo caused by Phytoplasma is not known, However, etiology of

Phytoplasma causing similar diseases in other hosts is available. Phytoplasmas are transmitted through insect vectors-aphids, leaf hoppers, etc. - during the process of sap sucking. Incubation period varies depending on the Phytoplasmas associated and the vectors.

DISEASE MANAGEMENT

Antibiotic treatment to control plant diseases associated with *Phytoplasma* has been attempted after the discovery of the suppressive effect of tetracycline antibiotics on symptom development. Since, in bamboos, the process of culm production, elongation and development are completed within six months, and after that only a biological consoldiation takes place, it is not worthwhile to control the disease of emerged culms by chemicals or antibiotics (Mohanan 2008).

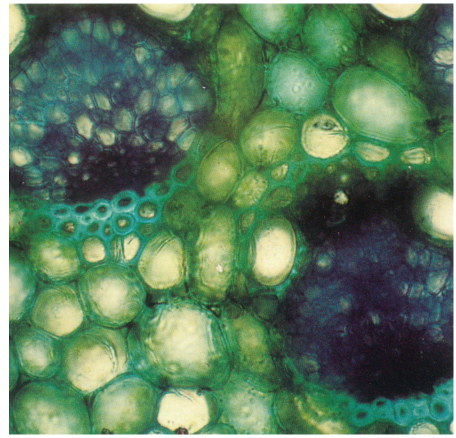


Fig.56 Diene's staining reaction of diseased culm internodal tissues (870x); note the deep blue staining in phloem tissue

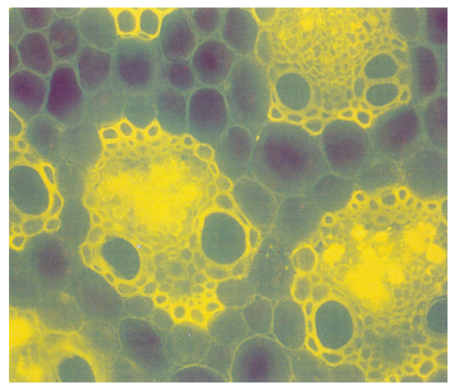


Fig.57 Aniline blue staining reaction of diseased culm internodal tissues (870x); note the yellow green fluorescent spots in phloem tissue

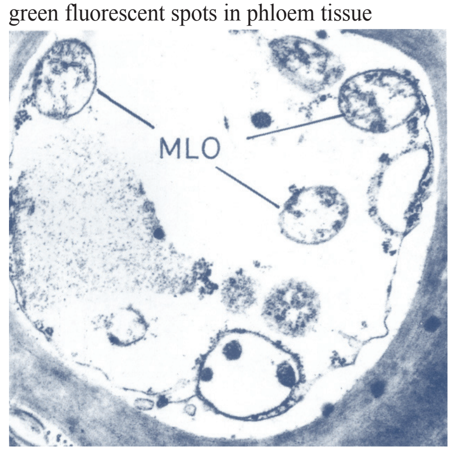


Fig.58 Transmission electron micrograph of diseased tissue showing phytoplasma (MLO) in the phloem sieve cells(19200x)

Virus Disease of Bamboos

1. Bamboo Mosaic

Mosaic disease affecting foliage and young developing culms of bamboo has been reported from Taiwan-China, China, and the Philippines. Bamboo Mosaic Virus (BaMV) was the first virus to be identified infecting bamboo plants. The virus was first isolated from *Bambusa multiplex* (Lour) Raeusch. and *B. vulgaris* and reported from Brazil in 1975 (Kitajima et al., 1975; Lin et al., 1977). Mosaic disease affecting foliage and young developing culms of bamboo has been reported from Taiwan-China. The disease affects two major cultivated bamboos - *Dendrocalamus latiflorus* Munro and *Bambusa oldhamii* Munro - and abolut 70-80% disease incidence has been reported (Lin et al. 1977, 1979, 1993; Chen 1985; Lin and Chen 1991).

So far, bamboo mosaic virus (BaMV) is known to infect bamboos exclusively with no other known natural host. This virus has been known to infect about 13 species of bamboos (mainly those with pachymorph rhizomes) namely: *B. mutabilis, B. beecheyana, B.*

dolichoclada, B. edulis, B. multiplex, B. oldhamii, B. pachinensis, B. utilis, B. ventricosa, B. vulgaris, D. giganteous, D. latiflorus and *Melocanna baccifera* (Kitajima et al. 1975; Kitajima et al. 1977; Lin et al. 1977; Chen 1985; Lin and Chen 1991; Lin et al. 1992; Lin et al. 1993; Elliot and Zettler 1996; Chang et al. 1997; Lee et al. 1998; Dodman and Thomas 1999).

Experimentally BaMV can be transmitted mechanically to *B. vulgaris* 'vittatu', *Nicotiana benthamiana, Chenopodium amaranticolor, C. ficifolium, C. murale, C. quinoa, C. occidentalis, Gomphrena globosa* and *Hordeum vulgare* (Chen 1985; Lin and Hsu 1994; Elliot and Zettler 1996; Chang et al. 1997; Lee et al. 1998).

SYMPTOMS

Characteristic symptoms caused by this virus include foliar mosaic and stripe, brown internal streaking of the shoots and culms, and culm abortion (Lin and Chen 1991; Elliot and Zettler 1996). Culms are poorly developed with shortened internodes and the newly emerging shoots are hard in texture, thereby, depleting their quality for eating and canning (Lin and Chen 1991). For these reasons, Bamboo mosaic virus is being considered as a limiting factor in the production of edible bamboos in Taiwan-China (Lin and Chen 1991; Hsu et al. 2000).

CAUSAL ORGANISM

Bamboo mosaic virus belongs to the genus Potex virus in the family Alphaflexivirideae (Hull 2013). BaMV particles are flexuous, filamentous rods, 480-500 nm in length and 15 nm in diameter (Lin et al. 1977). The virus is thermally inactivated between 75° to -6 80°C and loses infectivity when diluted to 10. The virus is infectious when stored at 24°C for one month or at -15°C for four months (Chen 1985). Under the electron microscope, the virions of BaMV can be seen in epidermis, mesophyll and vascular bundles of the infected tissues (Lin and Chen 1991). Within the infected cells, the virus appears in the form of electron dense crystalline bodies (EDCBs) with varying shapes and sizes (0.1 to 2.7 µm) and aggregates of virions in the chloroplast, cytoplasm, vacuoles and the nucleus. Within these organelles, the virions are arranged in loose parallel or helical fashion and can also be seen irregularly distributed in the cytoplasm. The precise location of virions and the EDCBs within the infected cells can indicate the stage of infection (Lin and Chen 1991; Chang et al. 1997). Some isolates of the virus, also contain a satellite RNA (sat BaMV) which is a single stranded RNA sub-viral agent whose replication is supported by Bamboo mosaic virus, encapsidated by BaMV capsid protein to form rod shaped particles of length 60 nm (Lin and Hsu 1994). SatBaMV was first identified to be associated with BaMV isolated from *B. vulgaris* and reported from Taiwan in 1994 (Lin and Hsu 1994).

ETIOLOGY

BaMV has no known insect vectors and is likely to be transmitted mechanically, as well as through vegetative planting materials. The infection process and development are the same as in the case of other virus transmitted diseases. The virus proliferates in the affected culm, leaf and rhizome tissues. The affected culms become hard in texture, and internal tissues get discoloured and quality deteriorates. Immunological detection of BaMV antigen by tissue blotting (Lin et al. 1993) demonstrated that most cultivated bamboo species in Taiwan-China with patchymorph rhizomes including *Bambusa* and *Dendrocalamus,* are susceptible to bamboo mosaic. Infection of *B. oldhamii* results in the formation of a large number of unusual electron-dense bodies in the infected cells.

DISEASE MANAGEMENT

Bamboos are normally vegetatively propagated and the virus is probably transmitted through vegetative propagation of infected, nonindexed planting material and mechanically by the unclean practices employed in the routine cutting of bamboo shoots (Lin and Chen, 1991). The large-scale use of vegetative propagules of bamboos has caused the disease spread throughout Taiwan-China. Once established, the disease caused by Bamboo mosaic virus cannot be eradicated without destroying the infected plants. The infected stock should be isolated and only virus free planting material be used for further propagation of the nursery stock. Infection studies showed that *Phyllostachys edulis*, *P. nigra, and Bambusa vulgaris* var. *striata* (Lodd.) Gamble are susceptible to the disease, while *P. makinoi, P. pubescens, Dendrocalamus giganteus* and *D. strictus* are resistant. Cultivation of bamboos resistant to mosaic disease should be promoted in disease prone areas. For managing the disease as well as checking the spread of the disease, preparation and use of vegetative propagules from diseased clumps should be avoided. Meristem tip culture technique is being used for the production of virus free bamboos, but for such plants also, it is necessary to know whether the material is virus free. Pruning of diseased plants should be done carefully and blades must be sterilized between each use to minimize dissemination of the disease from infected to the healthy plants (Hsu et al. 2000; Nelson and Borth 2011). Also, strict quarantine measures against the movement of infected planting materials within the growing areas also should be practised.

2. Cherry Necrotic Rusty Mottle Virus (CNRMV)

Cherry necrotic rusty mottle virus (CNRMV) has mainly been associated with a disease of sweet cherries. The first incidence of the disease was described in 1945 in Utah (Rhoads, 1945) and since then the virus has been reported from many cherry growing regions of the world like Chile, China, Japan, Europe, Germany, India, Korea, New Zealand and North America (Wadley and Nyland, 1976; Rott and Jelkmann, 2001a; Gentit et al., 2002; Isogai et al., 2004; Mandic et al., 2007; Fiore and Zamorano, 2013; Noorani et al., 2013; Zhou et al., 2013; Cho et al., 2014). CNRMV naturally infects *Prunus avium* (sweet cherry), *P. armeniaca* (apricot), *P. cerasus* (sour cherry), *P. domestica* (plum), *P. mahaleb* rootstock, *P. persica* (peach), flowering cherry accessions (*P. serrulata* and hybrids) (Li and Mock, 2008; Zhou et al., 2013) and about 21 species of bamboos: *A. falconerii, B. balcooa, B. bambos, B. multiplex, B. nutans, B. pallida, B. tulda, B. ventricosa, D. asper, D. asper (Chinese), D. bambusoides, D. bannaenensis, D. barbatus, D. dianxiensis, D. giganteus, D. hamiltonii*, *D. sinicus, D. yunnanensis, F. somnigensis* and *M. baccifera* (Awasthi et al., 2014)

SYMPTOMS

The brown, angular, necrotic spots, abnormal colours and pattern, abnormal leaf fall, yellowing, rusty chlorotic areas, shot holes of the leaves (Wadley and Nyland, 1976); blisters, gummosis, resinosis, canker on woody stem; dieback and general necrosis of the bark; dieback of growing points and early senescence of the whole plant constitute the most important diagnostic symptoms of the disease (Richards and Reeves, 1951; Wadley, 1966). The symptoms of CNRMV on bamboo plants constitute mosaic, chlorosis, yellow streaks, necrotic spots and curling on the foliage of infected plants (Awasthi et al. 2014), while the effects of this virus on the growth and production of stem, pulp, shoot and rhizome of bamboos are yet to be determined.

CAUSAL ORGANISM

Cherry necrotic rusty mottle virus (CNRMV) is an unassigned member of the family Betaflexiviridae, flexuous filamentous plant viruses (Adams et al., 2012). Not much is known about their physical or chemical properties.

ETIOLOGY

The disease caused by CNRMV is easily transmitted by grafting and budding but not mechanically by sap inoculation. There is no evidence of seed or pollen transmission of CNRMV (Rott and Jelkmann, 2012). In addition to graft transmission, natural spread of the disease has been observed in sweet cherry orchards in Oregon (Cameron and Moore, 1985), Utah (Wadley and Nyland, 1976), Montana (Afanasiev and Mills, 1957) and amongst bamboo clumps in India (Awasthi et al., 2014). CNRMV has been detected in two aphid species and in a delphacid (Awasthi et al. 2017 unpublished data) which might be acting as virus vectors.

DISEASE MANAGEMENT

The newly discovered virus and virus-like diseases may emerge as serious threat to bamboo stands. Unlike the bacterial or fungal diseases, the viral diseases cannot be eliminated from the infected plant and remain for a lifetime. There are even more serious consequences when the infected planting material is used for further propagation of nursery plants. Increasing knowledge of virus and virus-like diseases of bamboos necessitates the adoption of preventive measures. The most important preventive method seems to be production and use of virus-free propagating material. A few viruses which are implicated in the diseases of commercial pome and stone fruit trees, have found alternate host amongst the bamboo plants. Though the information on these emerging viral diseases of bamboos is very preliminary and lacks details with regard to their impact on bamboo production, the findings indicate that these bamboo plants, besides themselves developing disease symptoms, may also be acting as source of infection for the stone and pome fruit trees. It would be important to understand the influence of insect vector populations on the distribution and spread of these viruses among other plant species.

Thread Blight

Thread blight affecting culms, branches and foliage of different bamboo species has been reported from India. In Kerala States, the disease affects *Bambusa balcooa, B. bambos, B. multiplex* (Lour.) Raeusch. ex J.A. & J.H. Schultes, *B. polymorpha, B. tulda, B. tuldoides Munro, B. vulgaris, Dendrocalamus brandistii, D. longispathus, D. strictus and Thyrsostachys siamensis* in plantations, and *B. bambos, D. strictus, O. scriptoria and O. ebracteata* in natural stands (Mohanan 1990, 1994a,b, 2008). In *B. vulgaris* plantations, 95% disease incidence was observed during 1991 (Mohanan 1994b). Thread blight affecting *Dendrocalamus* sp. has also been reported from Karnataka State (Rogers 1943). Recently, the disease affecting *Bambusa gigantina*, *Bambusa vulgaris*, and *Melocanna baccifera* has been recorded in a Bambusetum at Palappilly, Thrissur, Kerala, India (Mohanan 2017 unpublished observation). Disease appears during monsoons, subsides, and almost disappear during the dry period. Usually, infection occurs after the onset of south-west monsoon during June, and continues till the end of north-east monsoon during September-October. In high altitude areas, the disease affects reed bamboos during June-July and continues till December-January, often affecting the entire shoots of the clump, depending on the prevailing microclimatic conditions.

SYMPTOMS

Large, water-soaked, irregular lesions with greyish green centres and greyish white margins occur on leaves. Usually, the lesions appear at the base of the leaf and advances towards the tip. Fine silvery white mycelial strands appear on the lower surface corresponding to the lesions on the foliage (Figs. 59-61).

Fig.59 Thread blight in *B. vulgaris*

Spread of the disease is mainly through physical contact of advancing fungal hyphae on diseased foliage with healthy neighbouring foliage. The mycelial weft makes the diseased foliage to stick together at the leaf margins, leaf tips and leaf bases, where they come into contact with each other. The whole foliage of the diseased shoot becomes greyish white, and often appears as though affected by chemicals. Infection causes browning and necrosis, leading to blight of the culm and branches, especially the foliage. White to pale orange pustules develop on the affected plant parts. During the dry period, the blighted foliage dries up, withers and defoliates; but many leaves remain struck together on the dried-up minor branches.

Fig.60 Thread blight in *B. polymorpha* leaves showing mycelial webs

Fig 61 Mycelial weft of *E. salmonicolor* on *O. travancorica* culm

CAUSAL ORGANISMS

The fungi associated with thread blight of bamboo include: *Erythricium salmonicolor* (Berk. & Broome) Burds (= *Botryobasidium salmonicolor* (Berk. & Br.) Venkatanarayanan, = *Pellicularia salmonicolor* (Berk. & Br.) Dastur (Balakrishnan et al. 1990; Mohanan 1994a,b) and *Corticium koleroga* (Cooke)Hohen. (= *Pellicularia koleroga* Cooke (Rogers 1943).

ETIOLOGY

Mycelial threads on the dried-up branches and minor branches perennate during the dry period and form the source of infection. Free water on the host surface and high atmospheric humidity favour the development and spread of the disease. The spread of the disease is mainly through physical contact of plant parts. Hyphae penetrate the internal tissues and cause necrosis. Under conducive environmental conditions, asexual and sexual spores of the fungus produced on the diseased tissues also serve as secondary sources of infection (Mohanan 1997).

DISEASE MANGEMENT

Although the disease is widespread in bamboo stands, no control measure has been suggested. Pruning the diseased branches from affected clumps, and cleaning and burning the debris from the ground around the clumps can minimize the inoculum and disease incidence.

Necrosis of Culm Internode

The disease has been reported in *Thyrsostachys oliveri* plantations in Kerala, India (Mohanan 1990, 1994a,b, 2008). The infection was observed in new culms which were produced late in the growing season i.e., during August-September. Disease incidence was only 1-3% during 1988-90. Possibly, mechanical injuries caused by cattle on the new developing culms open the way for fungal infection.

SYMPTOMS

Small, dark brown to black lesions, invariably associated with a small longitudinal split or crack, occur at the culm node. Lesions spread rapidly upwards and downwards in the internodes, forming a large necrotic area with a pale yellow halo. Under high humidity, the pathogen produces spores on the necrotic tissues. The infection results in the formation of numerous abnormal shoots (epicormic shoots) from the affected nodes (Fig. 62). The internal tissues of the nodes and internodes show pronounced discolouration. The affected culms are easily snapped at the point of infection by wind or animals.

CAUSAL ORGANISM

Curvularia lunata (Wakker) Boedijn, anamorph of *Cochliobolus lunatus* Nelson & Haasis (Mohanan 1994 a,b, 2008).

ETIOLOGY

The fungus is a weak pathogen, which usually enters the host tissue through wounds and causes infection of succulent tissues. The fungus proliferates in the wounded areas and spread to the surrounding tissues. High humidity and free water on the host surface favour disease development.

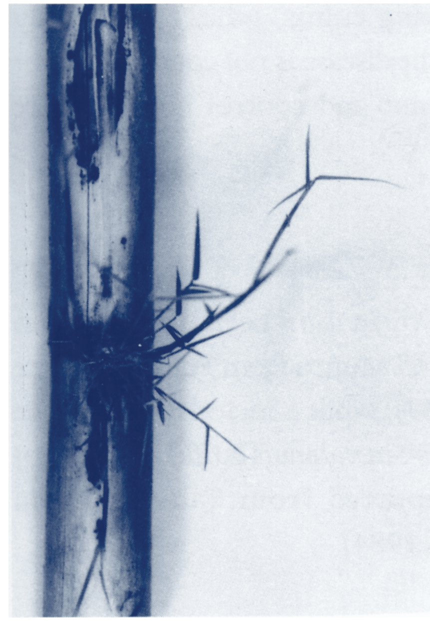


Fig 62 Necrosis of culm internode in *T. oliveri*

DISEASE MANAGEMENT

Since the disease affects only the late emerged and otherwise slow-growing culms, which are usually very few in number, the disease is not considered to be economically important and control measures are seldom considered.

Bamboo Wilt

Wilt disease of bamboo caused by *Fusarium* spp. has been reported on *Dendrocalamus latiflorus* Munro from Fujian Province in China (Xie et al. 1987), and on hybrid bamboo (Ma 2001; Ma et al. 2006,2008). *Bamdusa pervariadilisx Grandis* Nin 3# is a new hybrid species produced using *Bambusa pervariabilis* McClure as female parent and *Dendrocalamopsis daii* Keng f. as male parent, which has the characteristics of wide adaptability, very high shoot number, high branching, fast growing and large output of bamboo wood. This bamboo shoot is of sweet and refreshing taste with better than the other conventional varieties and have very good prospects in the food market in China (Zhao et al. 2004; Liang et al. 2010). Fusarium wilt affecting the hybrid bamboo was first recorded in Liuzhou region of Guangxi Province (Ma 2001; Ma et al. 2006) and at present the disease is widespread in Guangxi Province posing threat to the development of related industries (Liang et al. 2010). Recently, A chronic wilt disease affecting *Phyllostachys edulis* in Yinzhou District, Nigbo, China caused by *Gliocladium* sp. has also been reported (Shi and Wang 2005). While a bacterial wilt disease affecting *Dendrocalamus latiflorus (= Sinocalamus latiflorus* (Munro) McCl.) has been reported from Taiwan-China (Lo et al. 1966; Hsieh 1984; Liang et al. 2010).

SYMPTOMS

In both fungal and bacterial wilt diseases, yellowing of the foliage and premature defoliation occur. The basal part of the culm becomes discoloured and shrivelled. Rhizomes and roots of the affected culms show browning and necrosis. Severe infection leads to death of the culm.

CAUSAL ORGANISMS

Fusarium oxysporum (Ma et al. 2008; Liang et al. 2010); *Fusarium incarnatum (=Fusarium semitectum* Berk. & Rev.); *Gliocladium* sp. (Shi and Wang 2005); *Erwinia sinocalami* Lo.

ETIOLOGY

In the case of wilt disease caused by fungus, the fungal spores on the soil or disseminated by wind and rain splashes serve as the primary inoculum. The spores germinate on wounded areas on roots, rhizome and on the basal part of the culm. The infection spreads to the internal tissues causing damage on vascular tissues and blocks the conduction of water and nutrients resulting plant wilting.

Primary infection occurs during early March and peak infection during April-May. Conidia and ascospores of fungus are produced in the affected tissues. High humidity prevailing in the groves and cold injury on the culm are factors that favour the disease incidence. Optimum temperature for the growth of *F. oxysporum* strains was 24-28^{0}C (Liang et al. 2010). The fungal pathogen overwinters in soil and debris. The overwintered *F. oxysporum* propagules serve as the source of infection for the next season (Ma et al. 2008).

Information on etiology of wilt caused by the bacterium *Erwinia sinocalami* is not available. *E. sinocalami* is very close to *E. amylovora* and *E. carotovora* which cause various diseases in different hosts. The soil-borne bacterial propagule enters the host tissue through wounds and infects the roots and rhizome tissues; infection causes necrosis of the host tissues and affects the conductive system of the plant.

DISEASE MANAGEMENT

Recently, biocontrol experiments employing bacterial suspension were carried out (Qiao et al. 2011). A mutant strain of *Pseudomonas aeruginosa* ZB27 resistant to chloramphenicol was employed for studying its efficacy against the bamboo wilt in hybrid bamboo and application of bacterial suspension gave 70% control effect (Qiao et al. 2011). However, silvicultural measures, including selection of good planting sites and resistant bamboo species, have been suggested for managing the disease.

Bamboo Culm Rust

Fig 63 Culm rust on *Phyllostachys* sp. due to *S.corticioides*, Nanjing, China

Rust affecting the culms of bamboos has been reported from China, Japan and Pakistan (Spaulding 1961; Zhu et al. 1983; Chen et al. 1988; Wu 1993; Ding et al. 2000). The rust fungus affects species of *Bambusa, Chimonobambusa, Phyllostachys, Pleioblastus, Pseudosasa, Sasa, Arundinaria* and *Semiarundinaria* (Fig. 63).

In China, culm rust poses a major problem in bamboo stands. It affects more than 17 species, including *Phyllostachys glauca* McCl., *P. dulcis*, *P. viridis, P. praecox, P. heteroclada, P. incarnate, P. bambusoides, P. nidularia, P. aureosulcata, P. vivax, P. glabrato*, *P. propinqua* McCl., *P. congesta* (Pilger) Holtt., *P. meyeri* McCl., *Pleioblastus vaginatus* (Hackel) Nakai and *P. higoensis* Makino (Chen et al. 1988; Zhang 2000). Since 1978, the rust has spread rapidly in Jiangsu, Hunan, Zhejiang, Anhui, Sandong, Henan, Hubei, Guangxi, Guizhou and Shanxi Provinces in China (Zhang 2000). Severe infection occurs in Zhejiang, Jiangsu and Anhui Provinces affecting bamboo shoot production considerably. *Phyllostachys glauca, P. dulcis, P. praecox,* and *P. viridis* are the worst affected bamboos. Incidence of rust infection in *P. glauca* ranges from 30 to 90% (Zhu and Zhang 1987). In *P. meyeri*, 54% rust incidence has been recorded (Zhu 1988b). Recently, a serious outbreak of culm rust that destroyed about 200 ha of *P. glauca* stands has been reported in Yangzhong County (Chen et al. 1988) Severe disease outbreak was also reported from Dequin County, Zhejiang Province affecting over 10,000 ha of bamboo forest (Zhang 2000). The rust infection has also affected bamboo production for edible shoots (Zhu 1988c).

SYMPTOMS

Rusty patches occur on the lower parts of young culms and emerging shoots and spread upwards. Teliospores are produced on the affected areas during March-May. Later, urediniosori develop and golden yellow urediniospores are produced.

CAUSAL ORGANISM

Stereostratum corticioides (Berk. & Br.) Magn.

ETIOLOGY

Wind-dispersed urediniospores serve as the source of infection. Urediniospores germinate on the culm surface and invade the tissues through wounds. The incubation period is 7-19 months. From the infected tissues, teliosori develop and teliospores are produced; teliospores produce fresh crops of urediniospores. The alternate host of the rust is not known.

DISEASE MANAGEMENT

Silvicultural measures and chemical application against the culm rust have been developed in China. Scraping of the teliospores on the culm and coating the diseased portion with 1:1 coal tar and diesel oil mixture, or applying 15% liquor cresoli saponatus solution (containing liquor cresoli 50%) or Triadimefon solution (25%) + Jingbai-2B (1:1) have been recommended for controlling the rust infection (Li et al. 1986; Zhu and Zhang 1988; Chen et al. 1989; Zhang 2000; Zhong et al. 2000; Dong et al. 2001). Chemical treatment will be effective in controlling infection only if the chemicals are applied in early March, before the development of the urediniospores. Felling and removing the seriously affected bamboo culms and chemical treatment in the groves for 3-4 successive years are necessary to minimize the disease incidence (Zhu et al. 1988; Zhu and Zhang 1987; Zhu 1988b; Wu 1993; Zhang 2000).

Bamboo Culm Smut

Smut that affect culms and spring tips of *Phyllostachys* spp. has been reported from China (Zhu 1988a). The disease affects *Phyllostachys sulphurea* cv. *viridis*, *P. glauca, P. pubescens, P. nigra var. henonis, P. flexuosa, P. bambusoides, P. incarnata, P. congesta, P. aurea, Pleioblastus amarus, P. makinoi, Fargesia* sp., *Arundinaria* spp., *Sasa ramosa* and *Sasa nana* from Zhejiang, Jiangsu, Anhui, Henan, Hunan, Guizhou, Yunnan, Sichuang and Shanxi Provinces in China (Zhang 2000; Xie et al. 2007,2007). A smut disease affecting *Bambusa* sp. was reported by Pavgi and Mundkur (1948) from India; however, later it was confirmed by Thirumalachar and Pavgi (1950) that the pathogen was not an *Ustilago* sp. but *Papularia arundinis* (Corda) Fr.)

SYMPTOMS

Fungal spores cause black patches on culms and spring shoot tips; secondary shoots are usually free from infection (Fig. 64) in severely infected groves, all the spring tips become infected all over the surface, year after year.

Fig 64 Culm smut on *Phyllostachys* sp. caused by *B. shiraiana*; early symptoms and late symptoms (Source: Zhu and Zhang 1987)

CAUSAL ORGANISM

Bambusiomyces shiraianus (Henn.) Vanky (= *Ustilago shiraiana* P. Henn. (Zhu 1988a; Zhang 2000)

ETIOLOGY

Chlamydospores of the pathogen serve as the inoculum, which gets through to young shoots of bamboo from the soil surface. Chlamydospores do not have any resting period. The optimum temperature for spore germination is 20-21^{0}C. Under high atmospheric humidity (98-100%), the spores germinate and very short germ tubes are produced. Basidiospores grow in a budding way; they penetrate the host tissue, produce dikaryotic mycelium and cause typical infection.

DISEASE MANAGEMENT

Planting smut-resistant bamboo species and carrying out appropriate culm tending, including cutting and burning the severely infected shoots, are recommended for managing the disease (Zhu 1988a; Zhu and Zhang 1987; Zhang 2000).

Culm Staining and Die-back

The disease has been reported on *Bambusa vulgaris* and *Dendrocalamus longispathus* in Kerala, India (Mohanan 1994a,b; 1997, 2008). The disease was observed only in developing culms during July-August. In a *B. vulgaris* plantation, 10-98% disease incidence was recorded while in a *D. longispathus* plantation, the average disease incidence was 7% during 1990-92. The disease was observed to be brought on by wounds made by the bamboo hispine beetle *Estigmena chinensis*. The severity of infection depends on the build-up of the insect population during the culm emergence and growing stages. Die-back of culms in successive years results in the death of clumps.

SYMPTOMS

Pale purple to dark brown, linear lesions develop around the bore hole wounds on the growing culm. These later spread to the entire culm internodes and become necrotic. Raised black fructifications of the causal fungus develop on the affected internodes during September-October (Figs. 65, 66).

Infection also spreads to branches and minor branches. Usually, the discolouration of culm internodes, as well as the later necrosis and die-back, starts from the distal end and spreads towards the base of the culm. The affected branches and culm become completely covered with black fructifications of the fungus.

CAUSAL ORGANISM

Apiospora sp. (Mohanan 1994b, 1997).

ETIOLOGY

Infection appears to be brought on by borehole injuries made by the bamboo hispine beetle on newly developing culms. The culm borer attacks juvenile culms and makes 1-2 mm bore holes usually at each node. The wind dispersed spores of the fungus serve as the source of infection. The fungus, which is a wound parasite, enters the host tissue through the bore holes. Infection spreads very fast in the succulent tissues of the culms and causes staining and discolouration. The severity of infection depends on the insect activities and high atmospheric humidity.

Fig 65 Culm staining of *B. vulgaris*

DISEASE MANAGEMENT

Since infestation by bamboo culm borer predisposes bamboos to invasion by the fungus that causes the disease, the build-up of the borer population has to be checked. Application of the insecticide Endosulphan (0.05% a.i.) on emerging and growing culms is desirable for reducing damage to the culms.

Sooty Stripe Disease

Sooty stripe disease affecting the minor branches and culms of *Bambusa* sp. has been reported from India (Thirumalachar and Pavgi 1950). Earlier, the disease was described as a smut disease (Pavgi and Mundkur 1948). The disease is symptomatically similar to the staining and die-back disease. The disease, also known as ‘culm brown streak’, has been reported on widely cultivated bamboo, *Phyllostachys praecox* in Jiangsu and Zhejiang Provinces in China (Chen et al. 2014,2015).

Fig 66 Culm staining of *B. vulgaris*; note the fructifications of *Apiospora* sp.

SYMPTOMS

Discolouration on broken young branches occur and this gradually spreads downwards to the culm. The diseased tissues become greyish brown and later dry up. Infection always starts near a wounded area, and spreads downwardsd as a die-back. Linear sori develop and cover the entire diseased surface. They later coalesce to form long erumpent striae. Flaking away of the epidermis of infected tissues exposes powdery black masses of fungal spores, which get dispersed by wind. In the case of infection of *Phyllostachys praecox*, small yellow or sandy beige spots (1 to 2 mm diameter) develop initially on the culm, which expand and develop into fine brown streaks (10 to 15 × 1 to 2 mm), and the number of spots increases greatly at the mid-stage of the disease. The streaks continue to expand (10 to 30 × 2 to 3 mm) and may coalesce into brown patches that cover 70% of the culm surface in late stages of disease. Colour of the internal bamboo cavity gradually changes from white to brown without an alcoholic odour, and plants eventually die (Chen et al. 2014).

CAUSAL ORGANISMS

Arthrinium arundinis (Corda) Dyko & B. Sutton *(= Papularia arundinis* (Corda) Fr. *(=Coniosporium arundinis* (Corda) Sacc.) (Thirumalachar and Pavgi 1950) and *Arthrinium phaeospermum (= P. sphaerosperma* (Pers.) Honel) (Mason 1933; Sprague 1950).

ETIOLOGY

The fungus is a wound-parasite. It incites the formation of elongated stripes on culms, disintegrating the tissues and producing abundant brownish black conidia. The wind-dispersed conidia serve as the source of infection. The optimum temperature for disease development in *Phyllostachys praecox* was 20°C to 25°C (Chen et al. 2015). The temperature which was below 5°C or above 30°C was not conducive for the development of the disease and the peak of the disease appeared between May to July. The spores of *Arthrinium arundinis* could overwinter in rice hulls, spread by airflow or rain and infect through the wounds. *Phyllostachys praecox* stands in the forest edge or the older bamboo, such as 3 or 4 year-old were infected easily (Chen et al. 2014,2015).

DISEASE MANAGEMENT

The disease is not very damaging and control measures are seldom required.

A Note on Fungal Stains on Culms

Many fungi cause stains on culms, particularly when the culms have been subjected to excessive humidity and lack of sunshine. Usually, fungal stain causes blemishes, spots, streaks and lesions of different shades of grey to black and affects the aesthetic quality of culms. However, fungal stains which give a decorative appearance to the culms are highly prized in China and Japan for the manufacture of decorative panels and musical instruments (Figs. 67, 68). Quite a large number of such staining fungi have been recorded on different species of bamboos in various countries. The best known among these are: *Lembosia tikusensis* Hansf. on *Phyllostachys nigra* (Lodd.) Munro; *Asterinella hingensis* I. Hino & Hidaka on *P. bambusoides* (the most valued); *Asterosphaeriella fuscomaculans* Yamamoto on *P. nigra* var. *henonis.*

This fungus causes an irregularly elliptic speck, dark brown or with fine white stripes, on the culms, and the mycelium appears on the whole surface of the bamboo (Yamamoto et al. 1954); *Phragmothyrium semiarundinariae* I. Hino & Hidaka on *Semiarundinaria narikissae; Chaetosphaeria macrospora* (Kawam.) Hara *(=Miyoshiella macrospora* Kawam.) on *Bambusa shimadai* Hayata; *Chaetosphaeria fusispora* (Kawam.) Hino *(= Miyoshiella fusispora* Kana) on *Arundinaria narihira* Makino; *Phragmothyrium bambusicola* (Henn. & Shirai) I. Hino (= *Micropeltis bambusicola* P. Henn. et Shirai) on *Sasa paniculata* Makino et Shib. (Mohanan and Liese 1990).

Other culm-staining fungi reported (Bruhl and Sengupta 1927; Saikia and Sarboy 1982, 1985; Mohanan 1994a,b) include: *Balladyna butleri* Syd. & P. Syd., *Meliola bambusicola* Hansf. *Capnodium* sp., *Astrocystis mirabilis Berk.* Br., *Coniosporium bambusae* Henn., *Arthrinium arundinis* (=*Papularia arundinis*), *Geotrichum* sp., *Bambusaria bambusae* (J.N. Kapoor & H.S. Gill) Jakltsch, D.Q. Dai, K.D. Hyde & Voglmayr. (= *Valsaria bambusae* Kapoor & Gill), *Penicilliopsis bambusae* Nag Raj & Govindu, *Arthrinium* sp., *Arthrinium arundinis* (= *Apiospora montagnei*), *Apiospora indica, Xenosporium indicum* Panwar, Purohit & Gehlot, *Trichoderma* sp., *Aspergillus* sp., *Tremella fuciformis* Berk., *Periconia digitata* (Cooke) Sacc., *P. cookei* Mason et M.B.Ellis, and *Morrisiella indica* Saikia et Sarboy.

Fig 67 Culm staining on *P. edulis,*Japan

Fig 68 a Culm staining on *T. oliveri,*Kerala, India

Fungal staining on *Melocanna baccifera* (Roxb.) Kurz culms caused by *Arthrinium arundinis* (= *Apiospora montagnei* Sacc) has been reported from Pakistan (Khan 1960).

Recently, flyspeck signs on bamboos in China caused by *Cyphellophora sessilis* (de Hoog) Reblova & Unter (= *Phialophora sessilis* de Hoog) has been reported (Zhuang et al. 2010).

Fig 68 b Culm staining on *D. strictus,*Kerala, India

Foliage Blight

Foliage blight has been reported in bamboo plantations and natural stands in Kerala, India (Mohanan 1994a,b,1997,2008). The disease was observed on *Bambusa bambos, Dendrocalamus brandisii, D. longispathus, D. strictus and Pseudoxytenanthera ritcheyi* stands. About 80-97% disease incidence with low to medium severity was recorded in various plantations during 1991.

SYMPTOMS

Small, water-soaked, greyish brown, spindle-shaped lesions appear on both young and mature leaves during August-September. Around these lesions, pale yellow to yellowish orange haloes develop. The lesions coalesce and form large, spreading, irregular, greyish brown to yellowish brown lesions with dark brown borders, often covering the entire leaf lamina. Such leaves become necrotic and blighted. The colour of the lesion, its size and nature of spread vary slightly, depending on the bamboo species, leaf maturity, associated fungal species and prevailing microclimatic conditions.

Fig 69 Foliage blight in *B. bambos* due to *B. maydis*

Severe infection causes yellowing of the foliage, followed by leaf blight and withering. Often, greyish black to black fungal spore mass develops on the lower surface of the necrotic areas in the blighted foliage (Figs. 69-71).

Fig 70 *D. longispathus* leaves showing early stages of infection

CAUSAL ORGANISMS

Bipolaris maydis (Nisikado & Miyake) Shoem., anamorph of *Cochliobolus heterostrophus* (Dresch.) Dresch., and *Bipolaris bambusae* Mohan. (Mohanan 1994a,b).

Fig 71 *O. wightii* leaf showing Bipolaris infection

ETIOLOGY

Conidia of the fungus, dispersed through wind or rain splashes, germinate on the leaf surface and invade the leaf tissue through stomata; direct penetration through the epidermis also occurs. The fungal hyphae proliferate in the affected tissues and cause necrosis. The fungus sporulates in the necrotic tissues of the host under high humidity and the spores serve as the source of secondary infection. Warm-humid conditions favour the spread of the infection.

DISEASE MANGEMENT

Application of fungicides - Difolatan (0.2% a.i.) or Fytolan (0.4% a.i.) - is suggested for controlling the foliage disease in young bamboo stands.

Leaf Rusts

Leaf rusts, caused by more than 29 rust fungi belonging to the five genera *Kweilingia* (= *Dasturella*), *Puccinia, Uredo, Phakopsora* and *Tunicopsora,* have been reported on various species of bamboos from China, Hongkong, India, Japan, Malaysia, the Philippines, Singapore, Sri Lanka, Taiwan-China, Thailand and Vietnam. Leaf rusts caused by different genera of rust fungi are treated separately.

Kweilingia Leaf Rust

Kweilingia leaf rust on different species of bamboos has been reported from India (Mundkur and Kheswala 1943; Thirumalachar et al. 1947; Sujan Singh and Bakshi 1964; Mohanan 1994b,2005,2010), Taiwan-China (Sawada 1921; Lee 1995), Japan, Vietnam, Pakistan and Singapore (Spaulding 1961; Cummins 1971; Mao 1993; Zhu 1989; Hatakayama et al. 2005; Hashimoto et al. 2010; Zhang 2000; Ding et al. 2001; Xie et al. 2006; Zhou et al. 2011). Recently, the rust infection was also observed in *Bambusa vulgaris, Dendrocalamus asper* (Schultes) Baker ex Heyne and *D. strictus* stands in Kanchanburi, Thailand, and in *B. vulgaris* and *Gigantochloa* sp. stands in the Philippines (Mohanan 1995, unpublished observation).

In India, the rust disease is widespread in bamboo plantations and natural stands. Rust infection was recorded *B. balcooa, B. bambos, B. multiplex, B. polymorpha, B. tulda, B. tuldoides, B.*

vulgaris, D. brandisii, D. hamiltonii Nees et Arn. ex Munro, *D. lojngispathus, D. strictus, Pseudoxytenanthera ritcheyi* (Munro) Naithani, *Thyrsostachys oliveri, T. siamensis, Ochlandra travancorica* and *O. scriptoria* (Mohanan 1990, 1994a,b,2010; Vanitha et al. 2015). In bamboo plantations and natural stands in Kerala State, 30-100% disease incidence with low to medium disease severity was recorded during 1988-91 (Mohanan 1994b, 2005, 2008, 2010).

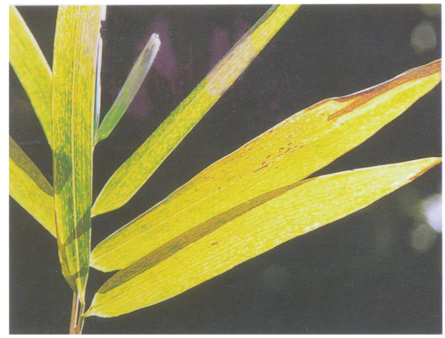


Fig 72 Leaf rust in *P. ritcheyi* causedby *K. divina*

In Taiwan-China, the rust infection has been reported on *B. oldhamii* and *D. latiflorus* plantations (Lee 1995). A severe outbreak of rust infection, affecting the stand productivity and quality of shoots, has been reported from Nan-Tou, Yun-Lin, Chiayi, Tainan, Kaoshsiung and Pingtong Counties in Taiwan-China (Ye 1983; Lee 1995). Disease incidence recorded was low (0.2%) during May, but increased in December covering about 36% of the leaf area (Yeh 1983).

Fig 73 Leaf rust in *D. strictus* causedby *K. divina*

Kweilingia leaf rust infection has also been reported on *B. multiplex, B. oldhamii, B. shimadai, D. latiflorus and Bambusa* sp. in Japan, on *Sasa* sp. in Zhejiang, Guangdong and Sichuang Provinces in China (Zhang 2000), and on *D. membranaceus* in Vietnam.

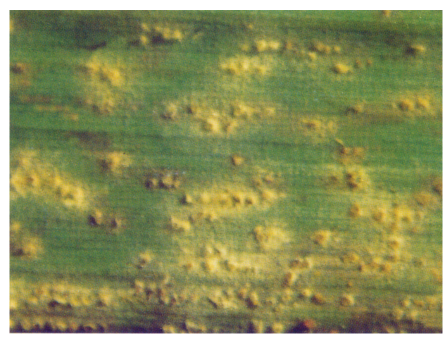


Fig 74 A magnified view of urediniosori of *K. divina*

SYMPTOMS

Water-soaked pin-head flecks appear on the lower surface of the foliage, where yellowish orange to rust brown, linear urediniosori develop. On the upper surface corresponding to the flecks, greyish brown to dark brown lesions with yellowish orange haloes form. Often numerous such lesions develop on a single leaf lamina and later coalesce to spread over the entire leaf (Figs. 72-74).

Severe infection causes yellowing and necrosis of the leaf tissues between the spots. Uredinia develop during June-July and continue to produce bright yellowish orange urediniospores till April-May. Development of uredinia on the upper surface of the leaves also occurs, though rarely. Teliosori develop linearly on the lower surface of the foliage, either in the degenerating urediniosori or separately during October. Severe uredinial infection causes yellowing of the foliage, followed by necrosis leading to abnormal defoliation even before the development of teliosori.

CAUSAL ORGANISMS

Rust fungi associated with the disease include: *Kweilingia divina (*Syd.) Buritica (= *Dasturella divina* (Syd.) Mundk. & Khes. *(= Dasturella oxytenantherae* Sathe; *Puccinia inflexa* Hori ex Fujik.*; = Uredo inflexa* Ito) (Thirumalachar et al. 1947; Sathe 1965; Bakshi and Singh 1967; Mohanan 1994 a,b, 2011; Lee 1995); *Dasturella bambusina* Mundk. & Khes. (Mundkur and Kheswala 1943), and *Dasturella* sp. (Rangaswami et al. (1970).

ETIOLOGY

Kweilingia divina is a heteroecious rust. In India, the rust alternates between *Randia* spp. (= *Catunaregum*) and bamboo, and produces pycnia and aecia on the former and uredinia and telia on the latter (Mohanan 2005, 2011). Bright orange aecia are produced on the leaves and fruits of *R. dumetorum* Lam*., R. brandisii* Gamb. and *R. candolleana* during May-June. The aeciospores serve as the source of infection of bamboos. The aeciospore germ tube penetrates through stomata. Extensive development of intercellular hyphae occurs and later, uredinia develop in the infected area. Urediniospores produced in June-July readily infect the healthy leaves of bamboo, causing secondary infections, and are mainly responsible for the spread of the disease. After the development of uredinia, telia develop in the uredinial cavity or separately during October. Teliospores remain fused both laterally and at either ends to form a fan-shaped, crusty head. The epidermis ruptures and the telial column becomes exposed. Teliospores require a rest period of 2-3 months (Mohanan 2005,2010; Mohanan and Yeshodharan 2005).

DISEASE MANAGEMENT

Although leaf rust is widespread in bamboo plantations and natural stands, the disease is not considered as economically important and control measures are seldom required. However, in *Bambusa oldhamii* and *Dendrocalamus latiflorus* plantations in Taiwan-China, rust infection had great impact on photosynthesis, which, in turn, affected the growth and vigour of the infected clumps and thus decreased the stand productivity. Intensive stand management, including removal of alternate hosts and integrated pest control measures, are recommended in such cases.

Puccinia Leaf Rust

Puccinia leaf rust has been reported in different species of bamboos from India (Sydow and Butler 1907; Butler and Bisby 1960; Bakshi and Singh 1967; Mohanan 1997; 2005), China, Hongkong, Japan, the Philippines and Taiwan-China (Kusano 1908; Spaulding 1961; Cummins 1971; Yeh 1983; Hsieh 1987; Kobayashi and Guzman 1988; Zhu 1989; Wei and Zhuang 1990; Zhuang and Wei 1992; He et al. 1993a,b,c; Zhang 2000; Zhou et al. 2010; Ye and Wu, 2012; Ye et al. 2011; Shen et al. 2017).

SYMPTOMS

Infection appears in the form of yellowish brown to dark brown, linear urediniosori scattered on the leaves, Telia, yellowish to dark brown or black depending on the rust fungal species, are scattered or serially arranged along the veins on the lower surface of leaves (Fig. 75). Severe infection leads to leaf blotching, withering and premature defoliation. In general, bamboo leaf rust caused by *Puccinia* spp. affect the growth of bamboos considerably.

Fig 75 Leaf rust in *Bambusa* sp. due to *Puccinia melanocephala*

CAUSAL ORGANISMS

A total of 25 species of *Puccinia* have been reported on different bamboos in Asia. These include:

1. *Puccinia aduncta* F. He & Kakish. On *Sasa chartacea* var. *nana* (Koidzumi) S. Suzuki in Japan (He et al. 1993a);
2. *Puccinia bambusicola* Weid & Xhaung on *Bambusa* sp. in Western Hunan Province in China (Wei and Zhuang 1990);
3. *Puccinia cymbiformis* F. He & Kakish. on *Phyllostachys nigra* var. *henonis* in Japan (He et al. 1993b);
4. *Puccinia dispori* Syd. on *Phyllostachys pubescens*, *P. aurea* in Zhejiang, Jiangsu, Henan, Guangdong Provinces in Chiana (Zhang 2000).
5. *Puccinia ditissima Syd. (= U. ditissima* (Syd.) Cumm.) on *Dendrocalamus latiflorus* in Taiwan-China (Lee 1995; Zhang 2000) and in *Schizostachyum lumampao* (Blanco) Merr. from the Philippines;
6. *Puccinia flammuliformis* Hino et Katumoto on *Bambusa* sp. and *S. tesselata* (Munro) Makino et Shibata in China (Cummins 1971);
7. *Puccinia gracilenta Syd*. et Butler on *Bambusa* sp. in India (Bakshi and Singh 1967);
8. *Puccinia hikawaensis* Hirats f. & S. Uchida on *Sasa kesuzu* Muroi et Okam in Japan;
9. *Puccinia ignava* (Arthur) Arthur (= *Uredo ignava* Arth. on *Bambusa bambos, B. vulgaris, Dendrocalamus* sp., *Schizostachyum* sp. from *Malayasia* and China (Cummins 1971), on *D. latiflorus* from Taiwan-China (Lee 1995), and on *Dendrocalamopsis oldhami* (= *Bambusa oldhamii*) in China (Zhang 2000; Ma et al. 2005);
10. *Puccinia kusanoi* Diet. On *Dendrocalamus latiflorus* in the Philippines (Quiniones and Dayan 1981), on *Nipponobambusa* sp., *Phyllostachys* sp., *P. pubescens, P.aurea Pseudosasa* sp., *Pleioblastus* sp., *Sasa* sp., *Sasaella* sp., *Semiarundinaria* sp., in Zhejiang, Anhui, Fujian, Guangxi, Yunnan and Shanxi Provinces in China (Zhang 2000), Japan and Taiwan-China (Cummins 1971). The rust also affects *Yushania niitakayamensis* in Taiwan-China (Shen et al. 2017). *Deutzia pulchra* is the aecial host of *P. kusanoi*. More than 20% of plants in Tataka and Nantou regions showed severe rust infection. Brownish lesions surrounded with yellow halo were seen on the leaves. Uredinia were brown errumpting through the epidermis on the

adaxial side of the leaves (Shen et al. 2017). *Puccinia kusanoi* alternates between *Yushania niitakayamensis* and *Deutzia pulchra* to complete its life cycle in mountainous areas in Taiwan-China (Shen et al. 2017).

11. *Puccinia kwanhsiensis* F.L. Tai on *Arundinaria atropurpurea* in Anhui, Fujian, Guangxi, Yunnan Provinces in China (Zhang 2000).
12. *Puccinia longicornis* Pat. et Hariot on *Nipponobambusa* sp., *Pleioblastus* sp. and *Sasaella* sp., *S. sendaica* in Anhui, Fujian, Guangxi, Yunnan and Shanxi Provinces in China (Zhang 2000).
13. *Puccinia melanocephala* H. Syd. et P.Syd. on *Arundinaria* sp. and *Bambusa* sp. in India (Butler and Bisby 1960); on *Arundinaria okadana, Disporopsis arisanensis* in Sichuang Province in China (Zhang 2000).
14. *Puccinia mitriformis* S. Ito on *Sasa paniculata* Makino, *Sasa septentrionalis* Makino, *Sasamorpha ambailis* Nakai and *S. purpurascens* Nakai in Japan (Zhu 1989);
15. *Puccinia nigroconoidea* Hino et Katumoto on *Phyllostachys* sp. in China (Cummins 1971);
16. *Puccinia phyllostachydis* S. Kusano on *Phyllostachys bambusoides*, *P. aurea* and *P. nigra* var. *henonis* in China (Zhang 2000), Japan and Taiwan-China (Cummins 1971; Hsieh 1987), on *Drepanostachyum suberecta* (Munro) Majumdar (=*Arundinaria suberecta* Munro) in India;
17. *Puccinia polliniae* Barclay on *Phyllostachys pubescens, P. aurea, Arundinaria atropurpurea* in Anhui, Fujian, Guangxi, Yunnan Provinces in China (Zhang 2000).
18. *Puccinia polliniae-imberbis* (S. Ito) Hirats. on *P. pubescens, P. aurea, Bambusa* spp. in Anhui, Fujian, Guangxi, Yunnan Provinces in China (Zhang 2000).
19. *Puccinia polliniicola* Syd. on *Bambusa tessellata, Ischurchola spinosa, Bambusa oldhami, B. vulgaris, Bambusa* spp. in Anhui, Fujian, Guangxi, Yunnan and Shanxi Provinces in China (Zhang 2000).
20. *Puccinia sasicola* Hara ex Hino et Katumoto on *Sasa borealis* Makino, S. kesuzu Muroi et Okam. in Japan (Cummins 1971);
21. *Puccinia sasae* Kusano on *Sasa* sp. in Japan (Zhu 1989);
22. *Puccinia scabrida* F.He & Kakish. on *Phyllostachys* sp. in Japan (He et al. 1993c);
23. *Puccinia sinarundinariae* J.Y. Zhuang & S.X. Wei on *Sinarundinaria nitida* in Japan (Wei and Zhuang 1990);
24. *Puccinia tenella* Hino et Katumoto on *Bambusa* sp. in China and Hongkong (Spaulding 1961; Cummins 1971; Kobayashi and Guzman 1988); and
25. *Puccinia xanthosperma* Syd. & P.Syd. on *Bambusa* sp. in India (Butler and Bisby 1960; Nema and Mishra 1965).

ETIOLOGY

Puccinia leaf rust of bamboo is caused by about 25 species of *Puccinia* including *Puccinia phyllostachydis* and *Puccinia longicornis.* Data on etiology and disease cycle are not available for most *Puccinia* spp. The overwintering of *Puccinia phyllostachydis* and *Puccinia longicornis* was mainly as the mode of teleutosorus on bamboo leaf. The primary infection source of the pathogens is the urediniospore produced by the mycelium under the teleutosorus, and the primary infection of *P. phyllostachydis* also includes the few uredinium that can live through the winter.

The bamboo leaf rust has an incubation period of 10-15 days. After several infections by urediniospores, the conditions of the disease reach peaks from June to October. During the process, heteroecism never occurs (Zhou et al. 2010). *Puccinia kusanoi* alternates between *Yushania niitakaymensis* and *Deutzia pulchra* to complete its life cycle in mountainous areas in Taiwan. *Deutzia pulchra* is the aecial host of *P. kusanoi* (Zhou 2010; Ye et al. 2011; Shen et al. 2017).

DISEASE MANAGEMENT

Bamboo leaf rust disease caused by *Puccinia* spp. affects the growth of bamboo severely. The severity of bamboo rust infection was often reduced by the presence of hyperparasitism on rust pustules. The hyperparasitism on rust pustules occurs naturally in the end of April or early May and peaked in the middle of August, then decreased slowly. The hyperparasites lived on uredia showing the white mold-like spots, which hindered development and release of urediniospores. The hyperparasite was identified as *Acremonium salmoneum* (Ye et al. 2011). Recently, biocontrol measures employing hyperparasite *Acremonium salmoneum*, in severely infected bamboo stands in China showed that control effect reached 64.8%. To improve the disease management further, measures for moisture preservation at the preliminary stage are suggested (Ye and Wu 2011, Ye et al. 2011, 2012). *Puccinia ignava* infection can be managed by application of fungicides Triadimefon and Kejunning. Field control tests showed that the fungicides Triadimefon and Kejunning could satisfactorily control the germination of the urediniospore of *Puccinia ignava*, with efficiency rates of 70% and 67%, respectively (Ma et al. 2005).

Uredo Leaf Rust

Uredo leaf rust affecting different bamboos has been reported from Singapore, Sri Lanka, China, the Philippines, Taiwan-China and Malaysia (Spaulding, 1961; Cummins, 1971; Lee, 1995; Ma et al. 2005). Information on severity and economic importance, etc. is not available.

SYMPTOMS

Infection appears as development of orange-brown urediniosori arranged linearly and scattered on the lower surface of the leaves. Severe infection leads to leaf blotch and premature defoliation.

CAUSAL ORGANISMS

A total of seven species of *Uredo* have been reported on different species of bamboos. These include: *Uredo arundinariae* Syd. and *Uredo sasae* Ito on *Arundinaria* sp. and *Sasa* sp. from Japan (Zhu, 1989); *Uredo arundinis-donacis* F.L. Tai on *Bambusa* spp., *Phyllostachys* sp., *Sasa septentrionalis, Sinarundinaria* spp., *Sasamorpha amabilis* in Zhejiang, Anhui, Guangdong Provinces in China (Zhang 2000). *Uredo bambusae-nanae* J.M. Yen on *Bambusa nana* Roxb. from Singapore and India; *Uredo dendrocalami* Petch on *Dendrocalamus strictus* from Sri

Lanka and on *Dendrocalamus latiflorus* from China (Cummins 1971); *Uredo inflexa* S. Ito (= *Physopella inflexa* (S. Ito) Buritica & J.F. Hennen) on different species of bamboos in Zhejiang, Hennan, Hubei Provinces in China (Zhang 2000); *Uredo ochlandrae* Petch on *Ochlandra stridula* Thwait from Sri Lanka (Spaulding 1961; Cummins 1971).

ETIOLOGY AND CONTROL

Information is not available on the etiology and disease cycle of the Uredo rust infection in bamboos. Since this rust infection is not an economically important one, control measures are not required.

Phakopsora Leaf Rust

This leaf rust disease has been reported in *Bambusa bambos, B. vulgaris, B. blumeana, Dendrocalamus asper, D. latiflorus, Gigantochloa levis* (Blanco) Merr. and *Phyllostachys* aurea in the Philippines (Dayan 1988).

SYMPTOMS

Tiny, yellowish flecks appear on the margins of the upper leaf lamina. Later, infection progresses towards the midrib and the colour of the flecks turns to brown. Dark orange urediniosori develop on the flecks (Fig. 76). The flecks later coalesce to form large necrotic areas.

CAUSAL ORGANISM

Phakopsora loudetiae Cumm. (Dayan 1988).

ETIOLOGY

The urediniospores germinate on the leaf surface and an appressorium is formed. Infection hyphae produced from the appressorium penetrate the leaf tissue within 24 hours.

DISEASE MANAGEMENT

The rust infection is of minor importance and control measures are not required.

Fig 76 Leaf rust in *D.latiflorus* due to *P. loudetiae,* Laguna, the Philippines

Tunicopsora Foliage Rust

Tunicopsora foliage rust affecting *Dendrocalamus strictus* has been reported from India (Sujan singh and Pandey 1971; Bakshi et al. 1972). The rust has been recorded as infecting the leaf sheaths, resulting in the death of leaves and minor branches above the region of infection.

SYMPTOMS

Development of orange-yellow urediniosori occurs on the upper surfaces of the leaf sheaths and petioles in September, and continues to appear until August of the following year. Teliosori develop in a continuous and concentric black sheath all along the length of the leaf sheath and petiole during monsoon in July-August. Severe rust infection results in the death of leaves and minor branches above the region of infection.

CAUSAL ORGANISM

Tunicopsora bagchii Singh & Pandey (Sujan Singh and Pandey 1971).

ETIOLOGY

Tunicopsora bagchii is very similar to *Kweilingia divina* (= *Dasturella divina*) in morphological characteristics of uredinial and telial stages; however, the life cycle of this rust is not known. The urediniosori are deep seated in the cortex and rupture the epidermis. The urediniospores serve as the secondary source of inoculum and spread of infection. Telia develop within the uredia along with urediniosori, appearing in groups at the periphery of uredia.

DISEASE MANAGEMENT

The rust infection is not very important and control measures are not required.

Leaf Spots

Exserohilum Leaf Spot

This leaf spot disease has been reported on *Dendrocalamus strictus*, *D. longispathus* and *Bambusa polymorpha* stands in Kerala State (Mohanan 1990, 1994a,b; 1997,2008), and in *D. strictus* plantations in Madhya Pradesh, India (Harsh et al. 1989). The disease was observed on mature leaves by the end of the rainy season in September and persisted till leaf fall. In young plantations, the disease incidence was high but infection restricted to leaves on the lower branches.

SYMPTOMS

Small, water-soaked, greyish black, linear to irregular lesions appear on mature leaves, and later coalesce and spread to the entire leaf lamina. The infection appears in August-September; leaf necrosis, withering and premature defoliation occur in October. The fungus sporulates profusely on the lower surface of the affected leaves (Figs. 77, 78).

CAUSAL ORGANISMS

Exserohilum rostratum (Dresch.) Leonard & Suggs, anamorph of *Setosphaeria rostrata* Leonard (= *Drechslera rostrata* (Drech.) Richardson & Fraser) and *Exserohilum holmii* (Luttr.) v. Arx., anamorph of *Setosphaeria holmii* (Luttr.) Leonard & Suggs (Mohanan 1990, 1994a,b). Recently, leaf spot caused by *Helminthosporium arundinis* Sawada on *Arundinaria* spp., *Dendrocalamus latiflorus, Phyllostachys* spp., *Pleioblastus amarus* in Zhejiang, Hunan and Fujian Provinces in China has been reported (Zhang 2000).

Fig 77 Leaf spot in *B. bambos* caused by *E. rostratum*; note the sporulation of the causal fungus

ETIOLOGY

Conidia of the causal fungus germinate on the host surface and the infection hyphae enter through stomata. Hyphal proliferation occurs in the mesophyll tissues and the infected tissues become necrotic. High humidity and low temperatures (20-27^{0}C) favour disease incidence and spread. The fungus sporulates profusely on the lower surface of the affected leaves and these conidia serve as the source of secondary infection.

Fig 78 Leaf spot in *D. longispathus* caused by *E. holmii*

DISEASE MANAGEMENT

Application of fungicides, such as Difolatan (0.25% a.i.) or Fytolan (0.4% a.i.), is suggested for controlling the disease in severely affected young clumps.

Zonate Leaf Spot

Zonate leaft spot has been reported on different species of bamboos in Kerala, India (Mohanan 1994a,b, 2008). The disease was recorded in *Bambusa bambos*, *B. polymorpha, Dendrocalamus strictus, D. longispathus, Ochlandra travancorica, O. scriptoria, O. ebracteata, Pseudoxytenanthera ritcheyi* and *Thyrsostachys* sp.

Infection was usually observed on foliage in the lower branches; development of zonate leaf lesions and spread of infection depends on bamboo species as well as on local microclimatic conditions.

SYMPTOMS

Minute, greyish brown spots 2-3 mm across appear in late July. The spots enlarge to 5-8 mm and become yellowish brown with dark brown margins. The spots further spread and form reniform, semi-circular to circular, greyish brown area 5-10 mm in width, and having dark brown wavy margins around the light coloured central spot. Later, these develop into large zonate leaf spots of 3-12 cm diameter, depending on the bamboo species and microclimatic conditions. In *Ochlndra travancorica* and *O, ebracteata*, a single spot often spreads and develops into a large zonate spot of 10-12 cm, extending the whole width of the leaf (Fig. 79). In *Bambusa bambos* and *Dendrocalamus strictus*, only two to three concentric rings develop around the central spot. In *Pseudoxytenanthera ritcheyi* and *Thyrsostachys* sp., after the development of one or two rings around the central spot, under very humid conditions, the outer ring, coloured deep magenta to dark brown, spreads to the entire leaf lamina.

Fig 79 Zonate leaf spot in *O. travancorica* caused by *D. bambusina*

CAUSAL ORGANISM

Dactylaria bambusina Mohan. (Mohanan 1994a, b; 1995d).

ETIOLOGY

The causal fungus enters the host tissue through stomata. Proliferation of fungal hyphae in the mesophyll causes necrosis of the tissues. Warm-humid environmental conditions favour the development and spread of infection. Conidiophores develop from the necrotic tissues, and the conidia produced abundantly serve as the secondary source of inoculum.

DISEASE MANAGEMENT

Since the disease is not a serious one, control measures are seldom required.

Colletotrichum Leaf Spot

The disease has been reported in different species of bamboos in Malaysia (Azmy and Maziah 1990), China (Zhang 2000), and India (Mohanan 1990, 1994b,2005,2008). In Malaysia, the disease has been recorded on *Gigantochloa ligulata* Gamble, *Bambusa vulgaris, B. vulgaris* var. *striata, Dendrocalamus asper* (Schultes) Baker ex Heyne, *D. giganteus* Wallich ex Munro, *D. pendulus* Ridley, *Gigantochloa levis* (Blanco) Merr., *G. latifolia* Ridley, *G. rostrata* Wong and G. *scortechinii* Gamble. The leaf spot disease has been recorded on *Phyllostachys pubescens, Phyllostachys* spp. and *Bambusa vulgaris* in Zhejiang and Guangdong Provinces in China (Zhang

2000). In India, the leaf spot has been recorded on *Arundinaria* sp., *Bambusa bambos*, *Dendrocalamus strictus*, *Ochlandra travancorica, P. ebracteata* and *O. Scriptoria* (Mohanan 1997)

Fig 80 Leaf spot in *D. strictus* caused by *C. gloeosporioides*

Fig 80 Leaf spot in *B. bambos* caused by *C. gloeosporioides*

SYMPTOMS

Water-soaked, small greyish brown spots occur on juvenile as well as on mature leaves. These spots spread and coalesce to form large, dark brown to purple, linear to irregular areas, which often cover the entire leaf lamina. Infected foliage become pale yellowish green and leathery. Infected leaves also show symptoms of chlorosis, which later turns necrotic during advanced stages (Fig. 80, 81). The necrotic area often becomes thin and detaches very easily, and shot-holes are formed. Infection also spreads to branches and minor branches, causing discolouration and necrosis. Severe infection results in premature defoliation.

CAUSAL ORGANISMS

Colletotrichum gloeosporioides (Penz.) Penz. & Sacc., anamorph of *Glomerella cingulata* (Stonem.) Spauld & Schrenk. (Azmy and Maziah 1990; Mohanan 1990, 1994a,b), *Colletotrichum septorioides* Sacc. (Zhang 2000), and *Colletotrichum* sp. (Azmy and Maziah 1990).

ETIOLOLGY

During the wet months of the year, the conidia of the fungus are dispersed by wind or rain splash. Infection starts when conidia develop appressoria and infection hyphae penetrate the host tissues. Moderate temperatures (25-28^{0}C), high humidity and free water on the host surface are the optimum conditions for the development and spread of the disease. Fungal conidia, as well as ascospores produced in the affected necrotic tissues under high humid conditions, serve as sources of secondary infection.

DISEASE MANAGEMENT

Plant sanitation, such as regular cleaning of bamboo clumps, has been suggested to reduce the incidence of infection. Fungicides -Thiram (0.2% a.i.), Benlate (0.5% a.i.) or Captan (0.1% a.i.) - are recommended as foliar spray in severely infected young bamboo clumps.

Ascochyta Leaf Spot

The disease has been reported in bamboo plantations and natural stands in India, Japan and the Philippines. The disease has been recorded on *Schizostachyum lumampao* (Blanco) Merr. in the Philippines (Dayan 1988). In India, the leaf spot has been reported on *Bambusa multiplex* in Maharashtra State (Rao 1962), on *Bambusa* sp. in Karnataka State (Rangaswami et al. 1970), in *Drepanostachyum falcatum* (Nees) Keng f., and on *B. bambos*, *Dendrocalamus strictus* and *Thyrsostachys* sp. in Kerala State (Mohanan 1990, 1994a,b; Balakrishnan et al. 1990).


Fig 82 Leaf spot in *D. strictus* caused by *A. dendrocalami*

SYMPTOMS

Minute, spindle-shaped, yellowish brown to brown, water-soaked spots appear on the upper surface of the leaf. Both juvenile and mature leaves are found affected by the disease. The spots enlarge to 3-5 mm with greyish white centres. During December-January, dark brown to black pycnidia develop over the necrotic spots, from which a pinkish white spore mass oozes out under high humidity (Figs. 82-84). In severe infection, the leaf margins become necrotic, extending towards the centre. Such leaves are gradually blighted and fall off.

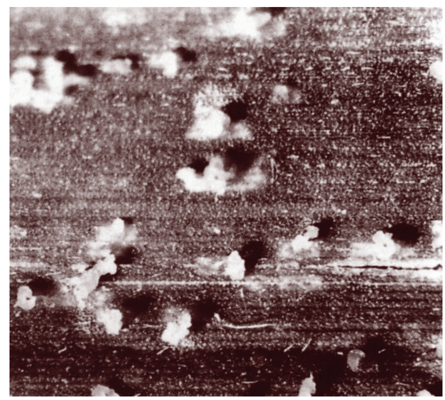


Fig 83 Magnified view of pycnidia of *Ascochyta dendrocalami*

CAUSAL ORGANISMS

Ascochyta arundinariae F. Tassi on *Drepanostachyum falcatum*; *Ascochyta Bambusinae* V.G. Rao (Rao 1962; Zhu 1989); *Boeremia exigua* (Desm.) Aveskamp, Gruyter & Verkley (= *Ascochyta phaseolorum* Sacc.) (Rangaswami et al. 1970; Balakrishnan et al. 1990); *Ascochyta dendrocalami* Mohan. (Mohanan 1994b; 1995d); *Ascochyta* sp. (Dayan 1988).

ETIOLOGY


Fig 84 Conidia of *Ascochyta dendrocalami* (640x)

The fungi enter the host tissue through stomata, and the hyphae proliferate in the mesophyll. Pycnidia develop in the necrotic tissues and under high humidity, the conidial mass oozes out. Wind-dispersed conidia serve as the source of secondary infection and spread of the disease.

DISEASE MANAGEMENT

Since the disease is not economically very important, control measures are not required.

Tar Spot

Tar spot disease has been reported in different species of bamboos in India, China, Japan and the Philippines. In the Philippines, disease has been recorded on *Bambusa blumeana, B. vulgaris* and *Bambusa* sp. (Dayan 1988). Tar spot has been recorded on *Phyllostachys* sp. in Japan (Spaulding 1961; Zhu 1989). In China, tar spot has been recorded on *Phyllostachys pubescens, P. glauca*, *P. heterocycla, P. bambusoides, Phyllostachys* spp., *Sasa longiligulata, Bambusa*, *B. multiplex, Bambusa* spp., *Pseudosasa japonica, Pleioblastus amarus, Sinocalamus affinis* in Zhejiang, Jiangsu, Anhui, Fujian, Sandong, Shanghai, Hunan, Guangdong, Henan, Shanxi, Yunnan and Sichuang Provinces (Zhang 2000).

In India, tar spot disease has been recorded on *Arundinaria* sp., *Bambusa bambos* and *Dendrocalamus strictus* in Maharashtra State (Parndekar 1964; Ananthanarayanan 1964; Awati and Kulkarni 1972), on *B. bambos* in Tamil Nadu State (Rangaswami et al. 1970), on *Bambusa* sp., *B. bambos, B. vulgaris, D. strictus, Pseudoxytenanthera ritcheyi, Thyrsostachys* sp., *Ochlandra travancorica* and *O. scriptoria* in Kerala State (Sydow and Butler 1911; Butler and Bisby 1960; Mohanan 1990, 1994a,b,1997, 2008) and on *Arundinaria* sp. in Assam State (Uppal et al. 1955).

Fig 85 Tar spots in *B. bambos* due to *Phyllchora* sp.

SYMPTOMS

Small, pale to dark yellowish brown lesions appear on the abaxial surface of the leaf. The lesions increase in size, spread and develop into oval or circular spots with dark brown centres and pale yellow margins. Usually, four to six small spots (each 3-6 mm) appear on the leaf lamina and the leaf sheath. Ascocarps develop as dark brown to black raised structures in the necrotic spots (Figs. 85-86).

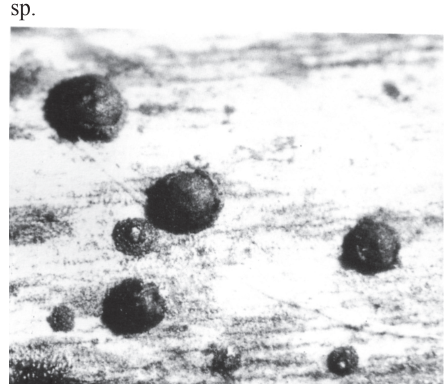


Fig 86 Ascocarps of *Phyllchora longinaviculata* on *B. bambos*

CAUSAL ORGANISMS

A total of sixteen *Phyllachora* species have been recorded as associated with the disease in different bamboo species. These include: *Phyllachora bambusae* Syd. & Butler on *Bambusa bambos* (Sydow and Butler 1911; Parndekar 1964; Awati and Kulkarni 1972); *Phyllachora chimonobambusae* I. Hino & Katum. on *Phyllostachys nigra* var. *henonis* (Zhu 1989);

Phyllachora dendrocalami Awati and Kulk. on *Dendrocalamus strictus* (Awati and Kulkarni 1972; Khan et al. 1995); *Phyllachora graminis* (Pers.) Fuck. on *Arundinaria* sp. (Ananathanarayanan 1964); *Phyllachora longinaviculata* Parbery on *B. bambos, D. strictus* and *Pseudoxytenanthera ritcheyi* (Mohanan 1990, 1994a,b); *Phyllachora malabarensis* Syd. et Butler on *Bambusa* sp. (Sydow 1932; Butler and Bisby 1960); *Phyllachora shiraiana* Sydow on *B. bambos, B. vulgaris, D. strictus, Ochlandra travancorica, O.scriptoria, Phyllostachys spp., P. ritcheyi, D. strictus, Thyrsostachys* sp. (Mohanan 1994a,b,2005), on *Arundinaria* sp. and *Bambusa* sp. (Uppal et al. 1955), and on *B. blumeana, B. vulgaris* and *Bambusa* sp. in the Philippines (Dayan 1988); *Phyllachora infectoria* Cooke has been recorded on *Bambusa balcooa* and *B. tulda* from Assam, India (Borah et al. 1998); *Phyllachora ischaemi* Syd. on *B. bambos* (Mohanan 1994a,b), on *B. balcooa* and *B. tulda* (Borah et al. 1998); and *Phyllachora* sp. on *Bambusa* sp. and *B. bambos* (Butler and Bisby 1960; Rangaswami et al. 1970).

Four spepcies of *Phyllachora* - *Phyllachora chimonobambusae* Hino et Katumoto, *Phyllachora shiraiana, Phyllachora graminis* and *Phyllachora phyllostachydis* Hara - have been recorded in different species of bamboos from Japan (Zhu 1989).

A total of seven species of *Phyllachora* - *Phyllachora phyllostachydis*, *Phyllachora orbiculata* (Schwein.) Sacc., *Phyllachora sinensis* Sacc., *Phyllachora leptotheca* Theiss & Syd., *Phyllachora maculans* (Mont.) Cooke, *Phyllachora ischaemi* (= *P. microstegii*), *Phyllachora phragmitis-karkae* Sawada have been recorded on different bamboo species in different Provinces in China (Zhang 2000).

ETIOLOGY

Airborne spores of the fungus germinate on the leaf surface and the infection hyphae penetrate through stomata. Mycelial ramification occurs in the mesophyll within 24 hours. Lesions develop 7-9 days after infection and black raised structures form in the necrotic infected tissues.

DISEASE MANAGEMENT

As the tar spot disease is not an important one, control measures are seldom warranted.

Ciliochora Leaf Spot

This leaf spot disease has been reported in bamboo natural stands and plantations in India. The disease has been recorded on *Bambusa* sp. in Karnataka and Tamil Nadu State (Subramanian and Ramakrishnan 1953; Rangaswami et al. 1970) and on *Bambusa bambos, Dendrocalamus, strictus, Arundinaria* sp., *Thyrsostachys* sp., *Ochlandra scriptoria* and *O. ebracteata* in Kerala State, India (Mohanan 1990, 1994a,b; 2005,2008).

SYMPTOMS

Water-soaked, brown, pin-head lesions appear on foliage, especially the lower parts of new culms. These lesions enlarge to 3-5 mm, oval to elliptical, dark violet spots with pale yellow haloes. Later, the spots appear as raised black structures bearing pycnidia of the causal fungus (Figs. 87, 88).

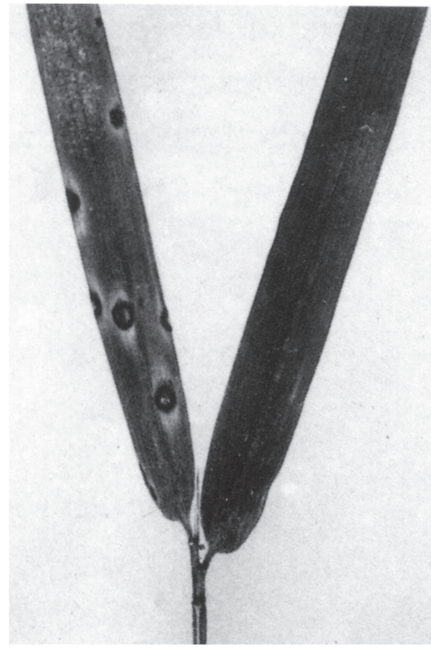


Fig 87 Leaf spot in *Thyrsostachys* sp. caused by *Petrakomyces bambusae*

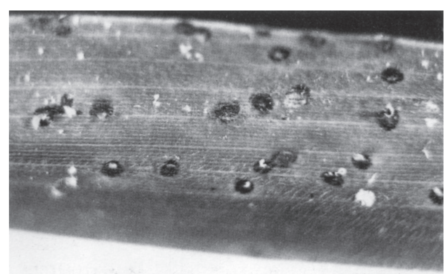


Fig 88 A magnified view of pycnidia of *Petrakomyces bambusae*

CAUSAL ORGANISMS

Ciliochora indica (Subram. & K. Ramakr.) Nag Raj (= *Petrakomyces indicus* Subram. & Ramakr.) (Subramaniam and Ramakrishnan 1953; Mohanan 1990, 1994a,b) and *Petrakomyces bambusae* Mohan. (Fig. 89) (Mohanan 1994a, b; 1995d, 2005) are the causal organisms recorded.

ETIOLOGY

The fungus enters the host tissue through stomata and the hyphae proliferate in the mesophyll tissues. Pycnidia develop in the affected areas and the conidia are extruded from them under warm-humid conditions. Conidia, dispersed by wind and rain splash, serve as the source of secondary infection.

DISEASE MANAGEMENT

As the leaf spot is not an important one, control measures are not required.

Phoma Leaf Spot

Phoma leaf spot has been reported on *Bambusa bambos* and *Dendrocalamus strictus* in natural stands and plantations in Kerala State, India (Mohanan 1990, 1994a,b; 2008), in *D. hamiltonii* plantations in North-East india (Bengyella et al. 2015), and in *Phyllostachys bambusoides* Munro and *Phyllostachys* sp. stands in Japan (Zhu 1989).

SYMPTOMS

Brown, pin-head lesions occur on the upper surfaces of leaves. Both juvenile and mature leaves are affected. Leaf spots develop during August-September; the spots become spindle-shaped.

They later coalesce to form large irregular spots with greyish white centres and dark brown margins (Figs. 90, 91).

Fig 90 Phoma leaf spot on *B. bambos*

CAUSAL ORGANISMS

Phoma arundinacea Sacc.; *Phoma herbarum* Westend; *Phoma dendrocalami* Mohan. (Mohanan 1994a,b, 1995d); *Phoma pelliculosa* Berk. et Br. (Zhu 1989); *Phoma* sp. (bengyella et al. 2015); *Epicoccum sorghinum* (Sacc.) Aveskamp, Gruyter & Verkley (= *Phoma sorghina* (Sacc.) Boerma, Dorenbosch & Van Kesteran are the causal organisms recorded.

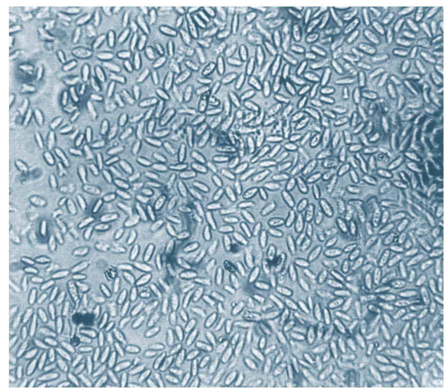


Fig 91Conidia of *Phoma dendrocalami*

ETIOLOGY

The fungus enters the leaf tissue through stomata or by direct penetration, and the mycelium ramifies in the mesophyll tissues. Pycnidia of the causal fungus are formed in the necrotic lesions during November-December as erupting structures. Under high humidity, a cream to pink coloured, gelatinous spore mass is extruded in cirri from the pycnidia.

DISEASE MANAGEMENT

Since the leaf spot disease is of minor importance, control measures are not required.

Phomopsis Leaf Spot

The disease has been reported on *Bambusa bambos*, *Dendrocalamus strictus* and *Thyrsostachys* sp. in Kerala State, India (Mohanan 1990, 1994a,b; 1997,2008).

SYMPTOMS

Minute, greyish brown, water-soaked lesions occur on mature leaves and later spread to form circular to irregular spots with dark brown wavy margins. In *D. strictus*, the spots enlarge to form larger spots of 5-8 mm diameter with 2-3 dark brown concentric rings (Fig. 92).

Fig 92 *Phomopsis bambausae* leaf spot in *B. bambos*

CAUSAL ORGANISM

Phomopsis bambusae Mohan. (Mohanan 1994a,b; 1995d).

ETIOLOGY

The spores of the fungus, dispersed through air currents or rain splash, germinate on the leaf surface and the infection hyphae penetrate through stomata. The hyphae proliferate in the mesophyll and parenchyma tissues. Pycnidia develop in the recrotic tissues during November-December and the conidia oozes out in yellowish cirri, which serve as the source of secondary infection.

DISEASE MANAGEMENT

As the leaf spot disease is not important, control measures are not required.

Stagonospora Leaf Spot

The leaf spot has been reported on *Bambusa bambos* and *Dendrocalamus strictus* in Kerala, India (Mohanan 1994a,b, 1997), and in *Phyllostachys* sp. in Japan (Zhu 1989). The disease has been observed only on mature leaves.

SYMPTOMS

Dark brown, irregular lesions, each 3-5 mm in diameter, appear on mature leaves, and later enlarge and become brownish black necrotic spots. The spots usually develop along the leaf margins.

CAUSAL ORGANISMS

Stagonospora bambusae Mohan. (Mohanan 1994 a,b;1995e); and *Stagonospora phyllostachydis* Hara and *Stagonospora septorioides* Hara (Zhu 1989) are the causal organisms recorded.

ETIOLOGY

The fungus enters the host tissue through stomata as well as by direct penetration through the epidermis. Warm-humid environmental conditions favour infection.

DISEASE MANAGEMENT

The disease is of minor significance and control is not required.

Septoria Leaf Spot

Septoria leaf spot has been reported on *Thyrsostachys* sp. in Kerala, India (Mohanan 1994a,b), and in *Bambusa* sp. in Japan (Zhu 1989). In India, the infection was observed on mature leaves of *Thyrsostachys* sp. during December-January.

SYMPTOMS

Greyish brown to dark brown lesions, each 2-4 mm in diameter, occur on the upper surfaces of mature leaves, Pale to dark brown pycnidia develop in the centre of the lesions. Usually, leaf spots caused by *Phomopsis* sp., *Ciliochora* sp. (=*Petrakomyces* sp.) and *Septoria* sp. were observed intermixed on the same leaf.

CAUSAL ORGANISMS

Septoria thyrsostachydis Mohan. and *Septoria bambusae* Broom. (Mohan 1994a,b, 1995d; Zhu 1989)

ETIOLOGY

The fungus enters the host tissue through stomata. Warm-humid atmospheric conditons favour infection.

DISEASE MANAGEMENT

Leaf spot disease is not a serious one and control measures are not required.

Chaetospermum Leaf Spot

The disease has been reported on *Bambusa bambos* in Kerala, India (Mohanan 1994a,b, 1997). It was observed during August-September, usually on mature leaves of the lower culm branches.

SYMPTOMS

The disease occurs as numerous minute, pale yellow lesions, arranged linearly on the upper surface of mature leaves. Usually, development of a large number of such lesions on the leaf imparts a yellowish colour to the affected foliage.

CAUSAL ORGANISM

Chaetospermum carneum Tassi (Mohanan 1994a,b).

ETIOLOGY

Fungus enters the host tissue through stomata. High humid atmospheric conditions favour the infection. Free water on the leaf surface helps in rapid spread of the lesions. Yellowish brown minute pycnidia develop in the necrotic areas during October.

DISEASE MANAGEMENT

This leaf infection is of minor importance and control measures are not needed.

Curvularia Leaf Spot

The leaf spot has been reported on *Arundinaria* sp., *Bambusa bambos, Thyrsostachys sp., Ochlandra travancorica, O. scriptoria* and *O. ebracteata* in Kerala, India (Balakrishnan et al. 1990; Mohanan 1990, 1994a,b, 1997, 2008). The leaf spot has been observed only on the juvenile foliage of new culms.

SYMPTOMS

Greyish black, irregular lesions appear on the juvenile, expanding foliage, especially on those in the lower branches of new culms. Later, the lesions enlarge and cover the entire leaf lamina and become necrotic. The causal fungus sporulate profusely on the affected tissues.

CAUSAL ORGANISMS

Curvularia lunata (Wakker) Boedijn anamorph of *Cochliobolus lunatus* Nelson & Haasis (Mohanan 1990, 1994a,b) and *Curvularia andropogonis* (Zim.) Boedijn (Balakrishnan et al. 1990).

ETIOLOGY

The infection hyphae of the fungus enter through stomata or injured tissues. Free water on the host surface favours the spread of infection. Under high humidity, the fungus sporulates profusely on the infected host tissue.

DISEASE MANAGEMENT

The disease is of little importance and control measures are not required.

Alternaria Leaf Spot

The leaf spot disease has been reported on *Bambusa bambos* and *Dendrocalamus strictus* in Kerala, India (Mohanan 1994a,b) and on *Dendrocalamus latiflorus, Phyllostachys* spp. in

Zhejiang, Hunan, and Guangxi Provinces in China (Zhang 2000). The infection has been observed on mature leaves, especially those of the lower branches.

SYMPTOMS

Small yellowish brown irregular lesions appear usually near the leaf tip, which later spread to form necrotic spots. Severe infection leads to leaf blight.

CAUSAL ORGANISMS

Alternaria alternata (Fr.) Keissler (Mohanan 1990, 1994a,b). *Alternaria tenuis* Link. (Zhang 2000) are the causal organisms.

ETIOLOGY

Warm-humid conditions favour the infection. The fungal spores, dispersed through air currents, germinate on the host surface and penetrate through stomata. Fungus sporulates profusely on the necrotic tissues under warm-humid conditions.

DISEASE MANAGEMENT

Infection is of little importance and control measures are seldom required.

Resenscheldiella Leaf Spot

This leaf spot has been reported on *Ochlandra travancorica* in natural stands in Kerala, India. It was observed during September-October (Mohanan 1994a,b).

SYMPTOMS

Minute, yellowish brown, linear lesions occur on the mature leaves during September-October. They enlarge to form necrotic, 3-5 mm spots with yellow haloes. Fungal fructifications develop in linear rows in the necrotic spots on the upper surfaces of the leaves (Fig. 93).

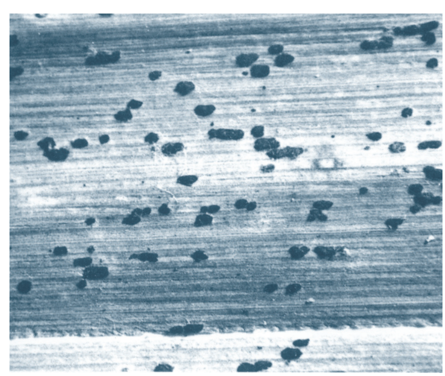


Fig 93 Fructifications of *R. ochlandrae* on *O. travancorica*

CAUSAL ORGANISM

Rosenscheldiella ochlandrae Mohan. (Mohanan 1994b, 1995d).

ETIOLOGY

The etiology of the disease has not been studied.

DISEASE MANAGEMENT

The disease is of minor importance and control measures are not required.

Coccodiella Leaf Spot

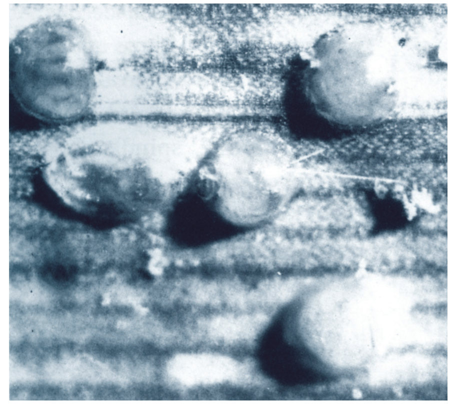


Fig 94 Fructifications of *C. ochlandrae* on *O. travancorica*

Coccodiella leaf spot has been reported on *Phyllostachys* sp. in China (Spaulding 1961), on *Phyllostachys* sp., *Sasa* sp., and *Sasamorpha purpurascens* Nakai in Japan (Spaulding 1961; Katumoto 1968; Zhu 1989), and on *Ochlandra travancorica* in Kerala, India (Mohanan 1994a,b,1997). In India, the disease was observed on mature leaves of bamboos during September-October.

SYMPTOMS

Yellowish brown, minute lesions appear on the upper surfaces of the leaves, and enlarge to form dark brown linear necrotic spots. Fructifications of the causal fungus develop in the necrotic spots on the lower surface of the leaf (Fig. 94).

CAUSAL ORGANISMS

Coccodiella arundinariae Hara *(=Coccostromopsis arundinariae* (Hara) Teng) (Spaulding 1961; Zhu 1989) and *Coccodiella ochlandrae* Mohan. (Mohanan 1994a,b, 1995d, 2005).

ETIOLOGY

The etiology of the fungus has not been studied.

DISEASE MANAGEMENT

The leaf spot is of minor significance and control measures are not required.

Cerodothis Leaf Spot

This leaf spot disease has been reported on *Bambusa bambos* stands in Karnataka State (Muthappa 1969), and on *B. bambos, Dendrocalamus strictus* and *Thyrsostachys siamensis* stands in Kerala State (Mohanan, 1994b). The disease has also been reported on *Gigantochloa levis*, *Bambusa philippinensis* (Gamble) McClure and *Schizostachyum lumampao* in the Philippines (Dayan

1988). The leaf spot diseased was recorded on *Bambusa blumeana* and *B. vulgaris* stands at Magalang, the Philippines (Mohanan 1995, unpublished observation).

Fig 95 Leaf spot in *D. strictus* caused by *C. aurea*; note the yellow micro conidia of the fungus

SYMPTOMS

Tiny, pale yellow spots appear on the upper surfaces of leaves. No visible necrotic spots are formed as the disease progresses. The ascocarps of the causal agent cause rupturing of the leaf epidermis. At maturity, the asocarps appear as tiny, golden yellow streaks on the leaves and are arranged in linear rows. Hyaline, spindle-shaped, microconidia of the fungus are also produced in the microconidial locule, which develop close to the margins of the developing ascostroma or are produced separately. The mucilaginous microconidia, pale yellow in colour, are extruded to the leaf surface through a pore formed in the locule. Severe infection affects the photosynthetic acticvity. Severely infected leaves become yellowish in colour and defoliate prematurely (Fig. 95).

CAUSAL ORGANISM

Cerodothis aurea Muthappa (Muthappa 1969; Mohanan 1994b).

ETIOLOGY

The fungus invades the leaf tissue and the hyaline intracellular mycelium penetrates the mesophyll, spongy parenchyma and vascular bundles. The epidermal cells are not invaded by the fungus. One or two hyphal tips of mycelium in the mesophyll at the corner of bulliform cells of the epidermal layer form tiny hyphal knots. These hyphal knots grow between the epidermis and the mesophyll to form a thin stroma. Microconidial locules develop in the stroma and microconidia are produced. Ascostroma develop very close to the microconidial locule.

DISEASE MANAGEMENT

The leaf spot is of minor importance and control measures are not required.

Leptostroma Leaf Spot

The disease has been reported on *Gigantochloa levis, Bambusa philippinensis* (Gamble) McClur and *Schizostachyum lumampao* in the Philippines (Dayan 1988). The leaf spot disease has also been recorded on *Bambusa blumeana* and *Bambusa vulgaris* stands at Magalang, the Philippines (Mohanan 1995, unpublished observation).

SYMPTOMS

Yedllowish to brown lesions appear on the leaves. Later, dark brown, shining pycnidia develop on the spots. Dehiscence of the pycnidia is by the rupture of epidermal cells, and conidia extrude from the fructification (Fig. 96).

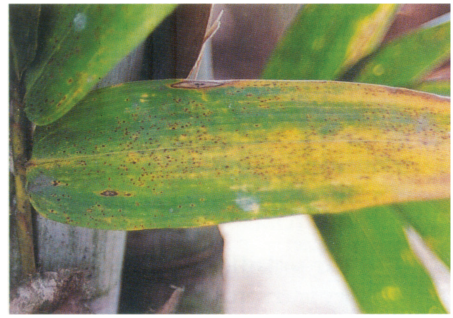


Fig 96 Leaf spot in *G. levis* caused by *Leptostroma* sp.,Laguna, the Philippines

CAUSAL ORGANISM

Leptostroma sp. (Dayan 1988).

ETIOLOGY

Etiology of the disease is not studied and information is not available.

DISEASE MANAGEMENT

Leaf spot disease is of little significance and control measures are not required

Fig 97 Leaf spot in *B. blumeana* caused by *E. calami* , Laguna, the Philippines

Eriosporella Leaf Spot

The disease has been reported on *Bambusa* sp., *Bambusa blumeana* (Dayan 1988) and on *Gigantochloa levis*, *G. aspera* and *Bambusa vulgaris* in the Philippines (Mohanan 1995, unpublished observation).

SYMPTOMS

Small, pale to golden yellow lesions appear on the leaves; later the lesions turn brownish to black, with small pycnidia in the necrotic tissue (Fig. 97).

CAUSAL ORGANISM

Eriosporella bambusicola Q.Q. Dai, N.N. Wijayawardene & K.D. Hyde (= *Eriosporella calami* (Neiss) Hohn.) (Dayan 1988).

ETIOLOGY

Etiology of the disease is not studied and information is not available.

DISEASE MANAGEMENT

Leaf spot disease is of little significance and control measures are not required.

Brown Leaf Spot

Fig 98 Leaf spot in *S. dulloa* caused by *F. pallidoroseum*

The disease has been reported on different species of bamboos in natural stands and plantations in India. Brown leaf spot has been recorded on *Melocanna arundina* Kurz and *Schizostachyum dullooa* (Gamble) Majumdar stands in Assam, India (Deka et al. 1990) and on *Bambusa bambos*, *B. vulgaris, Dendrocalamus strictus* and *Pseudoxytenanthera* ritcheyi stands in Kerala State (Mohanan 1990).

SYMPTOMS

Water-soaked lesions occur on the leaf. They later spread and cover the entire lamina, and eventually become brown. Usually, the infection occurs only in mature leaves; severe infection causes leaf necrosis and premature defoliation (Fig. 98).

CAUSAL ORGANISMS

Fusarium pallidoroseum (Cooke) Sacc. (Deka et al. 1990; Mohanan 1990) and *Fusarium incarnatum* (Desm.) Sacc. (=*Fusarium semitectum* Berk. & Rev.) (Balakrishnan et. al. 1990).

ETIOLOLGY

Warm-humid atmospheric conditions favour infection. Airborne fungal spores germinate on the leaf surface and invade the leaf tissues through natural openings or wounds on the surface. Under humid conditions, the fungus sporulates on the necrotic tissue.

DISEASE MANAGEMENT

The disease is of little importance and control measures are not required.

Culm Sheath Spot

Culm sheath spot has been reported on bamboos in China and India. In China, the disease has been recorded on *Phyllostachys* sp., *Phyllostachys sulphurea* cv. *viridis, P. glauca*, *P. pubescens, P. bambusoides, P. heteroclada, P. praecox, Pleioblastus amarus, Fargesai* sp., *Bambusa* sp. in Zhejiang, Jiangsu, Anhui, Fujian, Hunan, Guizhou, Henan and Sichuang Provinces (Tai 1932; Zhang 2000). In India, the disease has been recorded on *Bambusa bambos*, *B. polymorpha, B.*

vulgaris and *Dendrocalamus strictus* in Kerala, India (Mohanan 1990, 1994a,b). The spots were observed on culm sheaths of expanding culm internodes during June-July.

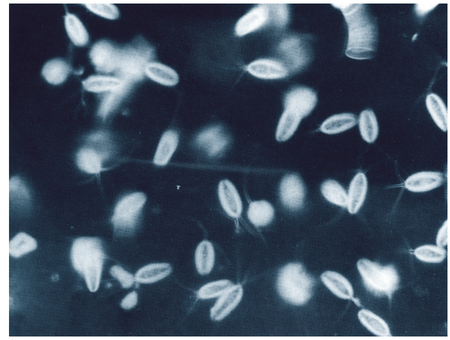


Fig 99 Conidia of *Pestalozziella bambusae*

SYMPTOMS

Small, brown, spindle-shaped to irregular lesions appear usually at the margins and tips of culm sheaths. The lesions spread to form large 5-12 mm, irregular, necrotic spots with dark brown to purple margins. The infection causes browning and necrosis of sheath margins and tips. Spots and necrosis are more pronounced in sheaths covering the lower 4 to 7 culm internodes.

CAUSAL ORGANISMS

Shiraia bambusicola (Tai 1932; Zhang 2000); *Myriangium haraeanum* F.L. Tai & C.T. Wei. (Zhang 2000); *Pestalozziella bambusae* Mohan. (Fig. 99) and *Sarocladium* sp. (Mohanan 1994a,b, 1995d).

ETIOLOGY

The causal agents are weak pathogens which enter the host tissue through wounds on the sheath. High humidity and free water on the host surface favour the infection. The causal fungi produce spores in gelatinous masses in the affected tissues. These spores serve as the source of secondary infection and spread of the disease. The disease affects developing culm internodes as well as nodal buds.

DISEASE MANAGEMENT

Since the culm sheaths fall off after the development of branches from the nodes and the infection does not spread to the culm, the disease is of little importance and control measures are not required.

Black Mildew

Black mildew is widespread in bamboo stands, especially in humid tropical areas with closed canopy. The disease has been reported on bamboos in China, India, Japan and Thailand. In Japan, the disease has been recorded on *Phyllostachys bambusoides*, *Phyllostachys* spp. *Sasa senanensis* Rehd. and *Semiarundinaria yashadake* Makino (Spaulding 1961; Zhu 1989). In India, black mildew has been recorded on *Bambusa* sp. (Browne 1968), *Bambusa bambos*, *Dendrocalamus strictus*, *Ochlandra travancorica, O. travancorica* var. *hirsuta, O. ebracteata* and *O. scriptoria* (Mohanan 2005).

The incidence of black mildew was recorded as high in humid areas during November-December. Recently, the disease has also been observed on different bamboo species including *Phyllostachys praecox, P. vivax, P. dulcis, P. glauca, Bambusa spp., Sasa spp., Pleioblastus cantori* in Zhejiang, Henan, Guangdong, Fujian, Provinces in China (Zhang 2000) and in Kanchanaburi, Thailand (Mohanan 1995, unpublished observation).

Fig 100 Black mildew on *B. bambos* due to *Meliola* sp.

SYMPTOMS

Cobweb-like to powdery black patches appear on the upper surfaces of mature leaves. As the infection develops, the upper leaf surface becomes densely coated with a black powdery growth of fungal hyphae (Fig. 100). The infected leaves clung together, become yellow and fall, if more damaged. Infection also occurs on leaf sheaths and minor branches. Severe infection reduces effective photosynthetic area of the leaves.

CAUSAL ORGANISMS

Meliola acristae Hansf., *Meliola arundinis* Pat. (Zhang 2000); *Meliola bambusicola* Hans. (Browne 1968); *Meliola pseudosasae* Hara (Zhu 1989); *Meliola bambusae* Pat., *Meliola furcata* Lev., *Meliola tenella* Pat., *Meliola phyllostachydis* W. Yamam. (Zhang 2000); *Meliola* sp. (Mohanan 1990, 1994a,b); *Dimerina bambusicola* Teng, *Meliolina stomata* Hara (Zhu 1989); *Hinoa bambusicola* (I. Hino & Katum.) Hara & H. Hino (= *Haraea bambusicola* I. Hino & Katum.) and *Haraea japonica* Sacc. et P. Syd. and *Asterinella hingensis* I. Hino & Hidaka (Spaulding 1961; Zhang 2000).

ETIOLOGY

Black mildew fungi are parasites, penetrate the host tissue by means of haustoria that arise from the characteristic superficial hyphopodiate mycelium. High atmospheric humidity and free water on the host surface favour infection and growth of the fungi.

DISEASE MANAGEMENT

Opening the canopy will reduce the infection.

Sooty Mould

Sooty mould has been reported on different bamboo species in India, Japan and China. The disease has been recorded on *Bambusa vulgaris, B. bambos, B. polymorpha, D. strictus, D.*

longispathus, Ochlandra travancorica, O. travancorica var. *hirsuta, O. scriptoria and O. ebracteata* in Kerala, India (Mohanan 1994a,b, 1997,2005). Sooty mould has also been recorded on *Dendrocalamus latiflorus, Phyllostachys* spp. *Arundinaria* spp, and *Pleioblastus* spp. in Zhejiang, Hunan, Jiangsu and Yunnan Provinces in China (Zhang 2000). Severe sooty mould infection has been recorded on *Bambusa blumeana, B. multiplex, B. vulgaris* and *Gigantochloa albociliata* (Munro) Kurz stands in Kanchanburi, Thailand (Mohanan 1995, unpublished observation). Very high incidence of sooty mould was recorded in humid areas during September-December. Extensive growth of the fungus on foliage markedly reduces the effective photosynthetic area of the leaves. Sooty moulds also absorb water readily from the atmosphere and keep the leaf surfaces moist for long periods. This creates a very humid environment within the canopy allowing the spread of other foliage diseases.

Fig 101 Sooty mould on *O. travancorica* caused by *Spiropes scopiformis*

SYMPTOMS

Infection usually appears on the upper leaf surface as a sparse, black network of hyphae or a thin, effuse, black, powdery fungal coating (Fig. 101). The disease also occurs on branches and minor branches. Sooty mould also occurs on the lower surfaces of the leaves.

CAUSAL ORGANISMS

Capnodium spp. and *Spiropes scopiformis* (Berk.) M.B.Ellis (Balakrishnan et al. 1990; Mohanan 1990, 1994a,b).

ETIOLOGY

Sooty moulds are saprophytic epiphytes and are not parasitic on their hosts. They normally obtain nourishment from the honeydew secreted by aphids, mealy bugs, scale insects and other sap sucking insects. In cases where insect infestation is absent, the fungi obtain their food from plant leachates, leached into water deposited on the leaf surface by rain, dew or mist. Surface water, together with the insects, are important in dispersing sooty moulds. The extent of damage they cause dependent on the occurrence and frequency of aphid and scale insects.

Fig 102 Shoot malformation in *Phyllostachys* sp. caused by *Myriangium* sp., Kanchanaburi, Thailand

DISEASE MANAGEMENT

In practice, sooty mould can be prevented by controlling aphid and scale insects population. The best way to control larva is to spray 40% dimethoate on the clumps.

Miscellaneous Foliage and Minor Branches Infections

Various fungi that cause infection of minor importance on leaves, minor branches and branches have been reported on different species of bamboos. A total of 131 species of fungi have been reported as causing minor infections on foliage and branches in in China, India, Japan, the Philippines and Taiwan-China (Cook 1892; Sydow and Butler 1906, 1911,. 1916; Miyake and Hara 1910, 1913; Rehm 1913, 1914, 1916; Tanaka 1922; Butler and Bisby 1931, 1960; Tai 1931; Teng 1938; Chowdhury 1948; Ding et al. 2001; Dong et al. 2001; Sprague 1950; Anonymous 1951, 1960; Hino and Katumoto 1955, 1958, 1961; Hino 1961; Hashimoto et al. 2008,2010; Kapoor and Gill 1961; Nema and Mishra 1965; Anahosur 1970; Rangaswami et al. 1970; Singh and Khanna 1970; Ellis 1971, 1976; Kar and Maity 1971; Sharma 1971; Sharada et al. 2013; Panwar and Gehlot 1973; Itoi et al. 1978, 1979; Kwan 1979; Sutton 1980; Saikia and Sarbhoy 1980, 1982, 1985; Mukerji and Bhasin 1986; Dayan 1988; Zhu 1989; Balakrishnan et al. 1990; Deka et al. 1990; Eriksson and Yue 1990; Bilgrami et al. 1991; Mohanan 1992, unpublished observation).

Fig 103 Shoots of *Phyllostachys* sp. caused by *Myriangium* sp., Kanchanaburi, Thailand

Fig 104 Leaf and leaf sheath infection by *Shiraia bambusicola* on *B. blumeana*

For instance, severe malformation of foliage in different species of *Phyllostachys* and *Bambusa multiplex* caused by *Myriangium bambusae* Rick has recently been recorded in Nanjing, China (Mohanan 1995, unpublished observation). The infected foliage shows symptoms similar to those produced by the witches-broom disease, except for the nature of fungal fructification (Figs. 102, 103). Recently, leaf spot caused by *Nigrospora oryzae* on *Bambusa nutans* in Karnataka State has been reported (Sharada et al. 2013). Bambusicolous fungi viz. *Fusarium* sp., *Cochliobolus* sp., *Phoma* sp., *Neodeightonia* sp. *Nigrospora* sp., affect *Dendrocalamus hamiltonii* in North-East India (Bengyella et al. 2015)

Another minor disease is the leaf and sheath infection by *Shiraia bambusicola* P. Henn. on *B.*

blumeana (Fig. 104). A list of miscellaneous foliage and minor branch infections is given in Appendix IIB. Detailed information is not available on most of these minor diseases.

Infection of Inflorescence and Seeds

Bamboo has a typical inflorescence which consists of one to many spikelets (Fig. 105). Each spikelet is protected by bracts called glumes, and contains one to few flowers called florets. Each floret consists of a lemma, a palea, three lodicules (sometimes absent), three or six stamens, and an ovary with one or three stigmas. The fruit of bamboo is mostly a caryopsis which consists of a pericarp enclosing the seed (Fig. 106). Each seed contains endosperm, and an embryo comprising a radicle, a plumule and a scutellum. Fungal infection on inflorescences of bamboos, causing smut and ergot, has been reported from India, Japan and Thailand.

Fig 105 inflorescence of *D. hamiltonii*

Fig 106 Developing seeds of *Thyrsotachys* sp.

Smut

Smut affecting the developing seeds in spikelets of bamboo species has been reported from India and Japan. Smut on *Bambusa bambos* and *Bambusa* sp. has been reported from Uttar Pradesh, India (Thirumalachar and Pavgi 1952). Severe infection completely replaces the seeds with a fungal spore mass. In Japan, smut affects *Phyllostachys heterocycla* var. *pubescens*, *Sasa nana* Mak. and *Sasa ramosa* Mak. et Shib. (Hori 1905; Zhu 1989). Bamboo smut has been recorded on *Phyllostachys sulphurea* cv. *viridis*, *P. glauca*, *P. pubescens, P. nigra* var. *henonis, P. flexuosa, P. bambusoides, P. incarnata, P. congesta, P. aurea, Pleioblastus amarus, P.makinoi, Fargesia* sp., *Arundinaria* spp., *Sasa ramosa* in Zhejiang, Jiangsu, Anhui, Henan, Hunan, Guizhou, Yunnan and Sichuang Provinces in China (Zhang 2000).

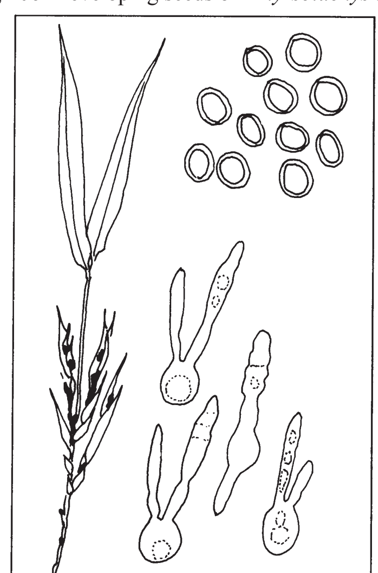


Fig 106 Symptoms of smut in *Phyllostachys* sp. caused by *B. shiraiana*

SYMPTOMS

The fungi attack young developing spikelets and often completely replaces the seeds with black fungal spores, causing smut (Fig. 107). Only seeds that are not infected attain maturity, but they also may contain fungal spores. Infected seeds on germination do not produce healthy seedlings.

CAUSAL ORGANISMS

Bambusiomyces shiraianus (Henn.) Vanky (=*Ustilago shiraiana* Henn.) and *Tilletia bambusae* Thirum. & Pavgi (Mundkur and Thirumalachar 1952; Thirumalachar and Pavgi 1952).

Fig 108 Ergot of *Bambusa* sp. caused by *Claviceps* sp.

ETIOLOGY

Smut fungi generally overwinter as chlamydospores (teliospores) on contaminated seeds or plant debris, in soil, or as mycelium in the infected kernels or plants. The chlamydospores germinate and produce basidiospores which, upon germination, either fuse with compatible ones and then infect, or penetrate the tissue and fuse to produce dikaryotic mycelium and cause typical infection.

DISEASE MANAGEMENT

Control of smut is possible by planting resistant species and seed treatment. Carboxin, Thiabendazole, Etaconazole and other systemic fungicides are effective in controlling the smut fungi.

Ergot

Ergot on *Phyllostachys* spp. has been reported from Japan (Spaulding 1961; Zhu 1989). From India, an *"ergot"* on *Bambusa* sp. affecting the apices of shoots, not the spikelets, has been reported (Ramakrishnan and Ramakrishnan 1949). The so-called ergot disease caused by *Claviceps* sp. is symptomatically very similar to the witches'-broom of reed bamboos caused by *Linearistroma linearis*. Recently, the disease has also been recorded affecting the inflorescence of *Dendrocalamus hamiltonii* in Thailand (Mohanan

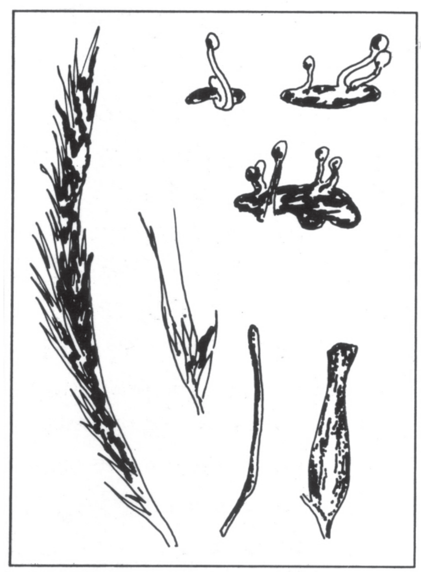


Fig 109 Ergot of *Phyllostachys* sp. caused by *Claviceps purpurea* (Source: Zhu 1989)

1995, unpublished observation)

.

SYMPTOMS

The fungi attack the developing spikelets and replace the seeds with fungal fructifications, causing ergot (Figs. 108, 109).

CAUSAL ORGANISMS

Claviceps purpurea Fr. Tul. (Zhu 1989); *Claviceps* sp.; *Mycocitrus phyllostachydis* (Syd. & P. Syd.) Yoshim. Doi. (= *Hypocreopsis Phyllostachydis* Syd. & P. Sd. and *Hypocrella semiamplexa* (Berk.) Sacc. (Berkeley 1856; Spaulding 1961) are the causal organisms.

ETIOLOGY

The fungus (*Claviceps* sp.) overwinters as sclerotia on or in the ground, or mixed with the seed. Sclerotia germinate and produce numerous stalks bearing perithecia. Ascospores are extruded in a viscous fluid under humid weather, and are disseminated by air currents or insects. The spore germinates and infects the ovary. Within a week of infection, the fungus produces stroma-like sporodochium that produces numerous conidia in a sticky liquid which extrude as creamy droplets or 'honey dew'. Later the seed becomes replaced by a hard mass of fungal mycelium, which eventually forms the characteristic ergot sclerotium.

DISEASE MANAGEMENT

Control of ergot depends entirely on cultural and sanitary measures.

Seed-borne Diseases

Bamboo seeds are invaded by fungi and bacteria during their different developmental stages on the plant and also after the seeds fall. Micro-organisms affect the developing fruits, invade the seeds and thus, reduce the amount of healthy seeds (Fig. 110).

When the seed falls to the ground, it is subjected to further invasion by decay organisms present on the forest floor. Seeds are also infected during storage and subsequent handling prior to sowing. In tropical humid areas, bamboo seeds are reported to be colonized by several field and storage fungi, and many of them are reported to be potential pathogens which may pose problems in nurseries (Mohanan 1990; Mohanan and Sharma 1991; Chacko et al. 2002; Seetha et al. 2002). The viability of seeds can be seriously affected by bacteria and fungi in all stages of transit and storage.

Fig 110 Fungal infection of developing seeds

To a large degree, poor quality seeds have been the cause of failure in nurseries.

Numerous fungi have been recorded on seeds of *Bambusa bambos, B. nutans, Dendrocalamus strictus, Gigantochloa hasskarliana* (Kurz) Backer ex Heyne and *Thyrsostachys siamensis* in Thailand (Chalermpongse et al. 1984; Pongpanich and Chalermpongse 1986; Anan 1987; Pongpanich 1990) and in *B. bambos* and D*, strictus* in India (Namdeo et al. 1989; Mohanan 1990). A total of 70 fungi belonging to 39 genera and two bacteria have been reported on stored seeds of different species of bamboos from India (Chacko et al. 2002) and Thailand (Appendix IID). Most of the fungi recorded are storage fungi, which affect the viability of seeds, while only a few are seed-borne and capable of causing infection of emerging seedlings. *Bipolaris* sp., *Exserohilum* sp., *Fusarium incarnatum, F. oxysporum, Prathoda longissima, Nigrospora oryzae, Drechslera* sp. and *Phomopsis* sp. are the important seed-borne fungi that cause seedling infection in bamboos (Mohanan 1990; Chacko et al. 2002) (Figs. 111, 112).

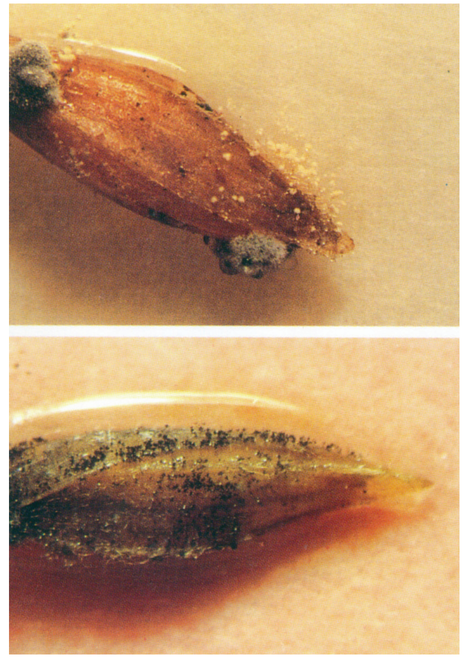


Fig 111 Fungi on stored seeds of *B.bamboos*

Apart from fungal infection on the radicle and plumule of the germinating seeds, seedling deformity at the hilum region of the seed has been recorded in the case of severe *Bipolaris* and *Exserohilum* infections (Mohanan 1990; Chacko et al. 2002).

Fig 112 Fungi on stored seeds of *D. strictus*

DISEASE MANAGEMENT

Bamboo seeds are usually collected from the forest floor, where they are open to attack by fungi and bacteria. Under such circumstances, the seed quality deteriorates before and after seed collecting. The period during which seeds are liable to infection by microorganisms can be greatly reduced if seed collecting is done immediately after seed fall. The cleaned seeds should be stored in airtight containers under reduced temperatures and moisture contents. Fungicidal seed treatment (Mancozeb, Ceresan D, Hexathir WP, Vitavax 70 WP @ 4g/kg of seeds) is suggested for seeds being stored for a short term and then used for sowing (Mohanan 2001).

Diseases of Rhizomes and Roots

The rhizome is the under-ground portion of the culm, closely resembling the culm and its branches in basic structure. There are two basic types of rhizomes: pachymorph (determinate, sympodial) and leptomorph (indeterminate, monopodial). Most of the tropical and subtropical bamboos have a pachymorph rhizome system. Each individual rhizome has short internodes and an apex that will continue to grow and become a culm. The culms are usually close together and form a densely tufted clump. Many of the temperate bamboos have a leptomorph rhizome system. Here, the rhizome is long and slender and usually hollow, and the apex extends and grows horizontally. Each internode has a solitary bud giving rise to either a culm or a rhizome. The plant has a spreading habit. True roots develop from the closely spaced nodes of the rhizome, and occasionally from the basal nodes of the above-ground culm. Every rhizome is potentially a culm bearer; but during development, some mechanical obstruction or other adverse factors may check the growth and prevent the production of culm. Diseases affecting the rhizome and roots - such as rhizome bud rot, root rot, decay of rhizome, root and basal culm - have been reported on different species of bamboo from India, Malaysia, Pakistan, the Philippines and Thailand.

Rhizome Bud Rot

The disease has been reported in 1-year-old *Bambusa bambos* plantations in Kerala State, India (Mohanan 1990, 1994a,b). Infection was observed during September-October in low lying and water-logged areas in the plantations. During 1987, the disease caused 16-72% mortality of seedlings in plantations in the central part of the State.

SYMPTOMS

Above-ground symptoms of the disease are yellowing of the entire foliage, resulting in complete defoliation within 15-20 days. The affected plants show browning and rot of the rhizome buds and tender tissues around the buds (Fig. 113). Both pointed scaly buds, which give rise to new shoots in the growing season, and flat buds, which promote rhizome proliferation, are affected by the disease. Discolouration and rot are restricted to the fleshy buds, roots and tender tissues at the growing points. Since the scaly buds, flat buds and the tender portions are affected, new shoot production and rhizome proliferation are greatly affected, causing stunted growth and death of the plants.

Fig 113 Rhizome bud root in *B. bambus* caused by *G. proliferatum*

CAUSAL ORGANISM

Globisporangium proliferatum (Cornu.) P.M. Kirk (= *Pythium middletonii* Sparrow (Mohanan 1990, 1994a,b).

ETIOLOGY

The fungus is a soil-borne pathogen, which usually infects the succulent plant tissues. The fungus enters the fleshy tissues and the rhizome buds and tender growing points of rhizomes through wounds caused to the seedling rhizome during collecting, transportation or planting, or by rodents, porcupines and pigs in the field. Infection spreads through rhizome tissues very slowly, and the discolouration often reaches the base of the shoots, causing the disease symptoms to appear. Infection affects the conductive tissues in roots, rhizomes and the basal portion of culms. Water-logging around the plants favours the development of infection.

DISEASE MANAGEMENT

The disease can be managed by using a healthy planting stock, as well as by improving the cultural and management practices in the plantations. During the dismantling of seedbeds and pulling out the bareroot seedling for planting, care should be taken to avoid causing injuries to the seedling rhizome. Storage and transportation of planting stocks should be done under hygienic conditions. Planting in water logged areas should be avoided.

Fig 114 Rhizome and root rot in *B.bambos* caused by *M. similis*

Fig 115 a Rhizome and root rot in *P. stocksii* caused by *A. campbelli*

Fig 115 b Aclose view of sporophores of *A. campbelli*

Rhizome and Root Rot

Rhizome and root rot has been reported in different species of bamboos in India and Pakistan. In Pakistan, the disease was recorded in 2 to 4-year-old *Dendrocalamus strictus* irrigated stands at Sargodha (Sheikh et al. 1978). In India, the disease was recorded on *Bambusa bambos* in West Bedngal (Bose 1919; Banerjee 1947; Banerjee and Mukopadhyay 1962), on *Thyrsostachys oliveri* in Uttar Pradesh (Mitter and Tandon 1932), in *D. strictus* plantations (2 to 5-year-old clumps) in Madhya Pradesh (Tahir et al. 1992), and in *B. bambos* natural stands in Kerala (Mohanan 1994a). The disease incidence in 2 to 5-year-old of plantations in Madhya Pradesh, India has been recorded as 1-2%. Recently, rhizome and root rot in *Dendrocalamus strictus, D. longispathus, B. Bambos, B. balcooa, Ochlandra travancorica* caused by *Amylosporus campbelli* has been reported (Mohanan 1994; 2008,2011,2013)

SYMPTOMS

The infection appears as yellowing of the leaves followed by die-back of the culms. The disease causes white fibrous or white spongy rot of root and rhizome. The fungal sporocarps develop on the exposed part of rhizomes and on humus around the infected clumps (Figs. 114, 115a,b).

CAUSAL ORGANISMS

Amylosporus campbellii (Berk.) Ryv. (= *Polyporus friabilis* Bose) (Tahir et al., 1992; Mohanan 1994a; 2007;2011); *Serpula similis* (Berk. & Broom.) Ginns. (= *Merulius similis* Berk. & Br.), *Serpula eurocephala* (Berk.& Broom.) W.B. Cooke (=*Merulius eurocephalus* (Berk. Br.) Petch); *Sphaerostilbe bambusae* Pat., *Polyporus* sp., *Poria* sp. (Mathur 1936; Banerjee 1947; Mitter and Tandon 1932; Sydow and Mitter 1933; Sheikh et al. 1978; Mohanan 1994a). Recently, *Amylosporus campbelli* infection has been recorded on *Bambusa balcooa, Dendrocalamus longispathus* at KFRI campus, Peechi, Thrissur, Kerala and on *Pseudoxytenanthera stocksii* and *Bambusa tulda* in a Bambusetum at Palappilly, Kerala, India (Mohanan 2017 unpublished observation).

ETIOLOGY

The fungus (*Amylosporus campbellii*) established in cut stumps of bamboos and their rhizomes, and in forest debris, spreads to the healthy culms and rhizomes through rhizomorphs. The rhizomorphs spread from infected culms into the soil up to a depth of 0.5 to 1 metre. The rhizomorphs become thinner and profusely branched which they come in contact with roots and rhizomes. The fungus causes white fibrous rot of roots and rhizomes. The sporocarps of the fungus develop on the exposed points of the affected rhizomes and also on the humus around the infected clumps. Clump to clump spread of the disease is mainly through fungal rhizomorphs.

DISEASE MANAGEMENT

Removal of fungal sporocarps from affected bamboo clumps, and burning of dead rhizomes and roots of diseased culms are suggested to minimize the chances of further spread of the disease. Trenching and isolation of the diseased clump is suggested in a Bambusetum at Palappilly, Kerala to reduce the spread of disease through root contacts (Mohanan 1994; 2004). However, managing the spread of disease becomes very difficult under flood irrigation. Application of a copper fungicide (Copper oxychloride, 10 to 50 g per bamboo culm) and soil working around the clumps will help in checking the development or rhizomorphs of the fungus and thereby disease incidence. Severely affected clumps should be cut, and rhizomes dug out and burnt on the spot as a sanitary measure.

Decay of Rhizome, Root and Basal Culm

Disease causing decay of rhizome, root and basal culm has been reported on different species of bamboos from India, the Philippines, Malaysia and Pakistan. The disease has been recorded on *Bambusa bambos* in Uttar Pradesh, West Bengal and Kerala, India (Hennings 1901; Banerjee and Ghosh 1942; Balakrishnan et al. 1990; Mohanan 1994b), and on *Melocanna baccifera* in West Bengal and Assam in India and in Bangladesh (Bagchee 1954; Spaulding 1961). Root decay (white rot) of *Dendrocalamus giganteus* Munro caused by *Rigidoporus microporus* (Sw.) Overeem. (= *Fomes lignosus* (Klotzh) Bres.) has been recorded in Malaysia (Hilton 1961). Ganoderma root rot of bamboos has been recorded in Pakistan and the Philippines (Bakshi 1957; Spaulding 1961). Culm and rhizome rot caused by *Rosellinia* spp. has been reported on *Phyllostachys* spp. in Zhejiang, Jiangsu, Fujian, Guangdong, Guangxi and Yunnan Provinces in China (Zhang 2000).

Fig 116 Decay of basal culm in *B.bambos* caused by *Poliporus* sp.

SYMPTOMS

The disease causes white spongy to fibrous or brown cubical rot of root, rhizome and basal part of the culm. The sporophores of the fungus develop on the affected bamboo culms at the ground level and on the exposed parts of the affected rhizomes (Fig. 116).

CAUSAL ORGANISMS

Ganoderma lucidum (Curtis) P. Karst. (Banerjee and Ghosh 1942; Bakshi 1957; Spaulding 1961; Balakrishnan et al. 1990; Mohanan 1994b); *Amylosporus campbelli* (Mohanan 2011); *Coltricia bambusicola* (Henn.) D.A. Reid. (= *Polyporus bambusicola* P. Henn.) (Hennings 1901); *Antrodia rhizomorpha* (Bagchee) J.R. Sharma (= *Poria rhizomorpha* Bagchee) (Bagchee 1954); and *Rigidoporus microcarpus* (Sw.) Overeem. (= *Fomes lignosus* (Klotzch) Bres.) (Hilton 1961); *Rosellinia emergens* Sacc., *Rosellinia* sp. (Zhang 2000).

ETIOLOGY

Ganoderma lucidum is a serious root rot pathogen of worldwide distribution. It attacks a large number of broad-leaved, sub-temperate and temperate tree species. It is normally endemic to natural forests and does not cause any serious damage. However, when natural forests are clear-felled, *G. lucidum* spreads quickly to residual roots and stumps to build up a high inoculum potential. Raising new plantations in such areas without clearing the infected residual stumps and roots causes severe damage to susceptible species (Mohanan and Rajeshkumar 2008). The lateral spread of the disease takes place through root contact. The strictly parasitic habit of *G. lucidum* makes it incapable of freshly colonizing dead roots or stumps. The fungus is also unable to make free mycelial strands in the soil, except on root surfaces, or outside the roots when in contact with a solid surface like the roots of adjoining plant. Thus, healthy clumps become infected when their roots come in contact with decayed wood (Mohanan 2005,2011).

Fig 117 *B. bambos* culms affected by *Daedalia*

Antrodia rhizomorpha occurs as a saprophyte in the soil, forming abundant rhizomorph strands on decaying roots and other debris. It becomes parasitic in poor and badly drained soils and spreads by means of rhizomorphs. *Rigidoporus microcarpus* attacks living sapwood as well as heartwood. The food base or the wood mass colonized by the fungus is important in root disease development. Fructifications of the fungus are produced on the affected parts and on humus around the bamboo clumps which serve as the sources of fresh infection.

Fig 118 *B. bambos* culms affected by *Irpex sp.*

DISEASE MANAGEMENT

Silvicultural measures like isolation trenches may prove effective in containing the disease in between the trenches, thus preventing its spread.

Fig 119 *B. vulgaris* culms affected by *Poria sp.*

Fig 120 *T.oliveri culm* decayed by *S. commune*

Fig 121 Deterioration of culms of *O. travancorica*

Decay and Deterioration of Culms in Stands

A large number of fungi have been reported associated with decay and deterioration of bamboo culms, minor branches and branches in plantations and natural stands in China, India, Indonesia, Japan, Malaysia, Pakistan, the Philippines and Thailand. Many of them have been recorded on dead standing culms, while few have been observed on living and partially dead culms, minor branches and branches (Berkeley 1856; Gamble 1899; Sydow and Butler 1911; Theissen and Sydow 1915; Overeem 1926; Mitter and Tandon 1932; Banerjee and Ghosh 1942; Anonymous 1945, 1950; Padwick 1945; Banerjee 1947; Thirumalachar 1950; Bagchee and Singh 1954; Butler and Bisby1960; Tilak and Viswanathan 1960; Spaulding 1961; Bakshi et al. 1963; Tilak and Rao 1967; Browne 1968; Rangaswami et al. 1970; Bakshi 1971, 1976; Kar and Maity 1971; Mohanan1994b, 2011a,b,c; Narendra and Rao 1972; Patil and Rao 1972; Patil et al. 1980; Boa 1987a; Gupta and Rajak 1987; Shukla et al. 1988; Shojiro et al. 1989; Zhu 1989; Tiwari 1991; Mohanan 1994b). (Figs. 117-121). Decay and staining fungi reported on culms in stands from different countries in Asia are given in Appendix IIIA. Details are not available on decay of bamboos in stands or on the associated fungi.

Fig 122 *T. terrestris associated with B. bambos*

Fig 123 *Scleroderma verrucosum* associated with *B. bambos*

Fig 124 *Hygrocybe* sp. associated with *B. bambos*

Fig 125 *Clavaria* sp. associated with *B. bambos*

Mycorrhizae

Feeder roots of bamboos are generally infected by symbiotic fungi that do not cause any disease, but are beneficial. The infected feeder roots are transformed into a unique morphological structure called mycorrhizae. Mycorrhizae apparently improve plant growth by increasing the absorbing surface of the root system, by selectively absorbing and accumulating certain nutrients (especially phosphorus), by making available to the plant some of the normally insoluble minerals, and by keeping feeder roots are resistant to infection by certain soil fungi. In bamboos, both ecto- and endomycorrhizal associations have been reported. Ectomycorrhizal fungi associated with bamboos include: *Thelephora terrestris* Ehrh.; *Scleroderma verrucosum* (Bull.) Pers.; *Lactarius* spp., *Hygrocybe miniata* (Fr.) P. Kumm. (= *Hygrophorus miniatus* Fries,); *Tricholoma* sp. etc. (Mohanan 1995a; 2011a) (Figs. 122-125). Various other macro fungi are also commonly observed associated with bamboo roots. These include: *Clavaria* spp., *Clavulina* spp.; *Ramaria* sp.; *Xylosphaeria* sp.; *Geastrum triplex* Jung.; *Collybia* sp.; *Tricholomopsis* sp.; *Hygrocybe chlorophana* (Fr.) Wiinsche (= *Hygrophorus chlorophanus* Fries); and *Hygrocybe coccinea* (Scheff.) P. Kumm. (=*Hygrophorus coccineus*). However, their mycorrhizal status with bamboos is yet to be ascertained (Mohanan 1995a, 2005,2011,2013).

Endomycorrhizal fungi or vesicular arbuscular micorrhizal (VAM) fungi belonging to different genera – *Acaulospora, Glomus*, *Gigaspora, Paraglomus, Funneliformis, Rhizophagus*, *Scutellospora* – have been reported from Taiwan – China and India (Wu and Chen 1986; Appasamy and Ganapathy 1992; Battacharya et al. 1995; Mohanan 1995a; 2006). In India, more than 25 species of bamboos were recorded as naturally infected with various VAM fungi (Verma and Soni (2008) ; Mohanan 2005, Mohanan and Manoj 2006) (Figs. 126, 127). The bamboo species are: *Bambusa bambos, B. balcooa, B. multiplex, B. polymorpha, B. tulda, B. tuldoides, B. vulgaris, D. strictus, D. bandisii, D. longispathus, Melocanna baccifera, Phyllostachys stocksii* (Munro) Naithani*, Ochlandra ebracteata, O. scriptoria, Phyllostachys pubescens, P. aurea, Thyrsostachys oliveri, T. siamensis, Gigantochloa sp., Cephalostachyum pergracile* and *Arundinaria* sp. (Mohanan 1995a; Mohanan and Manoj 2006)). VAM fungi recorded in different bamboos are: *Rhizophagus aggregates* (N.C. Schenck & G. S. Smith) C. Walker(= *Glomus aggregatum) Glomus australe* (Berk.)S.M. Berch., *Paraglomus albidum* (C. Walker & L.H. Rhodes) Oehl, G.A. Silva & Sieverd. *(=Glomus albidum*), *Rhizophagus fasciculatus* (Thaxh.) C. Walker & A. Schub. (=*Glomus fasciculatum*), *Glomus botryoides* F. M. Rothell & Victor, *Funneliformis geosporum* (T.H.

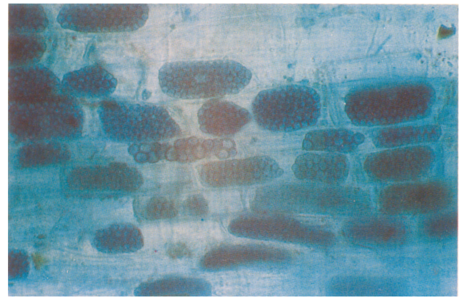


Fig 126 VAM fungal infection in *B.bambos* root

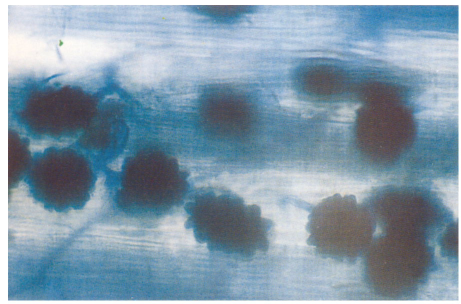


Fig 127 VAM fungal infection in *O.travancorica* root

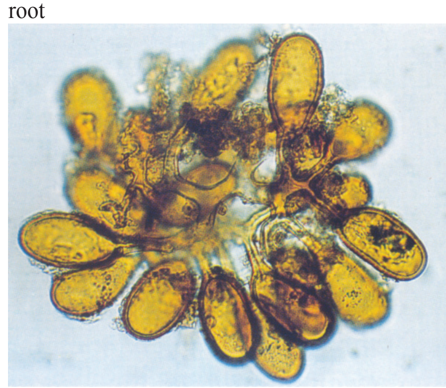


Fig 128 Spores of *Rhizophagus fasciculatum*


Fig 129 Spores of *Glomus botryoides* and *funneliformis geosporum*

Nicoloson & Gerd.) C. Walker & A. Schub. (= *Glomus geosporum*), *Glomus magnicaule* I. R. Hall., *Rhizophagus intraradices* (N.C. Schenck & G.S. Sm.) C. Walker & A. Schubler (=*Glomus intraradices* (Sacc. & Ellis) Trappe, *Funneliformis mosseae* (T.H. Nicolson & Gerd.) C. Walker & A. Schub. (= *Glomus mosseae*), *Glomus pubescens* Tul. & C. Tul., *Glomus reticulatum* Bhattacharjee & Mukerji, *Glomus macrocarpum* Tul. & C. Tul., *Glomus heterosporum* G.S. Smith & N.C. Schenck, *Gigaspora sp., Acaulospora* sp. and *Scutellospora* sp. (Mohanan 1995a; Mohanan and Manoj 2006)) (Figs. 128, 129). As far as is known, absence or poor association of mycorrhiae may result in plant stunting and poor growth. This condition can be seen in bamboos growing in water- logged areas. Clump vigour in the field as well as planting stocks can be improved by application of appropriate mycorrhizal fungi to the root system of bamboos.

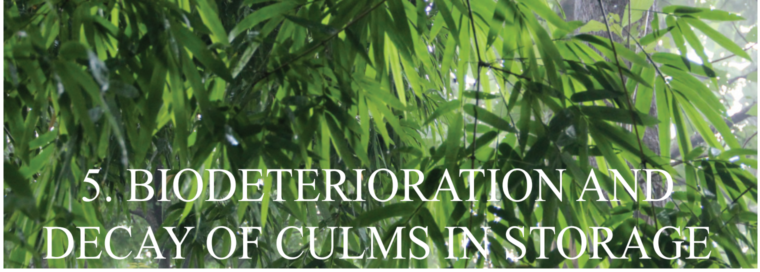
Non-infectious Diseases

Non-infectious diseases are caused by abiotic or non-living agents. Temperature and moisture extremes, chemical and fire injuries, nutrient abnormalities, air and water pollution, etc. are well known abiotic agents causing disorders. Non-infectious diseases are recognized by their uniform expression and the lack of progressive symptom development.

In bamboos, severe damage caused by glazed frost has been reported from China and Taiwan-China (Anonymous 1979; Qju 1982; Zhou 1988). During 1988, about 3 800 ha of *Phyllostachys pubescens* stands in Qjanshan County of Anhui Province, China, were severely affected by glazed frost (Zhou 1989; Tao 1990). An economic loss of 9 million renminbi yuan has been reported from the damage caused to bamboo stands. Other species of bamboos were also affected. The seriousness of the disaster was related to gradient and altitude of stand sites, and also to the stand density. The extent of glazed frost damage decreased with increase in stand density Young bamboo stands are severely affected by the frost. Foliage and young shoots are gravely injured during the winter, and injured shoots and foliage become susceptible to fungal pathogens (Figs. 130, 131). Weighing down by snow also reduces bamboo yield and affects culm quality. Silvicultural measures suggested to reduce glazed frost damage include: increasing the density in the groves; application of silica fertilizer to improve the hardness and elasticity of bamboo tissues; raising mixed stands of broad-leaved trees and bamboos; regulating the stand structure by rational harvest; removal of the small and weak bamboos; and planting cold-resistant bamboos (Zhou 1989; Tao 1990).

Fig 130 Frost damage in *Indosasa* sp. at Nanjing, China

Fig 131 Frost damage in *Shibataea chinansis* at Nanjing, China



5. BIODETERIORATION AND DECAY OF CULMS IN STORAGE

Bamboo is a major raw material in the pulp and paper industry in Asia. Large quantities of bamboo culms are used also in traditional industries. Usually, extraction of bamboo culms from the forest is often restricted to 6-8 months in a year and hence, culms for 6-9 months' pulp production have to be maintained by pulp mills. Bamboo culms for use in traditional industries, as well as for structural purpose, also have to be stored for long periods of time. Possible loss of bamboo clumps owing to gregarious flowering, often occurring extensively, also necessitates the storage of bulk quantities of culms as a precaution against shortage.

Bamboo, although one of the strongest structural material available, often succumbs to fungal decay and biodeterioration during storage. The natural durability of bamboos is low, and varies from 1 to 36 months, depending on the species and climatic conditions (Purushotham et al. 1954; Chandra and Guha 1979a, b, 1981; Tewari and Singh 1979; Guha et al. 1980; Liese 1980; Kumar et al. 1994). In tropical humid areas, enormous quantities of bamboo culms stored in forest depots, mill yards, etc. decay and deteriorate. The severity of decay and biodeterioration depends on the duration of storage, bamboo species, and environmental and storage conditions. During storage for up to 12 months, about 20-25% damage of culms has been reported in India (Varma and Bahadur 1980). Most bamboos used for structural purposes in rural and tribal housing deteriorate within a couple of years, and the demand for frequent replacements puts a heavy pressure on the resource.

Bamboo culms are vulnerable to attack by fungi and bacteria. Of these, fungi are the most ubiquitous ones. So far, more than 1 100 fungal species have been described and reported on bamboos globally, which comprise about 630 Ascomycetes, 150 Basidiomycestes and 330 mitosporic taxa (Hyde et al. 2002). Biodeterioration and decay of culms are caused mainly by fungi, and these include: soft rot, white not and brown rot. Bacteria also deteriorate culms under storage, with one or more of these organisms attacking the culms in succession. Colonization by the microorganisms and the severity of attack depend on the moisture content and nutrient status (starch content) in the culm, ambient temperature, humidity, etc. Bamboo consists of 50-70% hemicellulose, 30% pentosans and 20-25% lignin (Tamolang et al. 1980; Chen et al. 1985). Ninety percent of the hemicellulose is xylan, with a structure intermediate between hardwood and softwood xylans. Bamboo is known to be rich in silica (0.5-4%), but the entire silica is located in the epidermal layers, with hardly any silica in the rest of the cell wall. Although bamboo also has minor amounts of resins, waxes and tannins, none of these have enough toxicity to impart natural durability; furthermore, the large amount of starch makes bamboo highly susceptible to attack by staining and decay fungi (Hamada 1962; Mathew and Nair 1990; Gnanaharan et al. 1993). The sclerenchyma fibres which are responsible for the strength of bamboos are attacked by fungi and its strength is reduced considerably.

Fungal staining in stored bamboo culms develops as dark colouration. The affected culm becomes coloured in shades of brown to black. Although staining is usually superficial and may be easily brushed or scraped off, stains penetrating deep into the culm also occur. Staining is caused by fungi, which belong to Ascomycetes or mitosporic fungi.

Fungi causing decay of bamboo culms are grouped as white rot, brown rot and soft rot. White rot and soft rot cause more serious damage than brown rot. In white rot, both lignin and cellulose are attacked. White rot of culms is characterized by a bleached appearance caused by the utilization or modification of chromogenic material in the culm. In brown rot, cellulose and its associated pentosans are attacked, while ligning remains unaffected. The lignin-rich residue of the decay imparts a brown colour to the decayed culms. In soft rot, cellulose is removed like in brown rot, but the mechanism of action on the cell wall is different. The fungi causing soft rot, like those causing staining, belong to Ascomycetes and Fungi Imperfecti, although the species involved and their action mechanism are different. Bacterial degradation of culms also occurs, but it is a slow process unlike that caused by fungi. Many bacteria may attack cellulose, while some may attack the lignified cell wall.

Fungi causing deterioration and decay of bamboo culms in storage have been reported from different countries in Asia (Giatgong 1980; Wang 1985; Sutathip 1988; Arunee 1989; Shojiro et al. 1989; Mohanan and Liese 1990). In Japan, the decay fungi recorded on *Phyllostachys edulis, P. lithophila, P. nigra, Dendrocalamus latifolius* and *Chimonobambusa quadrangularis include: Irpex lacteus, Irpex consors Berk., Fomitopsis palustris (=Tyromyces palustris), Trametes coccinea* (*=Pycnoporus coccineus), Trametes sanguinea, Fibroporia vailanti* (*=Poria vaporaria*)*, Schizophyllum commune Fr., Trametes versicolor* (*=Polyporus versicolor = Coriolus versicolor),* etc. Of these, *Fomitopsis palustris*, the brown rot fungus, and *Irpex lacteus* and *Trametes versicolor*, the white rot fungi, are the important ones.

In India, the decay fungi recorded on stored bamboos are *Rigidoporus lineatus* (*=Polyporus zonalis*) *Berk., Fomes tenuiculus* (*=Polyporus tenuiculus* (Beauv) Fr.), *Favolus grammocephalus* (*=Polyporus grammocephalus* Berk.), *Polystictus steinheilianus* Berk. et Lev., *Oxyporus cervinogilvus* (*=Poria diversispora* Berk. et Br.), *Antrodia rhizomorpha* (*=P. rhizomorpha* Bagchee), *Pleurotus* sp., *Trametes elegans* (*=Lenzites elegans* (Fr.) Pat., *Nigroporus durus* (*=Fomes durus* (jung.) Cunn.), *Fomes hypoplastus* Berk., *Schizophyllum commune, Stilbella fimetaria (=Stilbum erythrocephalum* Ditm.) *Tubercularia lateritium* (*=Stilbum lateritium* Ber.), *Tetraploa aristata* Berk., *Thelephora palmata* (Scop.) Fr., *Earliella scabrosa* (*=Trametes persoonii* Fr.), *Tremella fuciformis* Berk., *Gloeophyllum striatum* (Fr.) Murr., *Cyathus limbatus* Hall., *Sphaerostilbe bambusae* Pat., *Sporidesmium nilgirense* Subram., *Ellisembia leptospora* (*=Sporidesmium leptospermum*)*, Cribaria intricata* Schard., *Gymnopilus dlipes* (*Flammula dilepsis* Berk., et Br.), *Arthrinium arundinis* (*= Apiospora montagnei* Sacc.), *Lacellina graminicola* (Berk et Br.) Petch, *Phellinus gilvus* (Schw.) Pat., etc. (Mathur 1936; Patel et al. 1949, 1951; Banerjee and Ghosh 1942; Subramaniam 1956; Bakshi et al. 1963; Kar and Maity 1971; Harsh N.S.K. 1995 personal communication; Mohanan 1994, unpublished observation) (Fig. 132-134).

White rot fungi recorded on different species of bamboos in Thailand include: *Daldinia childiae, Leiotrametes lactinea* (=*Trametes lactinea* Berk.), *Lentinus* sp., *Pycnoporus sanguineus* L. Murril. *Gloeophyllum sepiarium* (Fr.) Karst., *G. subferruginosum* (Berk.) Bond. et Singer, *Trametes cervino-gilvus* Aosh. and *Trametes lijubarsyi* (=*Haploporus lijubarskyi* (Pil.) Bond. et Singer). Brown rot fungi reported on different species of bamboo from Thailand are: *Fomitopsis pinicola* (Sw. Ex. Fr.) (Sutathip 1988; Arunee 1988). Staining and decay fungi recorded on stored culms of *Bambusa blumeana, B. vulgaris* var. *striata*, *Schizostachyum* lumampao and Bambusa spp. in the Philippines include: *Penicillium* spp., *Aspergillus* spp. *Trichoderma* spp. *Schizophyllum commune*, *Poria* sp., *Polyporus* sp., *Gloeophyllum striatum* (=*Lenzites striata*), etc. (Marcelina 1995, personal communication).

Fig 132 Decaying culms of *T.oliveri*; note the fructifications of different decay fungi

Fig 133 Culms of *B.bambos* decayed by *Lenzites* sp.

Fig 134 Moulds and staining fungi on stored bamboo culm

Among the soft rot fungi, *Xylaria* spp. and *Chaetomium globosum* Kuntze et Schme. are the most important. *Chaetomium globosum* has been observed as associated with soft rot of culms of *Phyllostachys reticulata* and *Phyllostachys* spp. in Japan (Shojiro et al. 1989). Split bamboo is molre rapidly destroyed by the fungi than round bamboos (Liese 1959; Gnanaharan et al. 1993).

Decay and deterioration has been considered a serious problem in bamboo culms stored for making pulp. Decay fungi seriously affect the pulp yield (up to 25% loss over one year storage) and pulp strength is reduced by 15-40% (Guha and Chandra 1979; Bakshi et al. 1960). White rot-affected bamboo culms can be used for pulping; however, the additional bleaching chemicals required cause low pulp yield and lower physical strength. In the case of brown-rot affected culms, the pulp yield becomes low and the permanganate number is high so that bamboo culms affected by brown rot are undesirable for pulping. Advanced brown rot results in 25% loss in yield and produces unbleachable pulp.

Fungal staining of the culm does not appreciably affect the yield; however, strength properties of pulp may be slightly lower than that of non-stained culms (Bakshi et al. 1960). Fungal staining also affects the brightness of the pulp, and an increase in bleach consumption (to the extent of

10%) to bring the stained pulp to acceptable brightness has been reported (Bakshi 1976). Hence, it may be said that, in general, fungal attacks increase pulping costs (Singh 1977).

Protective Measures

Decay and biodeterioration of bamboo culms during outdoor storage can be checked to a great extent by adopting good storage yard management practices. Culms should be stacked horizontally over raised walls to facilitate water drainage and air circulation. For reed bamboos, vertical stacking results in a small gain in pulp yield over horizontal stacking because the former suffers less fungal damage.

Recently, an exhaustive review on bamboo preservation techniques has been made by Kumar et al. (1994) on behalf of INBAR. Basically, there are two methods for increasing the durability of bamboo: (1) non-chemical method, in which preservatives are not involved; and (2) chemical method.

Bamboos used for structural purposes are often treated by non-chemical or traditional method, although not much is known about their real effectiveness. However, the treatment cost is almost nothing and can be carried out at village level without any special equipment. These methods include curing, smoking, lime-washing and soaking. (Martawidjaja 1986; Singh and Nigam 1968; Sulthoni 1987; Kumar et al. 1980, 1983; Liese 1993; Gnanaharan et al. 1993). Bamboo culms are treated during or immediately after extraction and before stacking in the storage yard. Curing involves leaving harvested culms, with branches and leaves intact, in open air. The leaves continue to transpire causing the starch content of the culms to fall. The second traditional method is to smoke bamboo culm over fire. This is considerd an effective treatment against insects and fungi. Painting of culm with lime is widely used and said to ward off fungal attack. Often, culms are painted with a mixture of tar and sand, or plaster, cow dung and lime, to prevent fungal and insect attacks. Another method is to submerge the culms in either stagnant or running water, or mud for several weeks.

Chemical protection ensures a longer life for bamboos. Culms can be treated using a variety of chemicals, depending upon the culm condition – green or dry – and also on the end use of bamboo. Various chemical treatments recommended for increasing the service life of fresh (green) bamboo include: steeping, sap displacement, diffusion process and boucherie process. Treatments for dry bamboo culms include soaking in a preservative solution, hot-cold process and pressure treatment.

Methods that use preservative chemicals are generally more effective than non-chemical methods in the protection of bamboo under storage, but they are not always economical or feasible. Recently, Gnanaharan et al. (1993) suggested a low-cost treatment for reed bamboos against biodeterioration. Reed bamboos used for mat weaving can be stored effectively even up to 8 months by keeping them under water (running or stagnant), or a disinfectant solution (bleaching powder or potassium permanganate) or preservative chemical solution (copper sulphate or boric acid) of very low concentration. Chemical treatment on a large scale is performed mainly in India, Japan and Taiwan-China. In Japan, prophylactic treatment and surface protection during processing is common. Brushing and spraying of bamboos are rarely carried out except for prophylactic purpose. However, these methods have only a temporary effect because of the very low penetration of the preservatives.

Prophylactic chemical treatment at the time of stacking and after 4-6 months is recommended for protecting structural bamboo culms stored outdoors (Kumar et al. 1990, 1994). For long-term storage of pulp bamboos in the open, chemical treatment (spraying) during different stages of stack forming – at 3, 4, 5 and 6 m heights – and covering with treated bamboo mats or thatch grass are recommended. Preservative chemicals recommended for treatment of bamboo include:

1. Coal tar creosote and fuel oil (50:50) by weight. In high termite-infested areas, it is preferable to add 1% dieldrin. Coal tar creosote should meet the relevant standard specification for preservation purposes (Anonymous 1961);
2. Copper-chrome-arsenic composition containing copper sulphate, sodium or potassium dichromate and arsenic pentoxide in the proportion of 3:4:1 (Anonymous 1981b);
3. Borated-copper-chrome-arsenic (SBOR) composition conforming to the composition (patent pending) prescribed by the Forest Research Institute, Dehra Dun, India;
4. Acid-copper-chrome composition containing copper sulphate 50 parts, sodium dichromate 47.5 parts, chromic acid 1.68 parts (equivalent to 2.5 parts of sodium dichromate) (Anonymous 1981a);
5. Copper-chrome-boron composition containing boric acid, copper sulphate and sodium or potassium dichromate in the proportion of 1.5:3:4 (Anonymous 1981c);
6. Ammoniacal copper-arsenite composition containing copper-sulphate, arsenic trioxide dissolved in ammonia (Dev et al. 1991);
7. Boric acid:borax in 1:1.54 proportion;
8. Copper naphthenate/abietate and zinc naphthenate/abietate containing 0.5% copper or 1% zinc;
9. Sodium pentachlorophenate, boric acid and borax in 5:1:1 proportion (2.5% solution) for prophylactic treatment;
10. Copper-chrome-arsenic composition, containing copper sulphate, sodium or potassium dichromate, and sodium pentachlorophenate in 2:0.5 proportion (2.5% solution) for prophylactic treatment; and
11. DP (2, 5-chloro-3-bromophenol) 0.1% solution for prophylactic treatment (Ma 1990).
12. Chemical preservatives recommended against fungal and insect attacks are invariably toxic to mammals. Slight carelessness in the use of such chemicals can endanger the safety of those handling the chemicals and freshly treated bamboos. Although the chemical preservatives recommended for bamboos have long safety records, many of them are still under constant scrutiny and a few are banned in some countries.

6. NEW FINDINGS AND POTENTIALLY SERIOUS DISEASES

Literature search for bamboo diseases and disorders recorded from different countries in Asia, during the past two decades employing CAB-Direct Database and E-Journals revealed a lot of information on diseases and disorders affecting bamboos and the causal organisms associated with them in the region. Earlier, 170 species belonging to 26 genera of bamboos were recorded as affected by various diseases and disorders in different countries in Asia (Mohanan 1997). An additonal 25 bamboo species belonging to 9 genera have been reported as hosts during the past two decades from the region. Similary, an additonal 140 species of fungi, two bacteria, two phytoplasma and one virus have also been recorded as causal agents of various diseases and disorders of bamboos. Thus, at present, a total of 580 species of fungi belonging to 300 genera, five bacteria, two viruses, three phytoplasma and one bacterium-like organism have been reported to be associated with various diseases and disorders of bamboos in Asia. Information retrieved on diseases, deterioration and decay, causal agents and bamboo species affected was incorporated at appropriated places in the text.

Emergence of a new disease of culm caused by an opportunist pathogen, *Pterulicium xylogenum* has recently been reporded on *Bambusa vulgaris* var. *waminii*, *Dendrocalamus giganteus* and *Gigantochloa* sp. from India (Harsh et al. 2000). The disease caused 36 to 45% mortality of emerging culms. The occurrence of disease has also been recorded on edible shoots of *Melocanna baccifera* from Tripura, India (Sandeep, 2010). Recently, the disease has also been observed on *Dendrocalamus giganteus, Bambusa pallida, D. longispicula, D. asper* and *B. tulda* stands at, Peechi, Thrissur and in a Bambusetum of Kerala Forest Research Institute Field Station at Palappilly, Thrissur, Kerala (Mohanan 2017 unpublished observation). The causal fungus reported is an opportunist pathogen which survives in bamboo litter saprophytically. Under conducive microclimatic conditions, the saprotrophic fungi infect the emerging culms and cause rot of the affected culms. Factors favouring for the infection and spread include heavy rainfall during and after the emergence of culms. This disease may pose threat to bamboo culm production as well as clump vigour.

Even though, mosaic disease affecting bamboos has been recorded during 1970s, and association of a virus has been detected, detailed information of virus associated with the bamboo mosaic disease is a recent one. The virus was first isolated from *Bambusa multiplex* (Lour) Raeusch. and *B. vulgaris* and reported from Brazil in 1975 (Kitajima et al., 1975; Lin et al., 1977). Mosaic disease affecting foliage and young developing culms of bamboo has been reported from Taiwan-China and China. The disease affects two major cultivated bamboos - *Dendrocalamus latiflorus* Munro and *Bambusa oldhamii* Munro - and abolut 70-80% disease incidence has been reported. Bamboo mosaic virus has been identified as belongs to the genus Potex virus in the family Alphaflexivirideae (Hull 2013). Some isolates of the virus, also contain a satellite RNA (sat BaMV) which is a single stranded RNA sub-viral agent whose replication is supported by Bamboo mosaic virus, encapsidated by BaMV capsid protein to form rod shaped particles of length 60 nm (Lin and Hsu 1994). SatBaMV was first identified to be associated with BaMV isolated from *B. vulgaris* and reported from Taiwan in 1994 (Lin and Hsu 1994). The affected culms become hard in texture, and internal tissues get discoloured and quality deteriorates. Immunological detection of BaMV antigen by tissue blotting (Lin et al. 1993) demonstrated that most cultivated bamboo species in Taiwan-China with patchymorph rhizomes including *Bambusa* and *Dendrocalamus,* are susceptible to bamboo mosaic. Infection of *B. oldhamii* results in the formation of a large number of unusual electron-dense bodies in the infected cells. So far, BaMV is known to infect bamboos exclusively with no other known natural host. At precent, this virus has been known to infect about 13 species of bamboos (mainly those with pachymorph rhizomes)

Cherry necrotic rusty mottle virus (CNRMV) associated with diseases of sweet cherries has recently been recorded on about 21 species of bamboos. CNRMV cause mosaic, chlorosis, yellow streaks, necrotic spots and curling on the foliage of infected bamboos (Awasthi et al. 2014). Even though, the information on the emerging viral disease of bamboos is very preliminary and lacks details with regard to their impact on bamboo production, the findings indicate that infected bamboos, besides themselves developing disease symptoms, may also be acting as source of infection for the stone and pome fruit trees

Rot of emerging culms, caused by *Fusarium fujikuroi* affecting mostly *Bambusa bambos* and *B. balcooa* in the high rainfall areas of Kerala and Karnataka States respectively, in India, reported during 1990s, has recently attained an epidemic status affecting different species of bamboos in natural stands as well as in plantations with a disease severity ranging from 70% to 100% (Mohanan 2008; Sharada et al. 2013) As bamboo natural stands in both the States mostly belong to protection forests and hence usual silvicultural stand management measures are seldom practised. The recent disease records from these areas indicate that the disease may pose serious threat to bamboo culm production and thereby related industries.

Witches'-broom disease, affected by a large number of closely related endophytic fungal pathogens including *Aciculosporium, Linearistroma, Heteroepichloe, Phaeosphaeria* species is widely distributed in bamboo growing areas in Japan, China, Taiwan-China, India, Indonesia, the Philippines and Vietnam (Tanaka 2003; Hashimoto et al. 2008; 2010; Mao 1993, 1996). At present, the pathogens have a wide host range in different bamboo growing contries in the region. Information is available mainly on the distribution of disease and the bamboo species affected. Even though, the disease was recorded during 1970s and information on causal organisms and symptomatology is available, etiology is little studied and proper disease management measures are not yet worked out. The causal organisms are endophytic fungi with different infection propagules like conidia, ascospores and rhizomorphs and cause almost systemic infection. The disease is widely distributed in bamboo growing areas in China with a wide host range. Recently, the disease has attained an epidemic status in Zhejiang, Jiangsu, Anhui, Hunan, Sichuang, Guangdong, Henan and Guizhou Provinces in China causing 95% to 100% in *Phyllostachys* stands. Similarly, witches'-broom disease is widespread in *Phyllostachys bambusoides* stands in Shizukoa Perfecture in central Japan and throughout the western Japan with an average disease incidence of 93% posing threat to culm production.

Even though, Little leaf disease of bamboo has been reported on *Dendrocalamus strictus* clumps in natural stands in Kerala, Karnataka, Tamil Nadu and Andhra Pradesh from India (Mohanan 1990,1997) and suspected association of *Phytoplasma* (mycoplasma-like-organism) providing supporting data from fluorescence microscopic and transmission electron microscopic studies and tetracline hydrochloride field therapy (Mohanan 1994a), identification and confirmation of *Phytoplasama* associated with *D. strictus* is a recent one. *Phytoplasma aurantifolia* (16SrII Group) has been identified as the causal organism associated with little leaf disease of *D. strictus* growing in five different geographical areas in Maharashtra State, India (Yadav et al. 2016). Recently, similar disease caused by *Phytoplasma* belonging to '*Candidatus Phytoplasma asteris'* has also been reported on *Phyllostachys nigra* var. *henonis* from Yeoungyang, Korea (Jung et al. 2006).

Wilt disease of bamboo caused by *Fusarium* spp. has been reported on *Dendrocalamus latiflorus* Munro from Fujian Province in China (Xie et al. 1987). Recently, a similar wilt disease affecting hybrid bamboo caused by *Fusarium incarnatum*, has been reported from China (Ma et al. 2008). *Bamdusa pervariadilisx Grandis* Nin 3# is a new hybrid bamboo species produced using *Bambusa pervariabilis* McClure as female parent and *Dendrocalamopsis daii* Keng f. as male parent, which has the characteristics of wide adaptability, very high shoot number, high branching, fast growing and large output of bamboo wood. This bamboo shoot is of sweet and refreshing taste with better than the other conventional varieties and have very good prospects in the food market in China (Zhao et al. 2004; Liang et al. 2010). Fusarium wilt affecting the hybrid bamboo was first recorded in Liuzhou region of Guangxi Province (Ma 2001; Ma et al. 2006) and at present the disease is widespread in Guangxi Province posing threat to the development of related industries (Liang et al. 2010).

The literature search revealed that many of the foliage disease causing pathogens have widened their host range in bamboo growing countries in the region. A very high species diversity, especially among fungi causing foliage rusts of bamboo has been recorded. A total of 25 species of *Puccinia* have been recorded on different species of bamboos from different countries in the region. In the case of leaf spot disease caused by *Phyllachora* species, a high species diversity, i.e. association of about 16 species of *Phyllachora* on different bamboo species in the region has been recorded.

During the past two decades, tremendous nomenclature changes especially on bambusicolus fungi have been noticed. Nomenclature of all the reported bambusicolous fungi was checked by using the Index Fungorum - Database of Royal Botanic Garden, Kew and Species Fungorum – CABI - Database and corrections incorporated in this version.

FUTURE RESEARCH

The available information on diseases and disorders of bamboos collected reveals that diseases, deterioration and decay play an important role in the depletion of the bamboo resources in Asia. From an economic point of view, the impact of diseases on bamboos is often difficult to assess.

Quantified data on the extent of damage caused by diseases and their economic implications are meagre. However, the present study exposes a clear picture on the potentially serious diseases of bamboos in the region. The diseases identified as potentially serious, affecting culm production as well as stand productivity, in different countries are: culm blight in Bangladesh and the coastal belts of Odisha State in India; rot of emerging and growing culms in India; culm wilt in China; culm rust and top blight in China; little leaf disease caused by Phtoplasma in southern India; witches'-broom in China, India, Japan and Taiwan-China; and culm mosaic in Taiwan-China, China and India. However, large-scale monoculture of bamboos with narrowed genetic base (using clonal material) could lead to the emergence of more diseases; also the diseases perceived as of minor significance may flare up under condusive microclimatic conditions and pose threats to planting stocks or stands.

Bamboo blight, reported in Bangladesh in the early 1970s, caused a large-scale mortality of bamboos in village groves during the 1980s and adversely affected the rural economy. No more new outbreaks have been reported from Bangladesh, but the present status is still uncertain. A similar disease affecting *Bambusa nutans* in village groves in the coastal belts of Odisha State, India, is spreading at a very fast pace. Even though a very elaborated symptomatology and possible etiology of the disease are available, qauantitative data on incidence, severity, and spread and extent of culm mortality are insufficient to make a disease impact assessment even at a lower scale. Culm rust and top blight in *Phyllostachys* stands in different Provinces of China, and culm mosaic in *Bambusa oldhamii* and *Dendrocalamus latiflorus* plantations in Taiwan-China are also widespread that they often have attained epidemic status. Large-scale mortality of culms and degradation of edible shoots by these diseases are posing threats to bamboo-based industries. Present information on the epidemiology of these diseases is insufficient, and disease control strategies adopted to check the diseases are often found inefficient. The same is true in the case of recently reported diseases like rot of growing and emerging culms in India, witches'-broom disease reported from Japan, China, Taiwan-China and India, and little leaf diseases reported elsewhere. This discrepancy seems to have arisen because bamboos, till recently, were considred less important among forestry species and the diseases affecting them were treated as less significant. Moreover, a systematic approach was not followed in the study of bamboo diseases and their impacts.

The lacunae in knowledge regarding the distribution, etiology and epidemiology of the diseases, impact on economy, and appropriate disease mangement measures, especially for the potential diseases have to be filled in by well-organized studies. Such a step will provide better understanding on the geographical distribution of bamboo diseases, causal organisms, their modes of dissemination and invasion, and spread of infection in relation to local weather condition and prevailing edaphic factors such as soil fertility, moisture availability and microsite conditions. Such information is required for precise disease impact assessments, as well as for evolving disease management strategies appropriate to the bamboo species grown and the silvicultural measures practised in a particular country or region.

Thrust areas identified for future research are:

- A systematic disease survey in bamboo nurseries and stands in different bamboo-growing countries in Asia;
- In-depth studies on the epidemiology of potential diseases such as bamboo blight, culm rust, culm wilt, top blight, little leaf, witches-broom, culm mosaic, and rot of emerging and growing culms;
- Development of appropriate silvicultural, biocontrol and chemical disease management strategies against important bamboo diseases;
- Development of disease-resistant, high-yielding bamboo genotypes through selection, introduction and field screening; and
- Mycorrhizal application to improve bamboo planting stocks and developing resistance against soil-borne pathogens

Fungal staining, deterioration and decay of post-harvest bamboo culms is another important problem confronting bamboo-based industries in Asia. Decay can be minimized by adopting appropriate storage practices and prophylactic treatments. More information on this regard has to be generated, particularly, low-cost, locally available and environmentally safe chemicals, as well as their effective mode of treatment, have to be developed and tested. Also, emphasis should be given to select disease and decay management strategies appropriate, and at the same time economically viable, ergonomically and environmentally safe, to the local stand/stack management practices.

REFERENCES

Alaka Pande; Rao, V. G. 1997. *Chaetosphaerulina bambusae* sp. nov. (Pleosporales) from India. Mycotaxon 61: 307-310.

Anahosur, K.H. 1970. Ascomycetes of Coorg (India) II. Sydowia 24: 177-182.

Anan, A. 1987. Flowering and seed characteristics of bamboo in Thailand. *In* Rao, A.N.; Dhanarajan, G.; Sastry, C.B.ed., Recent Research on Bamboo. Proceedings of the International Bamboo Workshop, Hangzhou, China, 6-14 October 1985. Chinese Academy of Forestry, Beijing, China: International Development Research Centre, Ottawa, Canada. pp. 136-145.

Ananthanarayanan, S. 1964. Studies in Indian Phyllachoraceae IV. Mycopathologia et Mycologia Applicata, 22: 3-7.

Anonymous 1945. Forest Research in India and Burma: 1944-45. Part I. The Forest Research Institute, Dehra Dun, India, 1499 pp.

Anonymous 1950. List of common names of Indian plant diseases. Indian Journal of Agricultural Science, 20: 107-142.

Anonymous 1951. Index of Fungi. Commonwealth Mycological Institute, Kew, Surrey, U.K. 2(2): 15-34.

Anonymous 1960. Index of Plant diseases in the United States. Handbook No. 165. United States Department of Agriculture, Washington D.C., USA.

Anonymous 1961. Specification for creosote and anthracene oil for use as wood preservatives. IS:218. Bureau of Indian Standards, Manak Bhawan, New Delhi, India.

Anonymous 1979. Observation on bamboo survival in winter and control of freezing: drought damage. Forest Science and Technology, 18-25.

Anonymous 1981a. Specification for water soluble type wood preservatives. IS: 10013. Part I. Acid-Copper-Chrome (ACC) wood preservative. Bureau of Indian Standards, Manak Bhawan, New Delhi, India.

Anonymous 1981b. Specification for water soluble type wood preservatives. IS: 10013. Part II. Acid-Copper-Chrome (ACC) wood preservative. Bureau of Indian Standards, Manak Bhawan, New Delhi, India.

Anonymous 1981c. Specification for water soluble type wood preservatives. IS: 10013. Part III. Acid-Copper-Chrome (ACC) wood preservative. Bureau of Indian Standards, Manak Bhawan, New Delhi, India.

Anonymous 1982. China forest diseases. China Forest Publishing House, Beijing, China, 24 pp.

Anonymous 1987. The investigation of purple-spot in Nanshan Village: Forest Prevention station of Yuyao City. Ningbo Forestry Zhejiang, 7: 33-35.

Appasamy, T. ; Ganapthy, A. 1992. Preliminary survey of vesicular-arbuscular mycorrhizal (VAM) association with bamboos in Western Ghats. Bamboo Information Centre India Bulletin, 2(2): 13-16.

Arjun Shukla; Aradhana Singh; Deepa Tiwari; Bhoopendra Kumar, K.A. 2016. Bambusicolous fungi: A reviewed documentation. International Journal of Pure & Applied Bioscience 4(2): 304-310.

Arunee, J. 1989. Natural durability of bamboo to brown rot fungi. *In* Proceedings of the Forestry Conference 1988. Royal Forest Department, Bangkok, Thailand. pp. 333-337.

Awasthi, P.; Dhyani, D.; Raja Ram; Zaidi, A. A.; Hallan, V. 2015a. Wild roses as natural reservoirs of Cherry necrotic rusty mottle virus. European Journal of Plant Pathology, 142 (2): 403-409.

Awasthi, P.; Ram, R.; Reddy, S. G. E.; Gireesh Nadda; Zaidi, A. A.; Hallan, V. 2015b. Himalayan wild cherry (*Prunus cerasoides*) as a new natural host of Cherry necrotic rusty mottle virus (CNRMV) and a possible role of insect vectors in their transmission. Annals of Applied Biology, 166 (3): 402-409.

Awasthi, P.; Ram, R.; Zaidi, A. A.; Prakash, O.; Sood, A.; Hallan, V.2015c. Molecular evidence for bamboo as a new natural host of Cherry necrotic rusty mottle virus. Forest Pathology, 45 (10): 42-50.

Awati, J.B.; Kulkarni, K.K. 1972. A new species of *Phyllachora* Nke. From India. Current Science, 41: 31-33.

Azmy, Hj. M.; Maziah, Z. 1990. Leaf disease of bamboo. FRIM Technical Information No. 18. Forest Research Institute Malaysia, Kuala Lumpur, Malaysia.

Bagchee, K. 1954. New and noteworthy diseases of forest trees and decay in timber in India. Indian Forester, 80: 373-378.

Bagchee, K.; Singh U. 1954. List of common names of fungi attacking Indian forest trees, timber and the herbaceous and shrubby undergrowths and list of cultures of forest fungi. Indian Forest Records. Mycology, 1(10): 199-348.

Bakshi, B.K. 1957. Fungal diseases of Khair (*Acasia catechu* Willd.) and their prevention. Indian Forester, 83: 61-66.

Bakshi, B.K. 1971. Indian Polyporaceae on trees and timber. Indian Council of Agricultural Research, New Delhi, India. 246 pp.

Bakshi, B.K. 1976. Forest Pathology: Principles and Practice in Forestry. Controller of Publications, New Delhi, India. 400 pp.

Bakshi, B.K.; Guha, S.R.D.; Gupta, S. 1960. Effect of fungal damage to bamboo in the yield and quality of pulp. Pulp Research and India, 5(2): 38-39.

Bakshi, B.K.; Reddy, M.A.R.; Puri, Y.N.; Sujan Singh 1972. Forest disease survey (final technical report). Forest Pathology Branch, Forest Research Institute, Dehra Dun, India 117 pp.

Bakshi, B.K.; Sujan Singh; Singh, B. 1963. A reexamination of *Fomes lignosus* and *Polyporus zonalis*. Transactions of the British Mycological Society, 46: 426-430.

Balakrishnan, B.; Nair, C.M.; Lulu Das 1990. Some common diseass of bamboo and reeds in Kerala. *In* Ramanuja Rao, I.V.; Gnanaharan, R.; Sastry, C.B., ed., Bamboos: Current Research. Proceedings of the International Bamboo Workshop, Cochin, India, 14-18 November 1988. Kerala Forest Research Institute, Kerala, India; International Development Research Centre, Ottawa, Canada. pp. 184-189.

Banerjee, S.; Mukopadhyay, S. 1962. A study on *Merullius similis* Berk. & Br. and the associated bamboo rot. Osterreichische Botanische Zeitsschrift, 109(3): 197-212.

Banerjee, S.N. 1947. Fungous flora of Calcutta and suburbs. I. Bulletin of Botanical Society of Bengal,1:37-54.

Banerjee, S.N.; Ghosh, T. 1942. Preliminary report on the occurrence of higher fungi on bamboos in and around Calcutta. Science & Culture, 8(4): 194-196.

Banik, R.L. 1984. Emerging culm mortality at early developing stages in bamboos. Bano Biggyan Patrika, 12: 47-52.

Banik, R.L. 1996. Domestication and improvement of bamboos. INBAR Working Paper No. 10. Chittagong, Bangladesh Forest Research Institute.

Bengyella, L.; Waikhom, S. D.; Talukdar, N. C.; Pranab Roy 2015. Black list of unreported pathogenic bambusicolous fungi limiting the production of edible bamboo.Journal of Plant Pathology and Microbiology, 6(4):264

Berkeley, M.J. 1856. Decades of fungi, 1-620. Journal of Botany, 3-8:1844-1856.

Bhat, M.N.; Hegde, R.K.; Hiremath, P.C.; Kulkarni, S. 1989: Unrecorded pathogen on bamboo causing blight in India. Current Science, 58(2): 1148-1149.

Bhattacharya, P.M.; Saha, J.; Banerjee, K.; Ali. Md. M.; Chaudhuri, S. 1995. Mycorrhizal relations of bamboos in West bengal. *In* Adholeya, A.; Sujan Singh, ed., Mycorrhizae: Biofertilizers for the Future. Tata Energy Research Institute, New Delhi, India. pp. 17-21.

Bilgrami, K.S.; Jamaluddin; Rizwi, M.A. 1991. Fungi of India: list and references. Today and Tomorrow's Printers and Publishers, New Delhi, India.

Boa, E. R.; Brady, B.L. 1987. *Sarocladium oryzae* associated with a blight of *Bambusa* spp. In Bangladesh. Transactions of the British Mycological Society, 89:161-166.

Boa, E.R. 1987a. Fungal diseases of bamboo: a preliminary and provisional list. *In* Rao, A.N.; Dhanarajan, G.; Sastry, C.B. ed., Recent Research on Bamboo. Proceedings of the International Bamboo Workshop, Hangzhou, China, 6-14 October 1985. Chinese Academy of Forestry, Beijing, China; International Development Research Centre, Ottawa, Canada. pp. 271-279.

Boa, E.R. 1987b. The occurrence of bamboo blight in Bangladesh with reference to *Sarocladium oryzae*. *In* Rao, A.N.; Dhanarajan, G.; Sastry, C.B. ed., Recent Research on Bamboo. Proceedings of the International Bamboo Workshop, Hangzhou, China, 6-14 October 1985. Chinese Academy of Forestry, Beijing, China; International Development Research Centre, Ottawa, Canada. pp. 280-299.

Boa, E.R.; Rahman, M.A. 1983. Bamboo blight in Bangladesh: an important disorder of bamboos. Overseas Development Administration, London, UK. 24 pp.

Boa, E.R.; Rahman, M.A. 1987. Bamboo blight and bamboos of Bangladesh. Bull. I. Forest Pathology Series, Forest Research Institute, Chittagong, Bangladesh. 43 pp.

Borah, R. K.; Dutta, D.; Hazarika, P. 1998. Some new records of fungi from north-east India. Van Vigyan, 36 (1): 41-43.

Borah, R. K.; Dutta, D.; Hazarika, P. 1998. Three new Phyllachora leaf spots from Assam. Indian Journal of Forestry, 21 (3): 256-258.

Bose, S.R. 1919. Descriptions of fungi in Bengal. Proceedings of Indian Association for Cultivation of Science, 4:109.

Browne, F.G. 1968. Pests and diseases of forest plantation trees. Clarendon Press, Oxford, UK.

Bruhl, P.; Sengupta, J. 1927. Indian slime fungi (Myxomycetes on Mycetozoa). Journal of Science, Calcutta University, 8:101-122.

Butler, E.J.; Bisby, G.R. 1931. The fungi of India. Science Monograph I. Imperial Council for Agricultural Research in India. 237 pp.

Butler, E.J.; Bisby, G.R. 1960 [1931]. The fungi of India (revised ed.). Indian Council of Agricultural Research, New Delhi, India.

Bystriakova, N., Kapos, V., Lysenko, I. & Stapleton, C. 2003. Bamboo biodiversity: information for planning conservation and management in the Asia-Pacific region. Cambridge, UK, UNEP-World Conservation Monitoring Centre; & Beijing, International Network for Bamboo and Rattan.

Caasi-Lit, M.; Lit, I. L., Jr.; Sinohin, V. O.1999. Is witch's broom sweeping Philippine bamboos? Canopy International, 25 (1): 4-5.

Chacko, K.C.; Pandalai, R.C.; Mohanan, C.; Seethalakshmi, K.K.; Sasidharan, N. 2002. Manual of Seeds of Forest Trees, Bamboos and Rattans. Kerala Forest Research Institute, Peechi, 331 p.

Chalermpongse, A.; Pongpanich, K.; Boonthavikoon, T. 1984. Seed-borne fungi and diseases of tropical forest tree seeds in Thailand. Forest Pest Control Branch, Thailand Royal Forest Department, Bangkok, Thailand.

Chandra, A.; Guha, S.R.D. 1979a. Studies on the decay of bamboo *Dendrocalamus strictus* during outside storage: degradation of cellulose. Indian Forester, 105(6): 444-450.

Chandra, A.; Guha, S.R.D. 1979b. Studies on the decay of bamboo *Dendrocalamus strictus* during outside storage: effect of hemicellulose. Journal of Timber Development Association of India, 25(3): 10-13.

Chandra, A.; Guha, S.R.D. 1981. Studies on the decay of bamboo *Dendrocalamus strictus* during outside storage:degradation of lignin. Indian Forester, 107: 54-59.

Chen Kai; Wu Xiao Qin; Xue Qi 2015. Occurrence regularity of brown culm streak of *Phyllostachys praecox*. Journal of Nanjing Forestry University (Natural Sciences Edition), 39 (2); 75-78.

Chen Tsang Hai; Lu Yau Tsuen 1995. Partial characterization and ecology of bamboo mosaic potexvirus from bamboos in Taiwan. Plant Pathology Bulletin, 4 (2): 83-90.

Chen Zuei-Ching; Tieh-Lan Hu; Koyama, T. 1980. A preliminary survey of uredinales on Formosan gramineae. Taiwania, 25: 152-165.

Chen, C.C. 1970. Witches'-broom: a new disease of bamboo in Taiwan. Memoirs College Agriculture, National Taiwan University, Taiwan-China. 11(2): 101-112.

Chen, C.C. 1971. Some studies on witches'-broom of tree and bamboos in Taiwan. Memoirs College Agriculture, National Taiwan University, Taiwan-China. 12(2): 67-82.

Chen, J.T. 1982. Studies on the etiology of the bamboo basal stalk (shoot) rot: a new disease of *Phyllostachys pubescens*. Journal of Bamboo Research 1&2, No. F:15: 54-61.

Chen, J.T.; Yu, C. Z.; Zhang, L.Q. 1988. Study of bamboo culm rust in Zhejiang province. Journal of Bamboo Research, 7: 74-83.

Chen, K.; Wu, X. Q.; Huang, M. X.; Han, Y. Y. 2014. First report of brown culm streak of *Phyllostachys praecox* caused by *Arthrinium arundinis* in Nanjing, China. Plant Disease, 98 (9): 1274.

Chen, S.; Chen, F.M.; Zhang, S.Q. 1989. Control of culm rust of glaucous bamboos with liquor cresoli saponatus. Forest Science and Technology in Jiangxi, 3: 32-33.

Chen, T.H. 1985. Bamboo mosaic virus associated with a mosaic disease of bamboos in Taiwan. Plant Protection Bulletin, 27: 111-116.

Chen, Y.; Quin, W.; Li, X., Gong, J.; Ni., M. 1985. Study on chemical composition of ten species of bamboos. Chemical industry and Forest Products Journal, 39-46.

Cheng, A. H.; Yeh, C. C. 2002. Production and extension of Bamboo mosic virus-free clones/plants of green bamboo. Plant Pathology Bulletin, 11 (4): 169-172.

Chowdhury, S. 1948. Some fungi from Assam III. Indian Journal of Agricuultural Science, 18: 177-184.

Clark, L. 2012. An updated tribal and subtribal classification of bamboos (Poaceae: Bambusoideae). 9th World bamboo Congress Proceedings, Antwerp, Belgium, pp. 3-27.

Cooke, M.C. 1892. New exotic fungi. Grevelia, 20: 90-92.

Corner, E.J.H. 1950. A Monograph of *Clavaria* and Allied Genera. Oxford University Press, London.

Cummins, G.B. 1971. The rust fungi of cereals, grasses and bamboos. Springer-Verlag, Berlin, Germany. 570 pp.

Dai Dong Qin; Bhat, D. J.; Liu Jian Kui; Chukeatirote, E.; Zhao RuiLin; Hyde, K. D.2012. Bambusicola, a new genus from bamboo with asexual and sexual morphs. Cryptogamie, Mycologie, 33 (3): 363-379.

Dayan, M.P. 1988. Survey, identification and pathogenicity of pests and diseases of bamboos in the Philippines. Sylvatrop, the Philippine Forest Research Journal, 13 (1&2): 61-77.

Deka, P.C.; Baruah, G; Devi, M. 1990. A preliminary investigation of disease of bamboo in the North-East region of India. Indian Forester, 116(9): 714-716.

Deng, Yu; Yu Guoliang. 1980. A summary of experiments on top drying of *Phyllostachys pubescens*, Forest Science & Technology in Yichun, 4: 29-34.

Dev, I.; Pant, S.C.; Prem Chand; Kumar, S. 1991. Ammoniacal copper-arsenite: a diffusible wood preservative for refractory timber species like eucalyptus. Journal of Timber Development Association of India, 37(3): 12-15.

Ding Li Ping, D.; Li Wen, W.; Guang, L.D.2000. The occurrence and integrated management of bamboo diseases and pests in Fujian Province. Journal of Jiangsu Forestry Science & Technology. 27(2):62-65.

Ding Li Ping; Wang Li Wen; Lu Deng Guang 2000. The occurrence and integrated management of bamboo diseases and pests in Fujian Province. Journal of Jiangsu Forestry Science & Technology, 27 (2): 62-65.

Dong D.Yi.; Hong Y.M.; Zheng, J.J. 2001. The occurrence and integrated management of bamboo diseases and pests in Fujian Province. Journal of Jiangsu Forestry Science & Technology, 20(2): 39-43.

Ellis, M.B. 1971. Demataceous Hyphomycetes. Commonwealth Agricultural Bureau, Farnham, UK. 608 pp.

Ellis, M.B. 1976. More Demataceous Hyphomycetes. Commonwealth Agricultural Bureau, Farnham, UK. 507 pp.

Eriksson, O.; Yue, J.Z. 1990. Notes on bambusicolous pyrenomycetes. Nos. 1-10. Mycotaxon 38: 201-220.

Eriksson, O.E.; Vue I.Z. 1998. Bambusicolous pyrenomycetes, an annotated check-list. Myconet, 1: 25-75.

FAO 2007. World bamboo resources- A thematic study prepared in the framework of the Global Forest Resources Assessment 2005. FAO Technical Paper, 18. Rome, Italy.

FAO 2010. Global Forest Resources Assessment 2010. Main Report. FAO Forestry paper 163, Rome, Italy.

FAO 2014. Food and Agricultural Organization of the United Nations. Enhancing the socio-economic benefits from forests. State of the World Forests 2014, Rome, Italy.

FAO 2015. Global Forest Resources Assessment 2015: How are the world's forests changing? FAO, Rome, Italy (http:// www.fao.org/forestry/fra)

Fu Hui; Chen Yu Hui; Wang Wen Jiu; Yang Yu Ming; Hui Chao Mao 1999. Studies on mould fungi and their characteristics on timber of five kinds of bamboos in Yunnan. Journal of Bamboo Research, 18 (1): 16-22.

Gamble, J.S. 1899. On the determination of fungi which attacks forest trees in India. Indian Forester, 25: 431-438.

Giatgong, P. 1980. Host index of plant diseases in Thailand (2nd ed.). Department of Agriculture, Ministry of Agriculture and Co-operatives, Bangkok, Thailand.

Gibson, I.A.S. 1975. Report on a visit to the Republic of Bangladesh. Overseas Development Administration, London, U.K.

Gilman, J.C. 1945. A manual of soil fungi. Iowa State College Press, Iowa, USA.

Gnanharan, R.; Mohanan, C.; Chand Basha, S. 1993. Post-harvest technology of reed bamboos. Bamboo Information Centre India Bulletin, 3(1): 1-6.

Guha, S. R. D.; Bakshi, B. K.;Thapar, H. S. 1958.The effects of fungus attack on Bamboo on the preparation and properties of pulp. Journal of Scientific and Industrial Research, 4: 72-74.

Guha, S.R.D.; Chandra, A. 1979. Studies on decay of bamboo (*Dendrocalamus strictus*) during outside storage: I- effects of preservatives, II-effect on pulping qualities. Indian Forester, 105(4): 293-300.

Guha, S.R.D.; Chandra, A.; Bist, J.P.S. 1980. Protection of bamboo during outside storage: prophylactic treatment and its economic feasibility. Indian Forester, 106(6): 437-440.

Gupta, B.N.; Jamaluddin; Bohidar, S.C.; Dadwal, V.S. 1990. Mortality of bamboo (*Bambusa nutans* Wall.) in Orissa. *In* Proceedings of the National Seminar on Bamboo, Bangalore, India, 19-20 December 1990. pp. 166-174.

Gupta, R.C.; Rajak, R.C. 1987. Studies on the ascomycetes of Madhya Pradesh II: Hypoxylon from Jabalpur. *In* Agarwal, G.P. ed., Preservatives in Mycological Research, Flestochrift, Vol. 43-51.

Hamada, H. 1962. Preservation of bamboo culms and products. Report of Fuji Bamboo Garden,6.

Harsh, N. S. K.; Singh, Y. P.; Gupta, H. K.; Mushra, B. M.; McLaughlin, D. J.; Dentinger, B.2005. A new culm rot disease of bamboo in India and its management. Journal of Bamboo and Rattan, 4(4): 387-398

Harsh, N.S.K.; Nath, V.; Tiwari, C.K. 1989. A common foliar disease of *Dendrocalamus strictus* in nurseries. Proceedings of the Seminar on Silviculture and Management of Bamboos, 13-15 December 1989.IDF, Jabalpur, India.

Hashimoto, Y.; Hattori, T.; Iwakiri, K.; Tamura, K.; Kuroda, A.; Sawada, Y. 2008. Current status of bamboo die back caused by the destructive disease "witches'-broom of bamboo" in western Japan. Japanese Journal of Conservation Ecology, 13(2): 151-160.

Hashimoto, Y.; Hattori, T.; Kuroda, A.; Ishida, H.; Minamiyama, N.2010. Influence of witches' broom on the species richness and composition of bamboo forests in Japan. Japanese Journal of Conservation Ecology, 15 91): 71-87.

Hatakeyama, S.; Tanaka, K.; Harada, Y. 2005. Bambusicolous fungi in Japan (5): three species of *Tetraploa*. Mycoscience, 46 (3): 196-22.

He; Kakishima, F.; Sato, S. 1993a. A new species of *Puccini*a on *Sasa chartacea* var. *nana*. Transactions of Mycological Society of Japan, 34(1): 133.

He; Kakishima, F.; Sato, S. 1993b. *Puccinia cymbiformis* on *Phyllostachys nigra* var. *henonis*. Transactions of Mycological Society of Japan, 34(1): 134.

He; Kakishima, F.; Sato, S. 1993c. *Puccinia scabrida* on *Phyllostachys* sp. Transactions of Mycological Society of Japan, 34(1): 135.

Hennings, P. 1901. Fungi Indiae Orientalis II. Hedwigia, 40: 323-342.

Hilton, R.N. 1961. Sporulation of *Fomes lignosus*, *Fomes noxious* and *Ganoderma pseudoferreum. In* Proceedings of the Natural Rubber Research Conference, Kuala Lumpur, Malaysia, 1960. pp. 496-502.

Hino, I. 1958. Parasitic fungi on Bamboos in Japan. General remarks. Bulletin of Faculty of Agriculture, Yamaguti University 9: 849-876 pp.

Hino, I. 1961. Icones fungorum bambusicolorum Japonicum. The Fuji Bamboo Garden, Nagahara, Gotemba City, Zhizuoka. 338 pp.

Hino, I.; Katumoto, K. 1955. Illustrations Fungorum Bambusicolorum III. Bulletin of the Faculty of Agriculture of Yamaguti University, 6: 29-68.

Hino, I.; Katumoto, K. 1958. Illustrations Fungorum Bambusicolorum VI. Bulletin of the Faculty of Agriculture of Yamaguti University, 9: 877-908.

Hino, I.; Katumoto, K. 1961. Icones Fungorum Bambusicolorum Japonicum. The Fuji Bamboo Garden, Nagahara, Gotemba City, Zhizuoka. 335 pp.

Hino, I.; Katumoto, K. 1961. Illustrations fungorum bambusicolorum IX. Bulletin of Faculty of Agriculture, Yamaguti University, 12: 151-162.

Hori, S. 1905. Smut of cultivated bamboo. Bulletin of Imperial Central Agricultural Experimental Station, Japan, 1(1): 73-89.

Hsieh, H.J. 1984. Survey of diseases of woody plants in Taiwan (VIII). Quarterly Journal of Chinese Forestry, 17: 61-73.

Hsieh, H.J. 1987. Survey of diseases of woody plants in Taiwan (XIII). Quarterly Journal of Chinese Forestry, 20(1): 65-75.

Hsiung, W.Y. 1983. The distribution, production and research of bamboo in the world. Bamboo Research, 2: 6-16.

Hsiung, W.Y. 1991. Prospects of bamboo development in the world. Journal of American Bamboo Society, 8(1&2): 168-178.

Hsiung, W.Y. ed. 1981. Bamboo Research. Vol. I. Nanjing Technological College of Forest Products, Nanjing, China. 122 pp.

Hyde, K.D.; McKenzii, E.H.C.; Dalisay, T. 2001. Saprobic fungi on bamboo culms. Fungal Diversity, 7: 35-48.

Hyde, K.D.; Zhou, D.Q.; Dalisay, T. 2002. Bambusicolous fungi. Fungal Diversity, 9: 1-14.

INBAR 2012. International trade of Bamboo and Rattan 2012. http://www.inbar.int/2015/small-and-medium- sized-bamboo-enterprises.

INBAR 2016. New standards for Bamboo and Rattan stories. INBAR News: The $ 60 Billion a year Industry made from a plant. http://www.inbar.int/new-standards-for-bamboo-and- rattan/

INBAR 2017. World Checklist of Bamboos and Rattans. INBAR Technical Report No. 37. http://www.inbar.int

Ito, S. 1950. Mycological flora of Japan. Vol.II.No.3. Yokendo, Japan.

Itoi, S; Nozu, M.; Sato, F.; Yamamoto, J.; Noda, C.; Uchita, T. 1978. On *Pyricularia* sp. parasitic to bamboo and bamboo grass. Annals of Phytopathological Society of Japan, 44(2): 209-213.

Itoi, S; Sato, F.; Yamamoto, J.; Uchita, T.; Noda, C. 1979. Overwintering of *Pyricularia* on the living bamboo and bamboo grass leaves, and pathogenicity of the rice blast fungus, *P. oryzae* Cavara to bamboo and bamboo grass. Annals of Phytopathological Society of Japan, 45: 375-385.

Jamaluddin; Gupta, B. N. 1996. Outbreak of bamboo (Bambusa nutans) blight disease in Orissa, India. Impact of diseases and insect pests in tropical forests. Proceedings of the IUFRO Symposium, Peechi, India, 23-26 November 1993, Kerala Forest Research Institute (KFRI),Peechi, Kerala, India, 199-208

Jamaluddin; Gupta, B.N.; Bohidar, S.C.; Dadwal, V.S. 1992. Mortality of bamboo (*Bambusa nutans* Wall.) in the coastal areas of Orissa. Journal of Tropical Forestry, 8: 252-261.

Jamaluddin; Khan, S. N.; Tiwari, R. K. 1999. Fungi on bamboo[s] from India. Journal of Tropical Forestry, 15 (4): 285-301.

Journal of Nanjing Forestry University (Natural Sciences Edition), 35 (3):84-88.

Jung Hee Young; Chang Moo Ung; Lee Joon Tak; Namba, S. 2006. Detection of "Candidatus Phytoplasma asteris" associated with henon bamboo witches' broom in Korea. Journal of General Plant Pathology, 72 94): 261-263.

Kao, C.W.; Leu, L.S. 1976. Finding perfect stage of *Aciculosporium take* Miyake, the causal organism of bamboo witches'-broom disease and its conidial germination. Plant Protection Bulletin, 18(3): 276-285.

Kapoor, J.N.; Gill, H.S. 1961. Notes on Indian ascomycetes I. Indian Phytopathology, 14: 149-153.

Kar, A.K.; Maity, M.K. 1971. Pyrenomycetes of West Bengal III. Transactions of the British Mycological Society, 56: 189-193.

Katumoto, K. 1968. On the genus *Coccodiella* Hara. Journal of Japanese Botany, 43: 277-284.

Kawakami, H. 1990. Degradation of bamboo by wood rotting fungi. Bamboo Research, 2: 112-116.

Kawamura, S. 1929. On some new Japanese fungi. Journal of Botany, 4(3): 291-302.

Khan, A.H.1960. Some new diseases of hardwoods and bamboo in Pakistan. Mycopathologia et Mycologia Applicata, 14(4): 241-262.

Kinsey, G. C. 2002. Phoma herbarum. [Descriptions of Fungi and Bacteria]. IMI Descriptions of Fungi and Bacteria, No. 151, Sheet 1501. CAB International,

Kobayashi, T.; Guzman, E.D. 1988. Monograph of tree diseases in the Philippines with taxonomic notes on their associated microorganisms. The Bulletin of Forestry and Forest Products Research Institute, No. 351, Ibaraki, Japan.

Kuai, S. 1987. Blight of basket bamboo (*Phyllostachys* sp.) Subtropical Forest Science and Technology, 15(3): 237-238.

Kuai, S.Y. 1996. A checklist of pathogenic bambusicolous fungi of mainland China and Taiwan. Journal of Forest Science and Technology, 4 (2): 64-71.

Kumar, S.; Dobriyal, P.B.; Tandon, R.C.; Tipre, D.S. 1990. Long-term protection of flowered bamboos during storage. *In* Proceedings of the Third Forest Products Conference, Forest Research Institute, Dehra Dun, India, 26-28 June 1990.

Kumar, S.; Kalna, K.K.; Dobriyal, P.B. 1983. Protection of pulp bamboo in outside storage. Journal of Timber Development Association of India, 31: 5-12.

Kumar, S.; Shukla, K,S.; Dev, I.; Dobriyal, P.B. 1994. Bamboo preservation techniques: a review. International Network for Bamboo and Rattan, New Delhi, India; Indian Council of Forestry Research Education, Dehra Dun, India. 59 pp.

Kumar, S.; Singh, M.M.; Guha, S.R.D. 1980. Protection of pulp wood in outside storage. Journal of Timber Development Association of India, 26(2): 30-42.

Kusano, S. 1908. Rusts on the leaves of bamboos. Bulletin of College of Agriculture, Tokyo Imperial University, 8(1): 37-50.

Kwan, S.K. 1979. The standing crops and soil-borne microfungal flora of *Phyllostachys reticulata* in Korea. Korean Journal of Mycology, 7: 91-116.

Lan, Y. 1980. Studies on culm brown rot of *Phyllostachys viridis*. Journal of Nanjing Technological College of Forest Products, No.1: 87-94.

Lee Ming-Jen. 1995. The occurrence and distribution of *Dasturella divina* and its influence on leaf characteristics of green and ma bamboos. Paper presented at the XX IUFRO World Congress, Tampere, Finland, 7-12 August 1995.

Li, K.D.; Wei, T.X.; Wang, Z.L.; Zhang W.J.; Wang, W.Z.; Zhao, J.X.; Li, X.Z. 1986. A preliminary report on the prevention and control of bamboo culm rust. Journal of Bamboo Research, 5(1): 120-123.

Liang, Zu, A. ; Cai Ji Miao; Liu Xian Bao; Li Chao Ping; Shi Tao; Huang Gui Xiu 2010. Biological characteristics of 11 wilt disease pathogens on hybrid bamboo. Journal of Plant Diseases and Pests, 1(4): 4-8.

Liese, W. 1959. Bamboo preservation and soft-rot. FAO Report to Government of India, No. 1106.

Liese, W. 1993. Methods of bamboo treatment and preservation. *In* Proceedings of the International Bamboo Festival 1993. Hamburg Forest Research Institute, Hamburg, Germany. pp. 25-28.

Liese, W.1980. Preservation of bamboo. *In* Lessard, G; Chouinard, A. ed., Bamboo Research in Asia. Proceedings of a workshop held in Singapore, 28-30 May 1980. International Development Research Centre, Ottawa, Canada. pp. 165-172.

Lin Qing Yuan 2001. Technology of integrated measures to control die-back of *Phyllostachys edulis*. Journal of Nanjing Forestry University, 25 (1):39-43.

Lin, G. 1988. *Ceratosphaeria phyllostachydis* and its control. Fujian Forestry, 6: 31-33.

Lin, M.T.; Kitajima, E.W.; Cupertino, F.P.; Costa, C.L. 1977. Partial purification and some properties of bamboo mosaic virus. Phytopathology, 67(12): 1439-1443.

Lin, N.S.; Chai, Y.J.; Huang, T.Y. 1993. Incidence of bamboo mosaic potex virus in Taiwan. Plant Disease, 77(5): 448-450.

Lin, N.S.; Chen, C.C. 1991. Association of bamboo mosaic virus (BoMV) and BoMV specific electron-dense crystalline bodies with chloroplasts. Phytopathology, 81(2): 1551-1555.

Lin, N.S.; Chen, M.J.; Kiang, T.; Lin. W.C. 1979. Preliminary studies on bamboo mosaic disease in Taiwan. Bulletin of Taiwan Forestry Research Institute, No. 317, p. 10.

Lin, N.S.; Lin, W.C.; Kiang, T.; Chang, T.Y. 1981. Investigation and study of bamboo witches-broom in Taiwan. Quarterly Journal of Chinese Forestry, 14(1): 135-148.

Lin, Q.; Qju, Z.L. 1993. A study on occurrence and development of the die-back of *Phyllostachys heterocycla*. Journal of Nanjing Forestry University, 17(2): 61-66.

Lin, W. W.; Zhang, J.; Yang, W. T.; Liu, Y. Y.; Wan, B. J.; Xu, X. L.; Wu, Z. J. 2015. First report of Bamboo mosaic virus infecting bamboo in the mainland of China. Plant Disease, 99 (8): 1189.

Lin, X.; Wu, G. 1987. Study on witches'-broom of fish-scale bamboo I: symptoms and pathogens. Journal of Central-South Forestry College, 7: 132-136.

Liu Jun; Zhou Yun'e; Xu Yue Cong; Zheng Jian Guo, 2001. Investigation and research on bamboo shoot disease and pests. Journal of Bamboo Research, 20(2): 72-79.

Liu Jun; Zhou Yun'e; Xu Yue Cong; Zheng Jian Guo 2001. Investigation and research on bamboo shoot disease and pests. Journal of Bamboo Research, 20 (2):72-79.

Liu, S.; Pan Hui. 1983. A preliminary report on occurrence and control methods of die-back on *Phyllostachys pubescens*. Forest Science & Technology in Yichun, 2: 21-32.

Lo, T.C.; Chen, D.W.; Huang, J.S. 1966. A new disease (bacterial wilt) of Taiwan giant bamboo 1: studies on the causal organism (*Erwinia sinocalami* sp. nov.). Botanical Bulletin of Academic Sinica Taipei, 7(2): 14-22.

Lobovikov, M.; Paudel,S.; Piazza, M.; Ren, H.; Wu, J. 2005. World Bamboo Resources : A thematic study prepared in the framework of the Global Forest Resources Assessment, FAO Non-Wood Forest Products 18, Rome.

Lou Jun Fang; Hu Guo Liang; Yu Cai Zhu; You Long De; Ye Yu Zhu 2001. Control of Balansia take damaging shoot bamboo forests. Journal of Zhejiang, Forestry College, 18 (2): 177-179.

Ma Liang Jin; Chi Wan Yin; Huang De Ren; Zheng Wen Jie; Xu Yue Biao 2005. Pathogenesis of leaf rust of *Dendrocalamopsis oldhami* [Bambusa oldhamii] and selection of its control chemicals. Journal of Zhejiang Forestry College, 22 (1): 66-69.

Ma Y. L; Wei Chun Yi; Li Jun Zhen 2008. Study on infection of wilt to hybrid bamboo of *Bambusa pervariabilis* × *Dendrocalamopsis daii*. Journal of Zhejiang Forestry Science and Technology, 28 (5): 29-32.

Ma, L.F. 1990. The efficiency of DP in controlling bamboo mould. Journal of Bamboo Research, 9(2): 30-36.

Ma, Y.L. 2001. Blight of hybrid bamboo. Guangxi Forestry, 4: 38.

Ma, Y.L.; Wei, C.Y.; He, H.J. 2006. Blight of hybrid bamboo. Forest Pest and Disease, 25 (4): 1-4.

Mao, T.V. 1993. Impact of diseases in nurseries, plantations and natural forests in Vietnam. *In* Proceedings of the IUFRO Symposium on the impact of Diseases and Insect Pests in Tropical Forests, Kerala, India, 23-26 November 1993. Kerala Forest Research Institute, Kerala, India.

Martawidjaja, A. 1986. Preservative treatment of bamboos in Indonesia. Rimba Indonesia, 9(1): 66-76.

Mason, E.W. 1933. Annotated account of the fungi received at IMI, Kew: List II, Fascicle 2, 19.

Mathew, G.; Nair, K.S.S. 1990. Storage pests of bamboos in Kerala. *In* Ramanuja Rao, I.V.; Gnanaharan, R.; Sastry, C.B., ed., Bamboos: Current Research. Proceedings of the International Bamboo Workshop, Cochin, India, 14-18 November 1988. Kerala Forest Research Institute, Kerala, India; International Development Research Centre, Ottawa, Canada. pp. 212-214.

Mathur, R.S. 1936. Notes on the fungi of Lucknow I: on the perithecial stage of *Sphaerostilbe bambusae* Pat. on *Bambusa indica*. Proceedings of Indian Science Congress, 23: 288.

Mitter, J.H.; Tandon, R.N. 1932. Fungous Flora of Nainital I. Journal of Indian Botanical Society, 11: 178-180.

Miyake, I.; Hara, K. 1910. Fungi on Japanese bamboos I. Botanical Magazine, Tokyo, 24: 331-341.

Miyake, I.; Hara, K. 1913. Fungi on Japanese bamboos II. Botanical Magazine, Tokyo, 27: 245-256.

Mohanan, C. 1990. Diseases of bamboos in Kerala. *In* Ramanuja Rao, I.V.; Gnanaharan, R.; Sastry, C.B., ed., Bamboos: Current Research. Proceedings of the International Bamboo Workshop, Cochin, India, 14-18 November 1988. Kerala Forest Research Institute, Kerala, India; International Development Research Centre, Ottawa, Canada. pp. 173-183.

Mohanan, C. 1994a. Diseases of bamboos and rattans in Kerala. KFRI Research Report No. 98. Kerala Forest Research Institute, Kerala, India. 120 pp.

Mohanan, C. 1994b. Studies on Diseases of Bamboo and Nursery Management of *Rhizoctonia* Web Blight in Kerala. Ph.D.thesis. Cochin University of Science & Technology, Kerala, India. 316 pp.

Mohanan, C. 1994c. Little leaf disease of bamboos. Bamboo Information Centre India Bulletin, 4(1/2): 30-37.

Mohanan, C. 1995a. Methods to control important diseases of bamboos. *In* Silviculture and Management of Bamboos in India. Phase II. Final Technical Report. International Development Research Centre, Ottawa, Canada.

Mohanan, C. 1995b. Diseases of emerging culms of bamboos in India and their possible significance in sustainable production. Paper presented at the XX IUFRO World Congress, Tampere, Finland, 7-12 August 1995.

Mohanan, C. 1995c. Diseases of bamboos in Asia: an overview. Paper presented in XXIUFRO World Congress, Tampere, Finland, 7-12 August 1995.

Mohanan, C. 1996a. Epidemiology and control of Rhizoctonia web blight of bamboos. Impact of diseases and insect pests in tropical forests. Proceedings of the IUFRO Symposium, Peechi, India, 23-26 November 1993. Kerala Forest Research Institute (KFRI), Peechi, Kerala, India, pp. 169-185.

Mohanan, C. 1996b. Impact of diseases on the productivity of bamboo stands in Kerala. Impact of diseases and insect pests in tropical forests. Proceedings of the IUFRO Symposium, Peechi, India, 23-26 November 1996. Kerala Forest Research Institute (KFRI), Peechi, Kerala, India, pp. 52-60.

Mohanan, C. 1997. Diseases of Bamboos in Asia: An Illustrated Manual International Network for Bamboo and Rattan, Beijing, 228 p.

Mohanan, C. 2001. Biological control of damping-off in forest nurseries in Kerala. KFRI Research Report No. 214. Kerala Forest Research Institute, Peechi, Kerala.

Mohanan, C. 2002. Diseases and disorders of bamboos in Asia. Bamboo for sustainable development. Proceedings of the Vth International Bamboo Congress and the VIth International Bamboo Workshop, San José, Costa Rica, 2-6 November 1998.

Mohanan, C. 2003. Mycorrhizae in forest plantations: Association, Diversity and Exploitation in Planting Stock improvement. KFRI Research Report No. 252 (World Bank Aided Project), Kerala Forest Research Institute, Peechi, Kerala, India 133p

Mohanan, C. 2004. Witches' broom disease of reed bamboos in Kerala, India. Forest pathology, 34(5): 329-333.

Mohanan, C. 2005. Biodiversity of Plant Pathogenic Fungi in the Kerala Part of the Western Ghats. Final Technical Report No. 23/10/2001/RE, Ministry of Environment and Forests, Govt. of India.

Mohanan, C. 2008. Culm, foliage, rhizome, root and inflorescence diseases of bamboos in Kerala, India and their management. Journal of Bamboo and Rattan, 7(3/4): 251-269

Mohanan, C. 2009. Forest health management in India: Present scenario and future challenges. Asia and the Pacific Forest Health Workshop Forest Health in a Changing World: IUFRO World Series Volume 24, pp.45-48.

Mohanan, C. 2010. Rust Fungi of Kerala. Kerala Forest Research Institute, Peechi, Kerala, 148 p. ISBN 81-85041-72-5.

Mohanan, C. 2011. Biodiversity of Terricolous and Lignicolous Macrofungi of the Western Ghats. Final Technical Report No. F. No. 23/15/2006-RE. MoEF, Government of India, New Delhi.

Mohanan, C. 2011. Macrofungi of Kerala. Kerala Forest Research Institute, Peechi, Kerala, 670p.ISBN81-85041-73-3.

Mohanan, C. 2013. Mushrooms of Kerala. Kerala State Biodiversity Board, Thiruvananthapuram, Kerala, India, 57 p. ISBN 978-81-920338-7-7.

Mohanan, C.; Manoj Sebastian, 2006. Mycorrhizal status of nineteen species of bamboos in Kerala, India. *In* Mycorrhizae, Anil Prakash, V.S. Mehrotra, Scientific Publishers (India), Jodhpur, Chapter 17, pp. 90-95.

Mohanan, C.; Liese, W. 1990. Diseases of bamboos. International Journal of Tropical Plant Diseases, 8:1-20

Mohanan, C.; Sharma, J.K. 1991. Seed pathology of forest tree species in India: present status, practical problems and future prospects. Commonwealth Forestry Review, 70(3): 133-151.

Mohanan, C.; Yesodharan, K. 2005. Biodiversity of Plant Pathogenic Fungi in the Western Ghats. KFRI Research Report No. 280. Kerala Forest Research Institute, Peechi, Kerala, India 326 pp.

Mukerji, K.G.; Bhasin, J. 1986. Plant diseases of India: A source book. Tata Mcgraw-Hill Publishing Company Ltd., New Delhi, India.

Mundkur, B.B.; Kheswala, K.F. 1943. *Dasturella*: a new genus of the Uredinales. Mycologia, 35: 201-206.

Mundkur, B.B.; Thirumalachar, M.J. 1952. Ustilaginales of India. Commonwealth Mycological Institute, Kew, UK. 84 pp.

Muthamilselvan, T.; Lee Chin Wei; Cho Yu Hsin; Wu Feng Chao; Hu Chung Chi; Liang Yu Chuan; Lin Na Sheng; Hsu Yau Heiu 2016. A transgenic plant cell-suspension system for expression of epitopes on chimeric Bamboo mosaic virus particles. Plant Biotechnology Journal, 14 (1): 231-236.

Muthappa, B.N. 1969. Morphology of a new Loculoascomycetes on *Bambusa arundinacea*. Mycologia, 61: 737-747.

Nagraj, T.R.; Govindu, H.C. 1967. Fungi of Mysore IV. Sydowia, 23: 110-117.

Namdeo, R.K.; Jamaluddin; Dadwal, V.S. 1989. Studies on seed health testing of *Dendrocalamus strictus* Nees. Proceedings of the Seminar on Silviculture and Management of Bamboos, 13-15 December 1989. IDF, Jabalpur, India.

Narendra, D.V.; Rao, V.G. 1972. Some additions of fungi of India. Sydowia, 26: 282-287.

Nayar, R.; Ananthapadmanabha, H.S. 1977. Little leaf disease in collateral hosts of sandal (*Santalum album* L.). European Journal of Forest Pathology, 7(3): 152-158.

Nema, K.G.; Mishra, R.P. 1965. The Uredineae of Jabalpur, M.P. Nagpur Agricultural College Magazine, 6: 7-9.

Nonaka, S. 1989. Bamboo shoot: Information on special products No.6. Forest Experimental Station, Fukuoka Country, Japan.

Norul Hisham Hamid 2003. Fungal deterioration of naturally grown Gigantochloa scortechinii (buluh semantan) at different age. Malaysian Forester, 66 (3/4): 176-180.

Nozu, M.; Yamamoto, M. 1972. Ultrastructure of fasciculated tissue of *Phyllostachys bambusoides* infected with *Aciculosporium take*. Bulletin of the Faculty of Agriculture, Shimane University, No 6: 49-52.

Oguchi, T. 2001. *Aciculosporium sasicola* sp. nov. on witches' broom of *Sasa senanensis*. Mycoscience, 42 (2): 217-221.

Ohrnberger, D. 1999. Bamboos of the world: annotated nomenclature and literature of the species and the higher and lower taxa. Amsterdam, Elsevier.

Ou, Z.S.; Zhang, W.Q 1993a. A study on the epidemic status of the top blight of *phyllostachys heterocycla* in forest. Journal of Fujian Forest College, 13(1): 67-73.

Ou, Z.S.; Zhang, W.Q, 1993b. A study on the prediction method for the top blight of *Phyllostachys heterocycla*. Journal of Fujian Forest College, 13(2): 141-146.

Overeem, C.V. 1926. Demataceae Icones Fungorum Malayensium 13.

Padhi, B. 1954. *Sphaerostilbe* on bamboo. Proceedings of the 41st Indian Science Congress. Part I: 119-120.

Padwick, G.W. 1945. Notes on Indian fungi III. CMI Mycological Paper 12. Commonwealth Mycological Institute, Kew, UK, 15 pp.

Panwar, K.S.; Gehlot, C.S. 1973. Two species of *Leptosphaeria* new to India. Current Science, 42: 734.

Parndekar, S.A. 1964. A contribution to fungi of Maharashtra. Journal of University of Poona, 26: 56-64.

Patel, M.K.; Gokhale, V.P.; Kulkarni, N.B. 1951. Addition to fungi of Bombay I. Indian Phytopathology, 4: 64-66.

Patel, M.K.; Kamat, M.N.; Bhide, V.P. 1949. Fungi of Bombay. Supplement I. Indian Phytopathology, 2: 142-155.

Patil, A.S.; Rao, V.G.1972. *Articulospora*: A new record from India. Indian Phytopathology, 25: 455-456.

Patil, N.G.; Adiver, S.; Hegde, R.K. 1980. Bamboo diseases. *In* Proceedings of the III Southern Silviculturists and Forest Research Officers Conference, Dharwad, Karnataka, India, 3-5 March 1980. pp 67-69.

Pavgi, M.S.; Mundkur, B.B. 1948. A third contribution towards a knowledge of Indian Ustilaginales. Indian Phytopathology, 1: 107-118.

Phimmachanh S.; Ying Z.; Beckline M. 2015. Bamboo resources utilization: A potential source of income to support rural livelihoods. Applied Ecology and Environmental Science 3(6): 176-183.

Pongpanich, K. 1990. Fungi associated with forest tree seeds in Thailand. *In* Proceedings of the IUFRO Workshop on Pests and Diseases of Forest Plantations, Bangkok, Thailand. pp. 114-121.

Pongpanich, K.; Chalermpongse, A. 1986. Seed-borne diseases of some important bamboos in Thailand. *In* Proceedings on Thailand Bamboo Research, Thailand. pp. 19-20.

Purushotham, A.; Sudan, S.K.; Vidyasagar. 1954. Preservative treatment of green bamboos under low pneumatic pressures. Indian Forestry Bulletin No.178.

Qiao Tian Min; Zhu Tian Hui; Li ShuJiang 2011. Colonization of Pseudomonas aeruginosa ZB27 and its control effect on hybrid bamboo blight. Acta Phytophylacica Sinica, 38 (2): 133-138

Qiu, F.; Yi, D.; Luo, G. 1982. Glaze on *Phyllostachys pubescens* and its control. Journal of Bamboo Research, 2(2): 72-76.

Quiniones, S.S.; Dayan, M.P. 1981. Notes on the diseases of forest species in the Philippines. Sylvatrop, the Philippine Forestry Research Journal, 6(2): 61-68.

Rahman, M.A. 1978. Isolation of fungi from blight affected bamboos in Bangladesh. Bano Biggyan Patrika, 7: 42-47.

Rahman, M.A. 1988. Perspective of bamboo blight in Bangladesh. Indian Forester, 114(10): 726-736.

Rahman, M.A.; Khisha, S.K. 1983. Bamboo blight with particular reference to *Acremonium strictum*. Bano Biggyan Patrika, 10: 1-13.

Rahman, M.A.; Zethner, O. 1971. An interim report on results obtained in the Forest Pathology Section from September 1969 to August 1971. Forest Dale News, 4(1): 45-48.

Ramakrishnan, T.S.; Ramakrishnan, K. 1949. Ergot on bamboo. Current Science, 18(9): 344-345.

Rangaswami, G.; Sheshadri, V.S.; Lucy Channamma, K.K. 1970. Fungi of South India. University of Agricultural Science, Bangalore, India. 193 pp.

Rao, V.G. 1962. Some new records of Sphaeropsidales from India. Annals of Society of Pernambuco, 38: 3-13.

Razak Wahab; Mahmud Sudin; Tamizi Mustapa; Awang Ahmad, M. Y. 2010. Durability performance of *Gigantochloa scortechinii* through laboratory fungal decay tests. Research Journal of Microbiology, 5 (8): 828-832.

Rehm, H. 1913. Ascomyceten. In getrochneten exemplaren herausgeben. Fasc. XXIV (1151-12110). Hedwigia, 35: 146-150.

Rehm, H. 1914. Ascomycetes Philippinenses V. Leaflets of Philippine Botany 6: 2191-2239.

Rehm, H. 1916. Ascomycetes Philippinenses VIII. Leaflets of Philippine Botany, 8: 2935-2961.

Reid, D.a. 1984. Another British record of *Puccinia longicornis*. Bulletin of British Mycological Society, 18(2): 127-129.

Rogers, D.P. 1943. The genus *Pellicularia* (Thelephoraceae). Farlowa, 1: 95-118.

Saddler, G. S. 2000. Xanthomonas albilineans. [Descriptions of Fungi and Bacteria]. IMI Descriptions of Fungi and Bacteria, No. 146. Sheet 1452. CAB International, Wallingford.

Saikia, U.N.; Sarbhoy, A.N. 1980. Hyphomycetes of North – East India I. Indian Phytopathology, 33(3): 459-461.

Saikia, U.N.; Sarbhoy, A.N.1982. Hyphomycetes of India V. The genus *Periconia*. Indian Phytopathology, 36(2): 277-281.

Saikia, U.N.; Sarbhoy, A.N.1985. *Morrisiella*: A new genus of synnematous hyphomycete. Mycologia, 77(2): 318-320.

Sandeep Acharya 2010. New report of death terror *Pterulicium xylogenum* in edible bamboo of Tripura. Journal of Pure and Applied Microbiology, 4(2): 891-893.

Sathe, A.V. 1965. A new species of *Dasturella* (Uredinales) from India. Sydowia, 19: 148-149.

Sawada 1921. Report of Survey of Formosan Fungi III. Taiwan Central Research Institute, Taipei, Taiwan-China. 57 pp.

Seethalaksmi, K., Pandalai, R.C. and Mohanan, C. 2002**.** Nursery and Silvicultural Techniques for Bamboos. KFRI Handbook No. 16. Kerala Forest Research Institute, Peechi.

Sharada, P.; Nagaveni, H. C.; Remadevi, O. K.; Jain, S. H.2013. Toximetric studies on some major bamboo pathogens.Indian Forester, 139 (9): 814-820.

Sharma, N.D. 1971. Taxonomic and Physiological Studies on Some Folicolous Deuteromycetes. Ph.D. thesis, University of Jabalpur, Jabalpur, India.

Sheikh, M.I.; Ismail, C.M.; Zakaullah, C.1978. A note on the cause of mortality of bamboo around Sargodha. Pakistan Journal of Forestry, 28: 127-128.

Shen, Y. M.; Huang, T. C.; Chung, W. H.; Hung, T. H. 2017. First report of rust caused by *Puccinia kusanoi* affecting Yushan cane (Yushania niitakayamensis) in Taiwan. Plant Disease, 101 (2): 385.

Shi Hong Xia; Wang Guo Liang 2005. Identification of pathogen of moso bamboo chronic wilt. Journal of Nanjing Forestry University (Natural Sciences Edition), 29 (4): 117-119.

Shi, Q.; Huang, Y.; Liao, S. 1979. A preliminary investigation on causes of withering of introduced *Phyllostachys pubescens* in North China. Forest Science & Technology in Liaoning, 26-30.

Shinohara, M. 1965. Studies on witches'-broom of *Phyllostachys bambusoides* Sieb. et Zucc. 1. Symptoms and morphology of the causal fungus. Bulletin of College of Agricultural and Veterinary Medicine, Nihon University, No. 21: 42-60.

Shojiro, H.; Takafusa, H.; Koyoharu, F. 1989. Decay types and the frequency of their occurrence in bamboo in natural environment. Wood Preservation, 15(5): 14-22.

Shu, J.; Wang, H. 2015. Pests and diseases of bamboos. *In* Liese W. , Kohl, M. (eds). Bamboo. Tropical Forestry Vol. 10. Springer, Cham.

Shukla, A.N.; Singh, S.; Sehgal, H.S. 1988. Diseases and deterioration of bamboos in India. Indian Forester, 114(10): 714-719.

Singh, D.V.; Khanna, B.M. 1970. Some sphaeropsidous fungi from Kanpur. Indian Phytopathology, 23: 465-469.

Singh, M.M. 1977. Summary of FRI investigation on effects of storage on paper making raw materials. Proceedings of the IPPTA Zonal Seminar on Afforestation, Exploitation and Preservation of Forest Raw Materials, Dehra Duh, India, 27 August 1977.

Singh, S.; Nigam, P.N. 1968. Note on preservative treatment on green bamboos by the modified Boucherie and the diffusion processes. Journal of Timber Development Association of India, 14(1): 20-23.

Soreng R. J.; Peterson P.M.; Romaschenko K.; Davidse G.; Zuloaga F.O.; Judziewicz E.J.; Filgueiras T.S.; Davis J.I.; Morrone O. 2015. A world wide phylogenetic classification of the Poaceae (Gramineae). Journal of Systematics and Evoloution 53(2): 117-137.

Soreng R.J.; Peterson P.M.; Romaschenko K.; Davidse G.; Teisher J. K.; Clark L.G.; Barbera P.; Gillespie L J.; Zuloaga F.O. 2017. A world wide phylogenetic classification of the Poaceae (Gramineae) II: An update and comparison of two 2015 classifications. Journal of Systematics and Evoloution 55 (4): 259-290.

Spaulding, P. 1961. Foreign diseases of forest trees of the world. USDA Agriculture Handbook No. 197. United States Department of Agriculture, Washington D.C., USA.

Sprague, R. 1950. Diseases of cereals and grasses: North American fungi except smuts and rusts. Ronald Press Co., New York, USA. 583 pp.

Subramaniam, C.V. 1954. Some species of *Periconia* from India. Journal of Indian Botanical Society, 33: 339-361.

Subramaniam, C.V. 1956. Hyphomycetes I. Journal of Botanical Society, 5: 53-91.

Subramaniam, C.V.; Ramakrishnan, K. 1953. *Petrakomyces*: a new genus of Sphaeropsidales. Proceedings of the Indian Academy of Science, 37B: 110-113.

Sujan Singh; Bakshi, B.K. 1964. Notes on some Indian tree rusts. Indian Forester, 90: 469-472.

Sujan Singh; Pandey, P.C. 1971. *Tunicopsora*: A new rust genus on bamboo. Transactions of the British Mycological Society, 56: 301-303.

Sulthoni, A. 1987. Traditional preservation of bamboo in Java, Indonesia. *In* Rao, A.N.; Dhanarajan, G.; Sastry, C.B. ed., Recent Research on Bamboo. Proceedings of the International Bamboo Workshop, Hangzhou, China, 6-14 October 1985. Chinese Academy of Forestry, Beijing, China; International Development Research Centre, Ottawa, Canada. pp. 349-357.

Sungkaew, S.; Stapleton, C.M.A.; Salamin, N.; Fodkinson, T.R. 2009. Non-monophyly of woody bamboos (Bambusae: Poaceae): a multi-gene region phylogenetic analysis of Bambusoideae. Journal of Plant Research, 122: 95-108.

Sutathip, S. 1988. The effects of wood destroying fungi on some bamboo species. Proceedings of the Forestry Conference 1988, Bangkok. Royal Forest Department, Ministry of Agriculture, Thailand.

Sutton, B.C. 1980. The Coelomycetes: Fungi Imperfecti with Pycnidia, Acervuli and Stroma. Commonwealth Mycological Institute, Kew, UK. 696 pp.

Sydow, H. 1932. Novae fungorum species. XXI. Annals of Mycology, 30: 111-116.

Sydow, H.; Butler, E.J. 1906. Fungi Indiae Orientalis. Pars I. Annals of Mycology, 4: 424-445.

Sydow, H.; Butler, E.J. 1907. Fungi Indiae Orientalis. Pars II. Annals of Mycology, 5: 485-515.

Sydow, H.; Butler, E.J. 1916. Fungi Indiae Orientalis. Pars V. Annals of Mycology, 14: 177-220.

Sydow, H.; Mitter, J.H. 1933. Fungi Indici I. Annals of Mycology, 31: 84-97.

Tahir, M.; Soni, K.K.; Jamaluddin. 1992. Root and rhizome rot of *Dendrocalamus strictus* caused by *Amylosporus campbelli* (Berk.) Ryv. Myforest, 28(1): 88-90.

Tai, F.L. 1931. Observations on the development of *Myriangium bambusae* Rick. Sinesia Central Metropolitan Museum Natural History Academica Sinica, 1(10): 147-164.

Tai, F.L. 1932. Notes on Chinese fungi 1. Nanjing Journal 2: 171-172.

Tamolang., F.N.; Lopez, F.R.; Semana, J.A.; Casin, R.F.; Espiloy, Z.B. 1980. Properties and utilization of Philippine bamboos. *In* Lessard, G; Chouinard, A. ed., Bamboo Research in Asia. Proceedings of a workshop held in Singapore, 28-30 May 1980. International Development Research Centre, Ottawa, Canada. pp. 187-200.

Tanaka, E. 2009. Specific in situ visualization of the pathogenic endophytic fungus *Aciculosporium take*, the cause of witches' broom in bamboo. Applied and Environmental Microbiology, 75 (14): 4829-4834.

Tanaka, E. 2010. Mechanisms of bamboo witches broom symptom development caused by endophytic/epiphytic fungi. Plant Signaling and Behavior, 5(4): 415-418.

Tanaka, E.; Tanaka, C.; Gafur, A.; Tsuda, M. 2002. *Heteroepichloë*, gen. nov. (Clavicipitaceae; Ascomycotina) on bamboo plants in East Asia. Mycoscience, 43 (2):87-93.

Tanaka, E.; Tanaka, C.; Mori, N.; Kuwahara, Y.; Tsuda, M. 2003. Phenylpropanoid amides of serotonin accumulate in witches' broom diseased bamboo. Phytochemistry, 64 (5): 965-969.

Tanaka, E.; Tanaka, C.; Tsuda, M.2002. Transmission and intraspecific variation of Aciculosporium take, the causal agent of witches' broom of bamboo. Forest Research, Kyoto, 74: 13-20.

Tanaka, K.; Harad, Y. 2004. Bambusicolous fungi in Japan (1): Four *Phaeosphaeria* species. Mycoscience 45: 377-382.

Tanaka, K.; Harada, Y. 2004. Bambusicolous fungi in Japan (1): four *Phaeosphaeria* species. Mycoscience, 45 (6): 377-382.

Tanaka, T. 1922. New Japanese fungi. Notes and translations XI. Mycologia, 14: 81-89.

Tao, F.M. 1990. An investigation on glazed frost damage to *Phyllostachys pubescens* stands. Journal of Bamboo Research, 9(1): 78-86.

Teng, S.C. 1938. Additional fungi from China 8. Sinensia, 9: 219-258.

Tewari, M.C.; Singh, B. 1979. Bamboos: Their utilization and protection against biodeterioration. Journal of Timber Development Association of India, 25(4): 12-23.

Theissen, F.; Sydow, H. 1915. Die Dothidiales. Annals of Mycology, 13: 149-746.

Thirumalachar, M.J. 1950. Some new or interesting fungi II. Sydowia, 4: 63-73.

Thirumalachar, M.J.; Narasimhan, M.J.; Gopalakrishnan, G.1947. Morphology and spore forms and heteroism of the giant bamboo rust *Dasturella divina*. Botanical Gazette, 108(3): 371- 379.

Thirumalachar, M.J.; Pavgi, M.S. 1950. Sooty stripe disease of bamboo in India. Bulletin of Torrey Botanical Club, 77(5): 385-388.

Thirumalachar, M.J.; Pavgi, M.S. 1952. Notes on some Ustilaginae V. Sydowia, 6: 389-395.

Thirumalachar, M.J.; Pavgi, M.S. 1968. Notes on some Indian Ustilaginaceae X. Sydowia, 22: 250-253.

Tilak, S.T.; Rao, R. 1967. Contribution to our knowledge of Ascomycetes of India XVII. Sydowia, 21: 308-312.

Tilak, S.T.; Viswanathan, T.S. 1960. Addition to fungi of Bombay V. Mycopathologia et Mycologia Applicata, 13: 100-106.

Tiwari, D.N. 1991. A Monograph on Bamboo. International Book Distributors, Dehra Dun, India. 498 pp.

Umali, T. E.; Hyde, K. D.; Quimio, T. H.1999. *Arecophila bambusae* sp. nov. and A. *coronata* comb. nov., from dead culms of bamboo. Mycoscience, 40 (2): 185-188

Uppal, B.N.; Patel, M.K.; Kamat, M.N. 1955. The fungi of Bombay VIII, 1-56.

Vanita Mishra; Thakur, M. K.; Mishra, R. P. 2015.

Dasturella rust of bamboo in India. International Journal of Current Microbiology and Applied Sciences, 496): 467-470.

Varma, J.C.; Bahadur, K.N. 1980 Country report and status of research on bamboos in India. Indian Forest Records (Botany), 6: 28 pp.

Verma, R. K.; Soni, K. K. 2008. Development of arbuscular mycorrhizae and leaf blight disease in young plantation of 25 species of bamboos. Indian Forester, 134(9): 1236-1244.

Wang, H.M. 2007. Studies on biological characteristics of wilt pathogen in hybrid bamboo. Journal of Anhui Agricultural Sciences, 35(18): 5483-5561.

Wang, S. 1985. Mould of bamboo culm and control methods. Bamboo Research, 1: 47-50.

Wei, S.X.; Zhuang, J.Y. 1990. *Puccinia bambusicola* on leaves and leaf sheath of *Bambusa* sp. Mycosystema, 3: 53.

Wu De Xi; Ren Guo Min; Zhou Ping Yang; Dong Bao Guo; Li Tian Hui; Lu Zhi Guo; Chen Qi Bin; Xie Yong 2014. Disease cause and infection process of Ma bamboo withered disease in Dehong Prefecture. Journal of Yunnan Agricultural University, 29(4): 500-503

Wu Kai Yun; Weng Yue Xia 2000. Bamboo mildew-rotting and its relation with environmental condition. Forest Research, Beijing, 13 (1): 63-70.

Wu, C.G.; Chen, Z.C. 1986. The Endogonaceae of Taiwan I. A preliminary investigation on Endogonaceae of bamboo vegetation at Chi-tou areas, Central Taiwan. Taiwania, 31: 65-87.

Wu, G.J.1993. Experimental control of the rust disease of *Phyllostachys congesta*. Economic Forest Research (Hunan)m 10(2): 63-67.

Wysocki, W. P.; Clark, L. G.; Attigala, L.; Ruiz-Sanchez, E.; Duvall, M. R. 2015. Evolution of the bamboos (Bambusoideae; Poaceae): A full plastome phylogenomic analysis. BMC Evolutionary Biology, 15 (50): 18 March 2015.

Xia You Geng; Xu Er Na; Xu Cui Hua; Wang Guo Gui 2000. Making progress in bamboo research in China. Journal of Jiangsu Forestry Science & Technology, 27 (3): 44-48.

Xia, L. 1988. Studies on *Phyllostachys pubescens* butt rot. Document No.56. Nanjing Forestry University, Nanjing, China.

Xie Yan Bing; Lu Ting Gao; Xu Hua Chao 2006. Occurrence mechanism and control of pest and diseases in shoot-use bamboo forest in Zhejiang. Journal of Zhejiang Forestry Science and Technology, 26(5): 53-56,60.

Xie, Q; Lin.Y.; C. 1987. A study on the wilt disease of *Dendrocalamus latiflorus* 1. Identification of the pathogen, bionomics and control. Journal of Fujian College of Forestry, 7: 15-21.

Xu Mei Qing; Dai Yu Cheng; Fan Shao Hui; Jin Li Xin; Lu Quan; Tian Guo Zhong; Wang Lai Fa 2006. Records of bamboo diseases and the taxonomy of their pathogens in China(I). Forest Research, Beijing 19(6): 692-699.

Xu Mei Qing; Dai Yu Cheng; Fan Shao Hui; Jin Li Xin; Lu Quan; Tian Guo Zhong; Wang Lai Fa 2007. Records of bamboo diseases and the taxonomy of their pathogens in China (II). Forest Research, Beijing, 20 (1): 45-52.

Xu, L.C.; Liu, X.B.; Zhou, S.Q. 1989. Control of *Phyllostachys pubescens* withered tip disease by silvicultural method. Bulletin of Forest Science & Technology in Shangrao, 3: 37-40.

Yadav, A.; Thorat, V.; Shouche, Y. 2016. Candidatus Phytoplasma aurantifolia (16SrII group) associated with witches' broom disease of bamboo (*Dendrocalamus strictus*) in India. Plant Disease, 100(1): 209.

Yamamoto, W.; MaedaA, M.; Oyasu, N.1954. Studies on the speckled Bamboos caused by parasitic fungi. I. On the fuscous speckled bamboo or 'unmon-chiku ' of *Phyllostachys nigra* Mun. var. *henonis* Mak. Soi. Rep. Hyogo Univ. Agric. (Agric.). 1(2): 59-63 pp.

Yang Yong Gang; Wu Xiao Qin 2011. Research progress on pathogens of witches' broom of bamboo. Journal of Zhejiang Forestry College, 28 (1): 144-148.

Ye Li Qin; Wu Xiao Qin 2012. Prevention of bamboo leaf rust by *Acremonium salmoneum*. Journal of Nanjing Forestry University (Natural Sciences Edition), 36 (4): 153-156

Ye Li Qin; Wu Xiao Qin; Wang Liang 2012. Study on the culture condition of hyperparasite

Acremonium salmoneum of bamboo leaf rust. Journal of Nanjing Forestry University (Natural Sciences Edition), 36 (2); 64-68.

Ye Li Qin; Wu Xiao Qin; Ye Jian Ren 2011. Hyperparasitism of bamboo leaf rust and identification of the mycoparasite. Mycosystema, 30 (3): 414-420.

Ye Li Qin; Wu Xiao Qin; Ye Jian Ren 2011. Mycoparasitic activities of *Acremonium salmoneum* against bamboo leaf rust.Chinese Journal of Biological Control, 27 (4): 528-534.

Ye Mao; Luo Kuan; He Kun; Wang Ming Xu; Lian Ji 2001. Conditions of toxin production by *Ceratosphaeria phyllostachydis* and its impact on plants. Journal of Hunan Agricultural University, 27 (6): 449-452.

Yeh, C.C. 1983. How to control bamboo disease. Harvest, 33(8): 37-38.

Yu Guoliang. 1981. Forecasting and control of top drying of *Phyllostachys pubescens.* Forest Science & Technology in Yichun, 1: 116-119.

Yu Guoliang. 1986. Experimental integrated control of die-back of *Phyllostachys pubescens.* Forest Science & Technology, 3: 18-20.

Yu, C.Z.; Chen, J.T.1990. Research on the purple blotch of *Phyllostachys viridis.* Forest Science & Technology, 2: 4-7.

Zhang Jia Min 2000. Preliminary report of research on *Balansia take* endangering Phyllostachys prominens. Journal of Zhejiang Forestry Science and Technology, 20 (5): 38,53.

Zhang Li Qin 2000. Recent situation and control of bamboo diseases in China. Indian Journal of Forestry, 23(1): 104-109.

Zhang Su Xuan; Zhang Ning; Chen Zhen Yun; Chen Qin Hua; Yan Wei De 1999. Studies on the integrated control of Moso bamboo foot rot. Scientia Silvae Sinicae, 35 (2): 65-69.

Zhang, S. 1982. A new species of *Ceratosphaeria* associated with the bamboo shoot blight. Journal of Nanjing Technical College, Forestry Products No.1: 154-158.

Zhang, W.M. 1989. Study on the base rot of *Phyllostachys pybescens.* Master's Thesis. Nanjing Forestry University, Nanjing, China.

Zhang, W.Q.; Ou, Z.S. 1993. Studies on the infection cycle and life cycle of pathogen of top blight of *Phyllostachys heterocycla.* Journal of Fujian Forest College, 13(3): 247-253.

Zhishu, B.; Guoyang, Z.; Chong, L. 1985. Two species of Aphillophorales new to China. Acta Botanica Yunnanica, 7(4): 423-424.

Zhao, M.R.; Huang, J.D.; YAO, J.P. 2004. Effect of introducing *Bambusa pervariabilis x Dendrocalamopsis daii* to dry and hot valley of Huang County. Forest Inventory and Planning, 29(1): 24-26.

Zhong Li Qin; Fang Zhi Gang; Liu Zhen Yong; Zhou Yune; Liu Jun 2000. Bamboo culm rust control trial and its popularizing application. Journal of Bamboo Research, 19 (2):72-75.

Zhou Chun Lai; Wu Xiao Qin; Ji Jing; Ye Jian Ren 2011. Occurrence situation and control countermeasures of bamboo diseases in Nanjing. Journal of Nanjing Forestry University (Natural Sciences Edition), 35 (1): 127-131.

Zhou Chun Lai; Wu Xiao Qin; Ye Li Qin; Ye Jian Ren 2010. Studies on the pathogen and the occurrence trends of the bamboo leaf rust in Nanjing. Journal of Nanjing Forestry University (Natural Sciences Edition), 34 (3): 101-106.

Zhou ChunLai; Wu Xiao Qin; Ye Li Qin; Ye Jian Ren; Xu Xu Ling; Cao Yun 2011. Morphological and molecular identification of bamboo culm brown rot.

Zhou, D.Q.; Hyde, K.D.; Vrijmoid, L.P. 2000. Resources and diversity of bambusicolous fungi in China. Guizhou Science, 18: 62-70.

Zhou, X.Y. 1989. Measure to prevent snow weighing down. Report of Agricultural Division Office in Qjnshan, Anhui, China. Newspaper of Science and Technology in Anhui, China.

Zhou, Z.W. 1988. Causes for forest damage in *Phyllostachys pybescens* stands and remedial measures. Hunan Forestry, 7: 14.

Zhu, K. 1989. Pathological fungi of bamboo plants in Japan. Bamboo Research, 2: 97-119.

Zhu, X.Q. 1988a. A study on smut of bamboo and the biological characteristics of pathogen. Journal of Nanjing Forestry University, 3: 64-71.

Zhu, X.Q. 1988b. Experimednt on chemical control of *Stereostratum corticioides*. Newsletter of Forest Diseases and Insect Pests, 3: 27-29.

Zhu, X.Q. 1988c. Experiment on chemical control of *Stereostratum corticioides* upon the production of urediospores and development process. Forest Science & Technology (Beijing), 9: 19-20.

Zhu, X.Q. 1989a. Study on witches'-broom of bamboos (II): form and biological properties of the pathogenic fungus. Journal of Bamboo Research, 8(1): 44-51.

Zhu, X.Q. 1989b. The study on witches'-broom of bamboos (III): infection characteristics and control experiment of germs. Journal of Nanjing Forestry University, 13(2): 46-51.

Zhu, X.Q.; Zhang, J.N. 1987. Growth of bamboo stem rust and its control. Proceedings of the Symposium on Pest and Disease Control, November 1987, Jiangzu, China.

Zhu, X.Q.; Zhang, J.N. 1988. A study of the extended experiment for control of culm rust of bamboo. Journal of Nanjing Forestry University, 1: 35-39.

Zhu, X.Q.; Huang, H.H. 1988. Studies on witches'-broom of bamboos (I): symptoms, isolation of pathogen and inoculation test. Scientia Silvae Sinicae, 24(4): 483-487.

Zhu, X.Q.; Huang, H.H. 1992. Approach on witches'-broom of bamboo caused by mycoplasma – like organism. Journal of Bamboo Research, 2(1): 4-9.

Zhu, X.Q.; Zhang, J.N.; Chen, J.H. 1983. Studies on culm rust of bamboo. Journal of Nanjing Technical College, Forest Products No.1: 39-40.

Zhu, X.Q.; Zhang, J.N.; Chen, J.H.; Zhu, J.M. 1988. A study of an experiment for the control of culm rust of bamboo. Journal of Nanjing Forestry University No.1: 35-39.

Zhuang Jie Li; Zhu Ming Qi; Zhang Rong; Yin Hui; Lei Ya Ping; Sun Guang Yu; Gleason, M. L. 2010. *Phialophora sessilis*, a species causing flyspeck signs on bamboo in China. Mycotaxon, 113; 405-413.

Zhuang, J.Y.; Wei, S.X. 1992. *Puccinia sinarundinariae* on leaves of *Sinarundinaria nitida*. Mycotaxon, 5: 127.

ACKNOWLEDGEMENTS

Sincere thanks are due to:

Dr. Hans Friederich, Director General, International Network for Bamboo and Rattan (INBAR), Beijing, P.R. China;

Dr. T.P. Subramony, Director & Regional Coordinator for South Asia, INBAR, New Delhi, India;

International Development Research Centre (IDRC), Ottawa, Canada;

Drs. K.S.S. Nair, S. Chand Basha, J.K. Sharma, former Directors, Kerala Forest Research Institute (KFRI), Kerala, India;

Dr. C.T.S. Nair, former Senior Program Officer, FORSPA, Bangkok, Thailand;

Prof. Chao Chison, former President, Nanjing forestry University, Nanjing, China:

Prof. Zhu Kegong, Forest Pathology Department, Nanjing Forestry University, Nanjing, China;

Dr. Zhu Shilin, former Asst. Director, and Ms Zhang Xin Ping, Bamboo Information Centre China, Chinese Academy of Forestry, Beijing, China;

Dr. Emmanuel D. Bello, former Director, and Dr. Perla A. Centino, Research Specialist, Forest Products Research and Development Institute (FPRDI), the Philippines;

Mr Paulino A. Umali, Jr. And Mr Lucas L. Gonzales, Forest Products Research and Development Institute (FPRDI), the Philippines;

Dr. Emilio A. Rosario, Director, Ecosystem Research and Development Bureau (ERDB), Laguna, the Philippines;

Dr. Maria P. Dayan and Ms Veronica O. Sinohin, Ecosystem Research and Development Bureau (ERDB), Laguna, the Philippines;

Dr. Songkram Thammincha, Associate Dean, Faculty of Forestry, Kasetsart University, Thailand;

Mr Boonchoob Boontawee, Director, Silvicultural Research Division, Royal Forest Department, Bangkok, Thailand;

Mr Suthat Lawskul, Ms Oyi and Mr Chammong Kanchana Burangura, Silviculture Research Division, Royal Forest Department, Bangkok, Thailand;

Dr. Aniwat Chalerm Pongse, Ms Krisna Pongpanich, Microbiology and Plant Protection Laboratory, Royal Forest Department, Bangkok, Thailand;

Dr. Charunee Vongkaluang, Forest Products Research Division, Royal Forest Department, Bangkok, Thailand;

Dr. Ming-Jen Lee, Department of Forest Resources Management, National Chiayi Institute of Agriculture, Taiwan-China;

Mr. Tran Van Mao, Department of Resource and Environment Protection, College of Forestry, Xuan Mai-Hatay, Vietnam;

Dr. M.A. Rahman, Institute of Forestry, University of Chittagong, Bangladesh;

The Director, Institute of Rain and Moist-Deciduous Forests, Jorhat, Assam, India;

Dr. U.N.Saikia, Assam Agricultural University, Jorhat, Assam, India;

Dr. M.D. Mehrotra and Dr A.N. Shukla, Indian Council of Forestry Research & Education (ICFRI), Dehra Dun, India;

Mr. D. Swain, Silviculturist, Orissa Forest Department, Bhubaneswar, Orissa, India;

Dr. N.S.K. Harsh and Dr K.K. Soni, Tropical Forest Research Institute, Jabalpur, Madhya Pradesh, India;

Dr Eric Boa, Tree Health Specialist, International Mycological Institute (IMI), Commonwealth Agricultural Bureau (CABI), Kew, UK;

Dr. E.V. Reghu, Scientist, Kerala Forest Research Institute, (KFRI), Peechi;

Dr. N. Sarojam, Librarian, Kerala Forest Research Institute (KFRI), Kerala, India;

All persons in various institutions and forest department in different countries who responded to the questionnaire and provided valuable information on bamboos and bamboo diseases.

GLOSSARY

abaxial: on the side facing away from the axis or stem (dorsal)

accervulus (pl.acervuli): a sub-epidermal, saucer-shaped, asexual fruiting body that produces conidia on short conidiophores

adaxial: on the side facing the axis or stem (ventral)

aeciospore: a dikaryotic rust spore produced in an aecium

aecium: a cup-shaped fruiting body of the rust fungi which produces aeciospores

alternate host: one of two kinds of plants on which a parasitic fungus (e.g.rust) must develop to complete its life-cycle

anamorph stage: the part of the life cycle of a fungus in which no sexual spores are produced; also called imperfect stage

anastomosis: the union of one hypha with another resulting in the intercommunication of their contents

appressorium (pl. appressoria): the swollen tip of a hypha or germ tube that facilitates attachment and penetration of the host by the fungus

ascocarp: the fruiting body of ascomycetes bearing or containing asci

ascomycetes: a group of fungi that produce their sexual spores, ascospores, within asci

ascospore: a sexually produced spore borne in an ascus

ascus (pl. asci): a sac-like cell of a hypha in which meiosis (part of gamete formation process consisting of joining of chromosomes and two cell divisions) occurs and which contains the ascospores

asexual reproduction: any type of reproduction not involving the union of gametes or meiosis

autoecious fungus: a parasitic fungus that can complete its entire life cycle on the same host

basidiomycetes: a group of fungi producing their sexual spores, basidiospores, on basidia

basidiospore: a sexually produced spore borne on a basidium

basidium (pl. basidia): a special form of sporophore (spore-bearing hypha) on which the sexual spores are borne

biological control: total or partial destruction of pathogen populations by other organisms

blight: a disease characterized by general and rapid killing of leaves and culms

blotch: a disease characterized by large, irregular spots or blots on leaves, shoots and/or stems

culm: the main ascending axis (stem) of bamboo

culm sheath: the sheath of the culm leaf, borne singly at each node of the culm proper, below the level at which the sheaths of foliage leaves take their place

curing (open-air): traditional method for preserving bamboo culms in which harvested culms with branches and leaves still attached are left in open air for some time to reduce the starch content of the culms by continued transpiration of the leaves

cellulase: an enzyme that breaks down cellulose

cellulose: a poly saccharide (a carbohydrate containing more than three monosaccharide – carbohydrate unit that does not break down on hydrolysis – units per molecule) composed of hundreds of glucose molecules linked in a chain and found in the plant cell walls

chlamydospore: a thick-walled asexual spore formed by the modification of a cell of a fungus hypha

chlorosis: yellowing of normally green tissue owing to chlorophyll destruction or failure of chlorophyll formation

coalesce: to unite so as to form one mass

conidiophore: a specialized hypha on which conidia are produced

conidium (pl. conidia): asexual fungus spore formed from the end of a conidiophore

damping-off: destruction of seedlings near the soil line, resulting in the seedlings falling over on the ground

die-back: progressive death of shoots, branches, and roots generally starting at the tip

dikaryotic: mycelium or spores containing two sexually compatible nuclei per cell, common in the basidiomycetes

disease: any malfunctioning of host cells and tissues that results from continuous irritation by a pathogenic agent or environmental factor and leads to development of symptoms

disease cycle: the chain of events involved in disease development, including the stages of development of the pathogen and the effect of the disease on the host

disinfectant: a physical or chemical agent that frees a plant, organ or tissue from infection

epicormic: sprouts arising on stem or branch in response to infection or injury

epidemic: a widespread and severe outbreak of a disease; a drastic increase in disease-affected population

epidemiology: the study of factors affecting the outbreak and spread of infectious diseases epidermis: the superficial layer of cells, occurring on all plant parts

etiology: causes or origin of a disease and their relations to the host; the study of the causal factors of a disease

fructification: production of spores by fungi; also, a fruiting body

fruiting body: a complex fungal structure containing spores

fungicide: a compound toxic to fungi

genus (pl. genera): the smallest natural group containing distinct species

germ tube: the early growth of mycelium produced by a germinating fungus spore

haustorium (pl. haustoria): a projection of hyphae into host cells which acts as an absorbing organ

heteroecious: requiring two different kinds of hosts to complete its life cycle; pertaining particularly to rust fungi

hilum: the mark or scar on a seed produced when it separates from its stalk

hyaline: something glassy or transparent

hypha (pl. hyphae): a specialized threadlike element of the mycelium

inflorescence: the arrangement and mode of development of the flower on the floral axis

internode: the portion of the culm between two nodes

imperfect stage: see anamorph stage

incubation period: the period of time between penetration of a host by a pathogen and the first appearance of pathogenic symptoms on the host

infection: the establishment of a parasite within a host plant

infectious disease: a disease that is caused by a pathogen, which can spread from a diseased to a healthy plant

infested: containing great numbers of insects, mites, nematodes, etc. as applied to an area or field; also applied to a plant surface or soil contaminated with bacteria, fungi, etc.

inoculation: the arrival or transfer of a pathogen onto a host

inoculum: the pathogen or its parts that can cause infection; the portion of individual pathogens that are brought into contact with the host

integrated control: an approach that attempts to use all available methods of control of a disease, or of all the diseases and pests of a crop plant, for best control results but with the least cost and minimum damage to the environment

intracellular: within or through the cells

invasion: the introduction of a pathogen into the host

isolate: a single spore or culture and the subcultures derived from it; also used to indicate collections of a pathogen made at different times

isolation: the separation of a pathogen from its host and its culture on a nutrient medium

lamina: the blade or expanded portion of a leaf

lemma: the lower of the two membranous bracts enclosing the flower in grasses; the lower of the two glumes that surround each floret in the spikelet of grasses

lenticel: a body of cells formed on the stem surface of a plant as a lens-shaped spot, and serving as a pore

leptomorph: a term coined to designate a slender, elongated type of rhizome

lignin: a colloidal polymer of varying chemical structure that forms secondary wall material in xylem vessels, tracheids and sclerenchyma fibres

ligule: a thin, membranous outgrowth characteristic of most grasses

linear: long and narrow with parallel sides

leaf spot: a self-limiting lesion on a leaf

lesion: a localized area of discoloured, diseased tissue

life cycle: the stage or successive stages in the growth and development of an organism that occur between the appearance and reappearance of the same stage (e.g.spore) of the organism

locule: a small chamber or compartment

lodicule: one of the specialized scales at the base of the ovary certain grass flowers

midrib: the main vein of a leaf which is a continuation of the petiole

mesophyll: the parenchyma, usually containing chlorophyll, that forms the interior parts of a leaf mosaic: symptoms of certain viral diseases of plants, characterized by intermingled patches of normal and light green or yellowish colour

mould: any profuse or woolly fungus growth on damp or decaying matter or on plant tissue surfaces

mycelium: the hypha or mass or hyphae that make up the body of a fungus

mycorrhiza (pl. micorrhizae): a symbiotic association of a fungus with the roots of a plant

necrosis: a localized and rapid destruction of cell structures and consequent death of the protoplasts

necrotic: discoloured and dead

node: the point on the stem or branch at which a leaf or branch is borne

non-infectious disease: a disease that is caused by an environmental factor, not by a pathogen

ovary: the part of the pistil, usually the enlarged base, which contains the ovules and eventually becomes the fruit

overwinter: pass, spend or survive the wiwnter

pachymorph: a term coined to designate a short, thick type of rhizome

palea (pl. paleae): the scale-like, membranous organ in the flowers of grasses that is situated upon a secondary axis in the axil of the flowering glume, and envelops the stamens and pistil

parasite: an organism living on or in another living organism (host) and obtaining its food from the latter

parenchyma: a tissue composed of thin-walled cells, which usually leave intercellular spaces between them

pathogen: an entity that can cause a disease

pathogenicity: the capacity of a pathogen to cause disease

penetration: the initial invasion of a host by a pathogen

perfect stage: see telemorph

perithecium (pl. perithecia): the globular or flask-shaped ascocarp of the Pyrenomycetes, having an opening or pore (ostiole)

phytoplasma: a new name coined for mycoplasma like organism

plumule: the primary bud of an embryo or germinating seed

polycyclic: completes many life or disease cycles in one year

primary infection: the first infection of a plant by the overwintering or oversummering pathogen

primary inoculum: the overwintering or oversummering pathoghen, or its spores, that cause primary infection

propagule: a part of a plant which, when detached, can grow into a new plant.

Pruning: cutting off superfluous branches or shoots of a plant for better shaped or more fruitful growth

pustule: small blisterlike elevation of epidermis created as spores form underneath and push outward

pycnium (pl. pycnia): a flask-shaped or conical sporangium (the sac in which spores are produced) of a (rust) fungus which develops below the epidermis of the host and bears spores; also called a spermagonium

pycnidium (pl. pycnidia): an asexual, spherical or flask-shaped fruiting body, lined inside with conidiophores that produce conidia

quarantine: control of import and export of plants to prevent spread of diseases and pests

radicle: the first root of an embryo or germinating seed

reniform: kidney-shaped

resistance: the ability of an organism to exclude or overcome, completely or in some degree, the effect of a pathogen or other damaging factor

resistant: possessing qualities that hinder the development of a given pathogen; infected little or not at all

resting period: the period of time taken by some sexual or other thick-walled fungal spores- which are resistant to extremes in temperature and moisture- to germinate after their formation; spores in this stage are called resting spores

rhizome: an underground stem, which is different from a root because of the presence of nodes, buds and leaves or scales

rhizomorph: a root-like mycelial strand

rot: softening, discoloration and, often, disintegration of a succulent plant tissue as a result of fungal or bacterial infection

rust: a disease that gives a rusty appearance to a plant and caused by one of the uredinales (rust fungi)\

sanitation: the removal and burnintg of infected plant parts, decontamination of tools, equipment, hands, etc.

saprophyte: an organism that uses dead organic material for food

sclerotium (pl. sclerotia): a vegetative, resting, food-storage body in certain higher fungi, composed of a compact mass of hardened mycelia

scutellum: the shield-like cotyledon of certain monocots, such as bamboos

secondary infection: any infection caused by inoculum produced as a result of primary or a subsequent infection, an infection caused by secondary inoculum

secondary inoculum: inoculum produced by an infection that offured during the same growing season

seedling: the juvenile plant, grown from a seed

sieve tube : a series of phloem cells forming a long cellular tube, through which food materials are transported

smut: a disease caused by the smut fungi (Ustilaginales); it is characterized by masses of dark, powdery spores

solarization: turn and expose the soil to direct sunlight

sooty mould: a sooty coating on foliage and fruit, formed by the dark hyphae of fungi that live in the honedew secreted by insects such as aphids, mealybugs, scales and white files

spike: a simple indeterminate inflorescence with sessile (attached by the base, without any other support) flowers along a single axis

spikelet: a secondary spike-one of the basxic units of the inflorescencve in grosses-consisting of one or more cells

sporocarp: a multicellular structure in which spores form; a fruiting body

sporodochium: fungal fruiting a structure consisting of a cluster of conidiophores over woven together on a mass of hyphae

sterile: failing to complete fertilization and produce seed, as a result of defective pollen or ovules; not producing seed capable of germination

sterlization : the elimination of pathogens and produce seed, and a result of defective pollen or ovules, not producing seed capable of germination

sterilization: the elimination of pathogens and other living organisms from soil, containers, etc. by means of heat ort chemicals

stoma (pl.stomata): any of the small apertures in the epidermis of leaves, stems, stems, etc., through which gases are exchanged

strain : the descendants of a single isolation in pure culture; an isolate or a group of similar isolates

stroma (pl.stromata): a compact mycelial structure on or in which fructifications are usually formed

systemic: spreading internally throughout the plant body

teleomorph: the sexual stage in the life cycle of a fungus; considered the perfect stage

teliospore: the sexual, thick-walled, resting spore of the rust and smut fungi

telium: the fruiting structure in which rust teliospore are produced

tissue: a group of cells of similar structure which performs a special function

toxicity: the capacity of a compound to produce damage

transmission: the transfer or spread of a virus or other pathogen from one plant to another

uredinium (pl. uredinia): the fruiting structure of the rust fungi in which urediospores are produced; also called urediniosore (pl. urediniosori)

urediospores are produced; also called urediniosore (pl. urediniosori)

urediospore (or urediniospore): a dikaryotic, repeating spore of the rust fungi

vascular bundle: a longitudinal arrangement of strands of xylem and phloem that forms the fluid-conducting channels in vascular plants

vector: an insect capable of transmitting a pathogen.

vegetative: asexual; somatic

virulence: the degree of pathogenicity of a given pathogen

virulent: capable of causing a severe disease; strongly pathogenic

virus: a submicroscopic, obligate parasite consisting of nucleic acid and protein

wilt: loss or rigidity and drooping of plant parts, generally caused by insufficient water in the plant

witches'-broom : broom-like growth or massed proliferation caused by the dense clustering of branches of woody plants

wound: physical damage of a plant, caused by an insect, animal, physical or chemical agent

zonate: marked with zones, as of colour or texture

Appendix I

Checklist of Bamboo Diseases and Pathogens in Bamboo Nurseries Reported from Different Countries in Asia

Disease	Pathogen	Bamboo species affected	Country
Damping-off	*Rhizoctonia solani* *Fusarium fujikuroi* *F. oxysporum*	*Bambusa bambos, Dendrocalamus strictus,* *D. brandisii, Thyrsostachys siamensis*	India
	R. solani, Fusarium spp., *Athelia rolfsii* (*Sclerotium rolfsii*)	*Phyllostachys spp.,* *P. pubescens, P. sulphurea* cv. *viridis,* *P. glauca, P. aureosulcata,* *P. bambusoides*	China
Seeding spear rot	*R. solani*	*B. bambos, D. strictus*	India
Seedling wilt	*R. solani*	*B. bambos, D. strictus*	India
Web blight	*R. solani*	*B. bambos, D. brandsii, D. strictus,* *Thyrsostachys siamensis,*	India
		B. blumeana	Philippines
Leaf rust	*Kweilingia divina* (= *Dasturella divina*)	*B. bambos, D. brandisii, D. strictus,* *Ochlandra travancorica,* *O. scriptoria, Phyllostachys ritcheyi,* *T. siamensis, B. bambos, B. blumeana*	India
Bipolaris leaf blight	*Bipolaris maydis*	*B. bambos, D. strictus, D. brandisii,* *D. membranaceus, T. siamensis,* *O. wightii*	India
	B. urochloae	*P. pubescens*	India
	B. bambusae	*B. bambos*	India
Exserohilum leaf spot	*Exserohilum rostratum* *E. holmii*	*B. bambos, D. strictus* *B. bambos, P. pubescens*	India
Dactylaria leaf spot	*Dactylaria bambusina*	*B. bambos, D. brandisii, D. strictus,* *O. wightii, T. siamensis*	India
Colletotrichum leaf spot	*Colletotrichum gloeosporioides*	*B. bambos, D. strictus* *B. bambos, B. blumeana*	India Thailand
	C. septorioides, *Colletotrichum* sp.	*Phyllostachys* spp., *P. pubescens,* *Bambusa vulgaris*	China
Curvularia leaf spot	*Curvularia pallescens*	*B. bambos, B. vulgaris,* *D. longispathus, O. scriptoria,* *T. oliveri*	India
Alternaria leaf blight	*Alternaria alternata*	*B. bambos, D. strictus*	India
Seedling rhizome rot	*Rhizostilbella hibisci*	*B. bambos*	India
Leaf striping and seedling stunting	Possibly a virus	*B. bambos*	India

Appendix IIA

Checklist of Bamboo Diseases and Pathogens in Bamboo stands Reported from Different Countries in Asia (Diseases of Culms and Foliage)

Disease	Pathogen	Bamboo species affected	Country
Rot of emerging culm	*Fusarium fujikuroi* (= *Fusarium moniliforme* var. *intermedium*).	*Bambusa bambos, B. balcooa, B. polymorpha, B. vulgaris, Dendrocalamus strictus, D. longispathus, T. oliveri,*	India
	Unknown etiology	*B. bambos, B. balcooa, B. tulda B. vulgaris, Bamboo* spp.	Bangladesh, China, Thailand, Philippines Pakistan
		D. strictus,	India
	Rhizoctonia sp.	*O. travancorica*	
	Fusarium oxysporum	*O. scriptoria*	
		B. balcooa, D. asper	India
Rot of growing culm	*F. equiseti*	*B. bambos, B. balcooa, B. polymorpha, B. brandisii, D. strictus, D. longispathus, T. oliveri*	India
	Fusarium fujikuroi (= Fusarium moniliforme) *F. oxysporum*	*P. pubescens B. balcooa, D. asper*	China, India
Pterulicium culm rot	*Pterulicium xylogenum* (= *Clavaria xylogena*)	*Bambusa vulgaris* var. *waminii*, *Dendrocalamus giganteus*, *Gigantochloa* sp., *Melocanna baccifera, Bambusa pallida, D. longispicula, D. asper, B. tulda*	India
Culm brown rot	*Fusarium solani F. equiseti*	*P. viridis, P. viridis* f. *hauzeauana* (= *P. sulphurea*), *P. aureosulcata, P.glauca*	China
Culm base rot	*Arthrinium* sp.,	*P. pubescens*	China
	A. phaeospermum,	*P. pubescens*	
	Alternaria alternata	*P. pubescens*	
	Fusarium oxysporum, F. fujikuroi		
	Unidentified fungi		China
Culm purple blotch	*F. stilboides*	*P. viridis* (= *P. sulphurea*) *Phyllostachys pubescens, P. dulcis P. praecox*	China
Bamboo blight	*Sarocladium oryzae*	*B. bambos, B. balcooa, B. tulda, B. vulgaris*	Bangladesh
	Sarocladium strictum	*B. nutans*	India
	(= *Acremonium strictum)*	*B. bambos, B. balcooa,B. tulda,*	Bangladesh
	Paraconiothyrium fuckleii (= *Coniothyrium fuckelii*)	*B. vulgaris, B. tula*	Bangladesh
	Fusarium sp.		
	Pteroconium sp.	*B. vulgaris, B. tulda*	Bangladesh
	Arthrinium sp.	*B. vulgaris*	Bangladesh
BambooTop blight	*Ceratosphaeria phyllostachydis*	*Phyllostachys edulis P. heterocycla, P. pubescens*	China

Branch die-back	*Fusarium pallidoroseum*	*B. bambos, B. vulgaris,D. strictus*	India
	Fusarium sp.	*Phyllostachys sp.*	China
Witches'-broom	*Linearistroma lineare*	*Ochlandra travancorica*	
	(= *Balansia linearis*)	*O. travancorica* var. *hirsutaO. scriptoria,*	India
		O. ebracteata	
	Balansia take	*P. viridis f. hauzeauana,*(= *P. sulphurea*)	
	Aciculosporium take	*P. bambusoides, P. glauca, P. aurea*	China
		P. praecox, P. nuda, P. pubescens /	
		heterocycla/edulis, P. arcana, B. multiplex	
		Semiarundinaria fastuosa, Sasa spp.	
		P. aurea, P. bambusoides, P. pubescens,	Taiwan-China
		P. ngra var. *henonis, P. lithophila,*	
		P. makinoi, P. lithocarpa, P. nuda,	
		B. oldhamii, B. multiplex, B. dolichoclada	
		Phyllostachys nigra var. *henonis,*	Japan
		P. bambusoides, P. pubescens	
		Sasa veitchii var. *tyugokensis*	
		S. borealis var. *purpurascens*	
		S. kurilensis, S. paniculata, S. tectoria	
		Gigantochloa levis	Philippines
	Heterepichloe bambusae	*B. vulgaris, Bambusa* sp.	India
	(= *Epichloe bambusae*)	*Phyllostachys* sp.	China
		D. asper, Gigantochloa apus	Indonesia
		G. atter, G. robusta, B. nutans	Vietnam
		D. membranaceus	
	Heteroepichloe sasae	*Phyllostachys* sp., *Sasa* spp.	Japan
	(= *Epichloe sasae*)	*Phyllostachys* sp.	China
	Loculistroma bambusae		
	Bacteria-like organism+	*Phyllostachys* sp.	Taiwan-China
	Phytoplasma		
	Unknown etiology	*D. strictus*	India
Phytoplasma	Phytoplasama:		
disease Little Leaf	*Phytoplasma aurantifolia*	*D. strictus*	India
	(16SrII Group)	*Bambusa multiplesx*	Thailand
	'Candidatus	*Phyllostachys nigra* var. *henonis*	Korea
	Phytoplasma asteris'		
Bamboo mosaic	Bamboo Mosaic Virus	*B. oldhamii,D. latiflorus*	Taiwan-China
	(BaMV)	*B. mutabilis, B. beecheyana, B. dolichoclada*	Taiwan-China
		B. edulis, B. multiplex, B. oldhamii	China
		B. pachinensis, B. utilis, B. ventricosa	India
		B. vulgaris, D. giganteous, D. latiflorus	
		Melocanna baccifera	
Cherry Necrotic	Cherry necrotic rusty	*Arundinaria falconerii, B. balcooa, B. bambos*	China
Rusty Mottle Virus	mottle virus (CNRMV)	*B. multiplex, B. nutans, B. pallida, B. tulda*	India
Disease		*B. ventricosa, D. asper, D. asper (Chinese)*	Korea
		D. bambusoides, B. mutabilis, B. beecheyana	
		B. dolichoclada, B. edulis, B. multiplex	
		B. oldhamii, B. pachinensis, B. utilis	
		B. ventricosa, Fargesia somnigensis	
		M. baccifera	

Thread blight	*Erythricium salmonicolor* (= *Botryobasidium salmonicolor*)	*B. bambos, B. balcooa, B. polymorpha, B. vulgaris, B. gigantina,*	India
	Erythricium salmonicolor (= *Pellicularia salmonicolor*)	*Pseudoxytenanthera stocksii, B. polmorpha B. multiplex, B. tulda,B. tuldoides D. brandisii, D. longispathus O. travancorica, O. travancorica* var. *hirsuta, O. scriptoria, O. ebracteata*	India
	Corticium koleroga (= *Pellicularia koleroga*)	*D. strictus, Ochlandra* spp.	
Necrosis of culm internode	*Curvularia lunata*	*Thyrsostachys oliveri*	India
Bamboo wilt	*Fusarium incarnatum* (= *Fusarium semitectum*)	*D. latiflorus, D. latiflorus Bamdusa Pervariadilisx Grandis* Nin	China, Taiwan-China
	Fusarium oxysporum	*Dendrocalamus latiflorus* *Gliocladium* sp.	China
	Erwinia sinocalami	*Dendrocalamus latiflorus*	Taiwan-China
Culm rust	*Stereostratum corticioides*	*Arundinaria* sp., *Bambusa* sp., *Chimonobambusa* sp., *Phyllostachys* sp., *P. nigra* var. *henonis, P. congesta, P. meyeri, P. henonis, P. glauca, P. propinqua, Sasa* sp., *Semiarundinaria sp.,*	China
		Pleioblastus sp., Pleioblastus vaginatus P. higoensis, Pseudosasa sp., *Chimonobambusa* sp.	Japan
		Bambusa sp.	Pakistan
Culm smut	*Bambusiomyces shiraianus* (= *Ustilago shiraiana*)	*Phyllostachys sulphurea* cv. *viridis P. glauca, P. pubescens, P. nigra var. henonis P. flexuosa, P. bambusoides, P. incarnata P. congesta, P. aurea, Pleioblastus amarus P. makinoi, Fargesia* sp., *Arundinaria* spp. *Sasa ramosa, Sasa nana*	China
		Bambusa sp.	India
Culm staining and die-back	*Apiospra* sp.	*B. vulgaris, D. longispathus*	India
Sooty stripe disease	*Arthrinium arundinis* (=*Papularia arundinis*)	*Bambusa* sp.	India
	Arthrinium phaespermum (= *Papularia sphaerosperma*)	*Phyllostachys praecox*	China
Culm stain	*Apiospora indica*	*Bambusa* sp.	India
	Arthrinium arundinis	*Melocanna baccifera*	Pakistan
	(=*Arthrinium montagnei*)	*Bambusa* sp.	India
	Arthrinium sp.	*Bambusa* sp.	Pakistan,India
	Aspergillus sp.	*Bambusa* sp.	India,Philippines
	Asterinella hingensis	*Phyllostachys bambusoides*	Japan
	Astrocystis mirabilis	*Bambusa* sp.	India
	Asterosphaeria fuscomaculans	*Phyllostachys nigra*	Japan
	Balladyna butleri	*Bambusa* sp.	India
	Capnodium sp.	*Bambusa bambos,D. strictus*	India
	Chaetosphaeria fusispora	*Arundinaria narihira*	Japan
	Chaetosphaeria macrospora	*Bambusa shimadai*	Japan
	Arthrinium arundinis (= *Coniosporium bambusae*)	*Bambusa* sp.	India

	Cyphellophora sessilis (=*Phialophora sessilis*)	*Bamboo* sp.	China
	Geotrichum sp.	*Bambusa* sp.	India
	Lembosia tikusensis	*Phyllostachys nigra*	Japan,China
	Meliola bambusicola	*Bambusa* sp.	India
	Phragmothyrium bambusicola (= *Micropeltis bambusicola*)	*Sasa paniculata*	Japan
	Morrisiella indica	*Bambusa* sp.	India
	Arthrinium arundinis (=*Papularia arundinis*)	*Bambusa sp.*	India,Pakistan
	Penicilliopsis bambusae	*Bambusa* sp.	Japan, India
	Periconia cookei	*Bambusa sp.*	India
	P. digitata	*Bambusa* sp.	India
	Phragmothyrium semiarundinariae	*Semiarundinaria narikissae*	Japan
	Tremella fuciformis	*Bambusa sp.*	India
	Trichoderma sp.	*Bambusa* sp.	India
	Bambusaria bambusae (=*Valsaria bambusae*)	*Bambusa* sp.	India
	Xenosporium indicum	*Bambusa* sp.	India
Foliage *blight*	*Bipolaris bambusae*	*B.bambos,B. polymorpha,B. brandisii*	India
	Bipolaris maydis	*D. longispathus,D. strictus,*	
	Cochliobolus heterostrophus	*P. ritcheyi*	
Leaf rust Kweilingia leaf rust	*Kweilingia divina* (= *Dasturella divina*)	*B. bambos,B. balcooa, B. multiplex, B. tuldoides, B. vulgaris, D. brandisii, D. hamiltonii, D. longispathus, D. strictus, P. ritcheyi, Ochlandra travancorica, O. scriptoria, T. oliveri, T. siamensis*	India,
		B. oldhamii, D. latiflorus	Taiwan-China
		Bambusa sp.	Singapore
		B. multiplex, B. oldhamii, B. shimadai, D. latiflorus, Bambusa sp.	japan
		B. membranaceus	Vietnam
		B. vulgaris, D. asper, D. strictus,	Thailand
		B. vulgaris, Gigantochloa sp.	Philippines
	Dasturella bambusina	*Bambusa* sp.	India
	Dasturella sp.		
	Dasturella oxytenantherae	*Oxytenanthera* sp.	India
Puccinia leaf rust	*Puccinia aduncta*	*Sasa chartacea* var. *nana*	Japan
	Puccinia bambusicola	*Bambusa* sp.	China
	Puccinia cymbiformis	*P. nigra* var. *henonis*	Japan
	Puccinia ditissima (=*Uredo ditissima*)	*D. latiflorus*	Taiwan-China China
		Schizostachyum lumampao	Philippines
	Puccinia ditissima (= *Uredo ignava*)	*Schizostachyum* sp., *D. giganteus, B. vulgaris, B. bambos, Dendrocalamus* sp., *D. latiflorus*	China Malaysia Taiwan-China
	Puccinia flammuliformis	*Sasa tessellata, Bambusa* sp.	China
	Puccinia gracilenta	*Bambusa* sp.	India
	Puccinia hikawaensis	*Sasa kesuzu*	Japan

	Puccinia ignava	*B. bambos,B. vulgaris, Dendrocalamus* sp.	Malaysia
		Schizostachyum sp.	China
		D. latiflorus	Taiwan-China
		Dendrocalamopsis oldhami	China
	Puccinia kusanoi	*Nipponobambusa* sp.	Taiwan-China
		Phyllostachys sp.	Japan, China
		Pleioblastus sp., *Pseudosasa* sp., *Sasa* sp., *Sasella* sp., *Semiarundinaria* sp., *Sinobambusa* sp.	Taiwan-China
		Dendrocalamus latiflorus	Philippines
	Puccinia kwanhsiensis	*Arundinaria atropurpurea*	China
	Puccinia longicornis	*Nipponobambusa* sp., *Pleioblastus* sp., *Pseudosasa* sp., *Sasa* sp., *Sasella* sp.	China
	Puccinia melanocephala	*Arundinaria* sp., *Bambusa* sp.	India
	Puccinia mitriformis	*Sasa paniculata, S. septentrionalis, Sasamorpha amabilis, S. purpurascens*	Japan
	Puccinia nigroconoidea	*Phyllostachys* sp.	China
	Puccinia phyllostachydis	*Drepanostachyum suberecta, Phyllostachys aurea*	India, China
		P. bambusoides, P. nigra var. *henonis*	Japan
		Bambusa sp.	Taiwan-China
	Puccinia polliniae	*Phyllostachys pubescens, P. aurea P. atropurpurea*	China
	Puccinia polliniae-imberbis	*P. pubescens, P. aurea, Bambusa* sp.	China
	Puccinia pollinicola	*Bambusa tessellata, B. oldhami B. vulgaris, Bambusa* sp.	China
	Puccinia sasae	*Sasa* sp.	Japan
	Puccinia sasicola	*Sasa borealis, S. kesuzu*	Japan
	Puccinia scabrida	*Phyllostachys* sp.	Japan
	Puccinia sinarundinariae	*Sinarundinaria nitida*	Japan
	Puccinia tenella	*Bambusa sp.*	Hongkong, China
	Puccinia xanthosperma	*Bambusa* sp.	India
Uredo leaf rust	*Uredo arundinariae*	*Arundinaria* sp., *Sasa* sp.	Japan
	Uredo arundinis-donacis	*Bambusa* spp., *Phyllostachys* sp. *Sasa septentrionalis, Sinarundinaria* spp. *Sasamorpha amabilis*	China
	U. bambusae-nanae	*Bambusa nana*	India, Singapore
	U. dendrocalami	*Dendrocalamus latiflorus*	China
		D. strictus	Sri Lanka
	Uredo inflexa (= *Physopella inflexa*)	*Bamboo* spp.	China
	U. ochlandrae	*Ochlandra stridula*	Sri Lanka
	U. sasae	*Arundinaria* sp., *Sasa* sp.	Japan
Phakopsora leaf rust	*Phakopsora loudetiae*	*Bambusa bambos, B. vulgaris, B. blumeana D. asper, D. latiflorus, Gigantochloa levis Phyllostachys aurea*	Philippines
Tunicospora foliage rust	*Tunicospora bagchii*	*Dendrocalamus strictus*	India
Exserohilum leaf spot	*Exserohilum rostratum Teleomorph: Setosphaeria rostrata*	*B. polymorpha, D. longispathus*	India

	Exserohilum holmii Teleomorph: *Setosphaeria holmii*	*D. strictus, B.bambos, B. polymorpha*	India
	Helminthosporium arundinis	*Arundinaria* spp., *D. latiflorus Phyllostachys* spp., *Pleioblastus amarus*	China
Zonate leaf spot	*Dactylaria bambusina*	*B. bambos, B. polymorpha, D. strictus D. longispathus, Ochlandra ebracteata, O. travancorica, O. scriptoria, Thyrsostachys siamensis, Thyrsostachys* sp.	India
Colletotrichum leaf spot	*Colletotrichum gloeosporioides*	*Arundinaria sp., B. bambos, D. strictus O. ebracteata, O. travancorica, O. scriptoria*	India
	Colletotrichum septorioides	*Phyllostachys pubescens, Phyllostachys* spp. *Bambusa vulgaris*	China
	Colletotrichum sp.	*B. vulgaris var. striata,D. asper D. giganteus, D. pendulus, Gigantochloa ligulata, G. latifolia, G. levis, G. rostrata, G. scortechinii*	Malaysia
Ascochyta leaf spot	*Ascochyta arundinariae*	*Drepanostachyum falcatum*	India, Japan
	A. bambusinae	*B. multiplex*	India
	A. dendrocalami	*B. bambos, D. strictus, T. siamensis*	India
	Boeremia exigua (= *Ascochyta phaseolorum*)	*Bambusa bambos, Bambusa* sp.	India
	Ascochyta sp.	*Schizostachyum lumampao*	Philippines
Tar spot	*Phyllachora bambusae*	*Bambusa bambos, Bamusa* sp.	India
	Phyllachora chimonobambusae	*Chimonabambusa* sp.	Japan
	Phyllachora dendrocalami	*Dendrocalamus strictus*	India
	Phyllachora graminis	*Arundinaria* sp., *Phyllostachys* sp.	India, Japan China
	Phyllachora infectoria	*Bambusa balcooa, B. tulda*	India
	Phyllachora ischaemi	*B. bambos*	India
	Phyllachora ischaemi (=*Phyllachora microstegii*)	*Bamboo* spp.	China
	Phyllachora leptotheca	*Bamboo* spp.	China
	Phyllachora longinaviculata	*B. bambos, D. strictus, P. ritcheyi*	India
	Phyllachora maculans	*Bamboo* spp.	China
	Phyllachora malabarensis	*Bambusa* sp.	India
	Phyllachora orbiculata	*Bamboo* spp.	China
	Phyllachora phragmitis-karkae	*Phyllostachys* spp., *Sasa* spp.	China
	Phyllachora phyllostachydis	*Phyllostachys* sp.	JapanChina
	Phyllachora shiraiana	*Arundinaria* sp., *B. bambos, B. vulgaris P. ritcheyi, D. strictus, O. travancorica, O. scriptoria, Phyllostachys* sp.	Japan
	Phyllachora sinensis	*Bamboo* spp.	China
		A. blumeana, B. vulgaris, Bambusa sp.	Philippines
	Phyllachora sp.	*Bambusa bambos, Bambusa* sp.	India
Ciliochora leaf spot	*Ciliochora indica* (= *Petrakomyces indicus*)	*Arundinaria* sp., *B. bambos, D. strictus Ochlandra ebracteata, O. scriptora*	India
	Ciliochora bambusae (= *Petrakomyces bambusae*)	*Thyrsostachys* sp.	India
Phoma leaf spot	*Phoma arundinaceae*	*Phyllostachys bambusoides*	Japan
	Phoma dendrocalami	*B. bambos, D. strictus*	India
	Phoma herbarum	*B. bambos, D. strictus*	India

	Phoma pelliculosa	*Phyllostachys* sp.	Japan
	Epicoccum sorghinum (=*Phoma sorghina*)	*B. bambos, D. strictus*	India
	Phoma sp.	*Dendrocalamus hamiltonii*	India
Phomopsis leaf spot	*Phomopsis bambusae*	*Bambusa bambos, D. strictus* *Thyrsostachys* sp.	India
Stagonospora leaf spot	*Stagonospora bambusae*	*Bambusa bambos, D. strictus*	India
	Stagonospora phyllostachydis	*Phyllostachys* sp.	Japan
	Stagonospora septorioides	*Phyllostachys* sp.	Japan
Septoria leaf spot	*Septoria thyrsostachydis*	*Thyrsostachys* sp.	India
	Septoria bambusae	*Bambusa* sp.	Japan
Chaetospermum leaf spot	*Chaetospermum carneum*	*B. bambos*	India
Curvularia leaf spot	*Curvularia lunataTeleomorph: Cochliobolus lunatus*	*Arundinaria* sp., *B. bambos, Thyrsostachys* sp., *O. travancorica, O. scriptoria, O. ebracteata,*	India
	Curvularia andropogonis	*Bamboo* sp.	India
Alternaria leaf spot	*Alternaria alternata*	*Bambusa* sp., *B. bambos, D. strictus*	India
	Alternaria tenuis	*Dendrocalamus latiflorus, Phyllostachys* spp.	China
Rosenscheldiella leaf spot	*Rosenscheldiella ochlandrae*	*O. travancorica*	India
Coccodiella leaf spot	*Coccodiella arundinariae*	*Phyllosatchys* sp.	China
		Phyllostachys sp., *Sasa* sp. *Sasamorpha purpurascens*	Japan
	Coccodiella ochlandrae	*Ochlandra travancorica*	India
Cerodothis leaf spot	*Cerodothis aurea*	*B. bambos, D. strictus, Thyrsostachys* sp.	India
Leptostroma leaf spot	*Leptostroma* sp.	*Bambusa philippinensis, Gigantochloa levis Schizostachyum lumampao*	Philippines
Eriosporella leaf spot	*Eriosporella bambusicola* (=*Eriosporella calami*)	*Bambus asp., B. blumeana,B. vulgaris G. levis, G. asper*	Philippines
Brown leaf spot	*Fusarium pallidoroseum*	*Melocanna arundina, Sasa dullooa*	India
	Fusarium incarnatum (=*Fusarium semitectum*)	*B. bambos, B. vulgaris, D. strictus, Phyllostachys ritcheyi*	India
Culm sheath spot	*Shiraia bambusicola* *Myriangium haraeanum*	*Phyllostachys* sp., *P. sulphurea* cv. *viridis, P. glauca*, *P. pubescens, P. bambusoides, P. heteroclada, P. praecox, Pleioblastus amarus, Fargesia* sp., *Bambusa* sp	China
	Pestalozziella bambusae	*B. bambos, B. polymorpha, D. strictus*	India
	Sarocladium sp.	*B. vulgaris*	
	Sarocladium sp.	*B. vulgaris, D. brandisii, D. strictus*	India
Black mildew	*Meliola acristae*	*Phyllostachys praecox, P. vivax, P. dulcis P. glauca Phyllostachys* spp. *Bambusa* spp. *Sasa* spp. *Pleioblastus cantori*	China
	Meliola arundinis	*Phyllostachys praecox, P. vivax, P. dulcis, P. glauca Phyllostachys* spp. *Bambusa spp. Sasa* spp. *Pleioblastus cantori*	China
	Meliola bambusae	*Phyllostachys praecox, P. vivax, P. dulcis, P. glauca Phyllostachys spp. Bambusa spp. Sasa spp. Pleioblastus cantori*	China
	Meliola bambusicola	*Bambusa* sp., *B. bambos*	India
		Phyllostachys sp., *P. bambusoides, Sasa senanensis, semiarundinaria yashadake*	Japan

	M. pseudosasae	*Bambusa sp., B. bambos*	Japan
	Meliola tenella	*Phyllostachys praecox, P. vivax, P. dulcis*	
		P. glauca Phyllostachys spp. Bambusa spp.	China
		Sasa spp. *Pleioblastus cantori*	
	Meliola sp.	*B. bambos, D. strictus, O. travancorica*	India
		O. travancorica var. *hirsuta, O. ebracteata*	
		O. scriptoria	
	Melioliona stomata	*Phyllostachys* sp.	Japan
		B. multiplex, B. vulgaris,Gigantochloa levis	Thailand
		G. asper	
	Dimerina bambusicola	*Phyllostachys praecox, P. vivax, P. dulcis*	China
		P. glauca	
	Hinoa bambusicola	*Phyllostachys* spp.	China
	(= *Haraea bambusicola*)		
	Haraea japonica	*Phyllostachys* sp.	China
	Meliola stomata	*Phyllostachys* sp.	Japan
	Asterinella hingensis	*Bambusa* sp.	India, China
Sooty *mould*	*Capnodium* sp.	*Phyllostachys* sp.*, P. henonis*	Japan
		B. multiplex, B. blumeana, G. albociliata	Thailand
		B. bambos B. vulgaris, D. strictus,	India
		D. longispathus, Ochlandra spp.	
	Spiropes scopiformis	*B. vulgaris, B. bambos, D. strictus*	India
		O. travancorica, O. ebracteata	

Appendix IIB

Checklist of Bamboo Diseases and Pathogens in Bamboo Stands Reported from Different Countries in Asia (Miscellaneous Foliage and Minor Branch Infections)

Pathogen	Bamboo species affected	Country
Aithaloderma phyllostachydis	*Phyllostachys* sp.	Japan
Annellophragmia coonoorensis	*Bambusa nana*	India
Anthostomella bambusae	*Bambusa blumeana, Bambusa* sp.	India, Japan
Apiospora shiraiana (= *Hypoderma shiraiana* = *Munkiella shiraiana*)	*Sasa* sp.*Bamboo* sp.	Japan
Arthrinium phaeospermum	*Bamboo* sp.	Japan
Ascochyta sp.	*Bambusa* sp.	Philippines
Asterotheca nigrocornis	*Sasa senanensis*	Japan
Astrocystis mirabilis	*Bamboo* sp.	Japan
Asterosphaeriella fusispora (= *Amphisphaeria fusispora*)	*Phyllostachys* sp.	Japan
Astrosphaeriella minoensis (= *Leptosphaeria minoensis*)	*Phyllostachys* sp.	Japan
Balladyna butleri	*Bambusa* sp.	India
Calonectria bambusae	*Bamboo* sp.	Japan
Calonectria sasae	*Sasa* sp., *Phyllostachys* sp.	Japan
Camarosporium phyllostachydis	*Phyllostachys* sp.	Japan
Caryospora phyllostachydis (= *Amphisphaeria phyllostachydis*)	*Phyllostachys* sp.	Japan
Ceratosphaeria grisea	*Bamboo* sp.	Japan
Cercospora sp.	*Bambusa blumeana*	Philippines
Chaetopeltiopsis sasae	*Sasa* sp.	Japan
Chaetosphaeria fusispora	*Bamboo* sp.	Japan
Chaetosphaeria macrospora	*Bamboo* sp.	Japan
Charonectria sasae	*Sasa* sp., *Phyllostachys* sp.	Japan
Colletotrichum hsienjenchang	*Bambusa* sp.	Japan
Collodiscula japonica	*Sasa nebulosa, S. senanensis*	Japan
Coniosporium pulvinatum	*Phyllostachys* sp.	Japan
Coniosporium punctiforme	*Phyllostachys* sp.	Japan
Coniothyrium bambusae	*Bamboo* sp.	Japan
Coniothyrium fuckelii	*Ochlandra* sp.	India
Corynespora tsurudai	*Bambusa* sp.	Japan
Cylindrosporium bambusae	*Bamboo* sp.	Japan
Cytospora bambusina	*B. bambos*	India
Cytosporella bambusae	*Phyllostachys* sp.	Japan
Diaboliumbilicus mirabilis	*Sasa vetichii, S. kurilensis*	Japan
Diaporthe take	*Phyllostachys* sp.	Japan
Didimobotryum kusanoi	*Pleioblastus simonii*	Japan
Didimosphaeria pustulata	*Sasa kurilensis, S. senanensis*	Japan
Didimosphaeria striatuala	*Sasa vetichii*	Japan
Didimosphaeria striatula var. *minuta*	*P. bambusoids var. marhiana*	Japan
Dimerium japonicum	*Semiarundinaria yashadake*	Japan
Dimerium sasae	*Sasa sp.*	Japan
Dinemasporium graminum var. *stigosulum*	*Bamboo sp.*	Japan
Diplodia bambusae	*Bamboo sp.*	Japan
Diplodia maculans	*Bamboo sp.*	Japan
Diplozythiella bambusina	*Bambusa sp.*	India
Epicoccum nigrum	*Pleioblastus simonii*	Japan

Eutypa kusanoi	*Phyllostachys edulis*	Japan
Flabellospora crassa	*Bambusa sp.*	India
Fusarium bambusicola	*Bambusa sp.*	Japan
Fusarium phyllostachydicola	*Phyllostachys* sp.	Japan
Fusarium stromaticola	*Phyllostachys* sp.	Japan
Fusarium graminearum(= *Gibberella zeae*)	*Bamboo* sp.	Japan
Gloeosporium sphaerosporum	*Bamboo* sp.	Japan
Guignardia bambusina	*Bamboo* sp.	Japan
Haraea japonica	*Sasa senanensis*	Japan
Haraea sasae	*S. senanensis*	Japan
Hendersonia phyllostachydis	*Phyllostachys* sp.	Japan
Hendersonula toruloidea	*Bambusa nutans*	India
Mycosphaerella dianthii (*Heterosporium echinulatum*)	*Pleioblastus simonii*	Japan
Mycocitrus phyllostachydis (= *Hypocreopsis phyllostachydis*)	*Phyllostachys* sp.	Japan
Hypoxylon fuscopupureum	*Phyllostachys* sp., *Pleioblastus* sp.	Japan
Konenia bambusae	*Sasa nipponica*	Japan
Konenia sasicola	*Sasa* sp.	Japan
Kusanobotrys bambusae	*Phyllostachys* sp., *Sasa* sp.	Japan
Lasiosphaeria culmorum	*Phyllostachys* sp.	Japan
Lasiosphaeria phyllostachydis	*Phyllostachys* sp., *Sasa* sp.	Japan
Lasiosphaeria tigrisoides	*Phyllostachys* sp.	Japan
Lasiosphaeria culmorum	*Phyllostachys* sp.	Japan
Leptosphaeria phyllostachydis	*Phyllostachys* sp., *Sasa* sp.	Japan
Leptosphaeria tgrisoides	*Phyllostachys* sp.	Japan
Leptospora rubella (=*Ophiobolus porphyrogonus*)	*Semiarundinaria* sp.	Japan
Mazzantia yukawana	*Sasa hirtella*	Japan
Melasmia phyllostachydis	*Phyllostachys* sp.	Japan
Melanochylamys leucoptera	*Phyllostachys* sp., *sasa* sp.	Japan
Metasphaeria graminum (=*Leptosphaeria graminum*)	*Dendrocalamus* sp.	India
Melanochylamys leucoptera	*Phyllostachys* sp., *Sasa* sp.	Japan
Metasphaeria phyllostachydis	*Phyllostachys* sp.	Japan
Miyakeomyces bambusae (=*Calonectria bambusae*)	*Bamboo* sp.	Japan
Morrisiella indica	*Bambusa* sp.	India
Mycocitrus phyllostachydis (= *Hypocreopsis phyllostachydis* = *Shiraiella phyllostachydis* = *Ustilaginoidea phyllostachydis*)	*Phyllostachys* sp., *Pleioblastus hindsii* *Pleioblastus simonii*	Japan
Mycosphaerella bambusae	*Bambusa* sp.	Japan
Mycosphaerella bambusicola	*Phyllostachys* sp.	Japan
Mycosphaerella bambusina	*Bambusa* sp.	India
Mycosphaerella dianthii (=*Heterosporium echinulatum*)	*Pleioblastus simonii*	
Mycosphaerella shibataeae	*Shibataea* sp., *sasa* sp.	Japan
Mycosphaerella phyllostachydicola (=*Pseudomassaria bambusae*)	*Bamboo* sp.	Japan
Myriangium bambusae	*Phyllostachys* sp.	China
Myriangium haraeanum	*Phyllostachys sp.*, *P. kenois*	Japan, China
Myriangium sp.	*Bambusa multiplex*	China
Nectria phyllostachydis	*Phyllostachys* sp.	Japan

Neopeckia japonica	*Bamboo* sp., *Phyllostachys sp.*	Japan
Neottiospora take	*Sasa* sp., *Pleioblastus* sp.	Japan
Nigrospora oryzae	*Bambusa balcooa, B. nutans*	India
Paraconiothyrium fuckelii	*Ochlandra* sp.	India
(= *Coniothyrium fuckelii*)		
Passalora bambusae	*Arundinaria narihara, B. blumeana*	Japan, India
(=*Helminthosporium bambusae*)		
Periconia cookei	*Bambusa* sp.	India
Periconia digitata	*Bambusa* sp.	India
Periconia kambakkamensis	*Bambusa* sp.	India
Phaeospora bambusae	*Sasa hirtella*	japan
Phaeosphaeria bambusae	*Pseudosasa japonicaPleioblastus hindsii*	Japan
(=*Trematosphaerella bambusae*)	*Pleioblastus simonii*	
Phomatospora paniculata	*Sasa borealis var. tyugokensis*	Japan
Phragmocarpella japonica	*Phyllostachys* sp.	Japan
Phragmothyrium bambusicola	*Bamboo* sp.	Japan
(= *Micropeltis bambusicola*)		
Phragmothyrium semiarundinariae	*Semiarundinaria* sp.	Japan
Phyllachora bambusae	*Bambusa blumeana*	India
(= *Endodothella bambusae*)		
Phyllosticta bambusicola	*Bambusa* sp.	Japan
Phyllosticta bambusoids	*Bambusa* sp.	Japan
Phyllosticta take	*Bambusa* sp.	Japan
Polystigma haraeanum	*Semiarundinaria* sp.	Japan
Pseudocercospora bambusae	*Bambusa* sp.	India
Pseudomassaria inaequalis	*Sasa senanensis*	Japan
Pseurobillarda bambusae	*Bambusa* sp.	India
Purpureocillium lilacinum		
(= *Paecilomyces lilacinus*)	*Dendrocalamus hamiltonii*	India
Puttemansia miyakei	*Sasa tygokensis*	Japan
Pyricularia sp.	*Phyllostachys* sp., *Shibataea* sp.,	Japan
Pyricularia grisea	*Phyllostachys* sp., *Shibataea* sp.,	Japan
	Semiarundinaria sp., *Sasella* sp., *Pleioblastus* sp.	
Pyricularia oryzae	*Semiarundinaria* sp., *Semiarundinaria viridis*	Japan
	Shibataea sp.	
Rabdospora pleioblasti	*Phyllostachys henonis*	Japan
Rosellinia congesta	*Bambusa* sp.	India
Rossoellopsis japonica		
(=*Didymosphaeria japonica*)	*P. bambusoides* var. *marhiana*	Japan
Rosoellopsis macrospora	*Sasa borealis* var. *tyugokensis*	Japan
(= *Didymosphaeria macrospora*)		
Rosoellopsis toaensis	*Sasa vetichii*	Japan
(=*Didymosphaeria toaensis*)		
Shiraia bambusicola	*Bamboo* sp.	Japan
Shiraiella bambusicola	*Bamboo* sp.	Japan
Stigmatodothis sasae(=*Sphaerulina sasae*)	*Sasa* sp.	Japan
Taphrina deformans	*Bambusa vulgaris*	India
Telimena arundinariae	*Sasa hirtella*	Japan
Tomasellia dispersa	*Phyllostachys* sp., *Sasa senanensis*	Japan
Triglyphium bambusae	*Bambusa tulda*	India
Vermicularia straminis	*Bambusa* sp.	Japan
Vialaea bambusae	*Bambusa* sp.	Japan
Zythia stromaticola	*Bambusa* sp.	Japan

Appendix II C

Checklist of Bamboo Diseases and Pathogens in Bamboo Stands Reported from Different Countries in Asia (Infections of Inflorescence)

Disease	Pathogen	Bamboo species affected	Country
Smut	*Bambusiomyces shiraianus* (= *Ustilago shiraiana*)	*Phyllostachys mitis* var. *heterocycla*, *Sasa nana, S. ramosa, Bambusa bambos, Bambusa* sp.	Japan
	Tilletia bambusae	*B. bambos, Bambusa* sp.	India
Ergot	*Claviceps purpurea*	*Phyllostachys* sp.	Japan
	Claviceps sp.	*Bambusa* sp.	India
	Mycocitrus phyllostachydis (=*Hypocreopsis Phyllostachydis*)	*Phyllostachys* sp.	Japan
	Hypocrella semiamplexa	*Bambusa* sp.	India

Appendix IID

Checklist of Bamboo Diseases and Pathogens in Bamboo Stands reported from Different Countries in Asia (Infections of Seeds)

Pathogen	Bamboo species affected	Country
Acremonium sp.	*Dendrocalamus strictus*	India
Alternaria spp.	*Bambusa bambos, D. strictus*	India
Alternaria alternata	*B. bambos, B. tulda, B. nutans, D. strictus*	India, Thailand
Arthrinium sp.	*B. nutans, D. strictus, Gigantochloa hasskarliana, T. siamensis*	India, Thailand
Ascochyta sp.	*B. bambos, B. tulda, D. strictus, T. siamensis*	India, Thailand
Aspergillus spp.	*B. bambos, D. strictus*	India
Aspergillus flavus	*B. bambos, B. nutans, D. strictus, T. siamensis*	India, Thailand
Aspergillus fumigatus	*A. nutans, B. tulda, D. strictus*	India
Aspergillus niger	*Bambusa nutans, D. strictus, T. siamensis*	India, Thailand
Aspergillus wentii	*T. siamensis*	Thailand
Beltrania sp.	*A. bambos*	Thailand
Beltraniopsis sp.	*B.bambos, D. strictus*	India
Bipolaris sp.	*B.bambos, B. tulda, D. strictus*	India
Cephalosporium sp.	*Dendrocalamus strictus*	India
Cercospora sp.	*B.bambos, B. tulda, D. strictus*	India
Chaetomium sp.	*B. bambos, B. nutans, D. strictus, T. siamensis*	India, Thailand
Cladosporium sp.	*B. bambos, B. nutans, G. hasskarliana, D. strictus*	India, Thailand
Cladosporium cladosporioides	*B. bambos, B. tulda, D. strictus*	India
Curvularia sp.	*B. bambos, D. strictus*	India
Curvularia borreriae	*D. strictus*	India, Thailand
Curvularia brachyspora	*D. strictus, T. siamensis*	India, Thailand
Curvularia eragrostidis	*B. nutans,D. strictus*	India, Thailand
Curvularia geniculata	*B. nutans*	Thailand
Curvularia hawaiiensis (= *Drechslera hawaiiensis*)	*B. bambos, D. strictus*	Thailand
Curvularia lunata	*B. bambos, B. nutans, B. tulda,G. hasskarliana, D. strictus, T. siamensis*	India, Thailand

Curvularia oryzae	*D. strictus, T. siamensis*	India, Thailand
Curvularia pallescens	*B.bambos, D. strictus*	India
Curvularia senegalensis	*T. siamensis*	India, Thailand
Curvularia spicifera (= *Drechslera tetramera*)	*B. nutans*	India
Curvularia stapeliae	*B. nutans*	India, Thailand
Dactylaria sp.	*B. bambos, D. strictus*	India
Dinemasporium sp.	*B. bambos*	India
Drechslera sp.	*B. bambos, D. strictus*	India
Epicoccum sp.	*B. bambos, D. strictus*	India
Epicoccum nigrum (=*Epicoccum purpurascens*)	*B. bambos, D. strictus, T. siamensis*	India, Thailand
Exserohilum sp.	*B. bambos*	India
Exserohilum halodes	*B. bambos, D. strictus*	India
Exserohilum rostratum	*B. bambos, B. nutans, T. siamensis, D. strictus*	India, Thailand
Fusarium sp.	*B. bambos, B. nutans*	India, Thailand
Fusarium oxysporum	*B. bambos, D. strictus*	India
Fusarium incarnatum (=F. semitectum)	*B. bambos, B. nutans, D. strictus Gigantochloa hasskarliana, T. siamensis*	India, Thailand
Graphium sp.	*B. bambos, G. hasskarliana*	Thailand
Memnoniella sp.	*B. bambos, D. strictus*	India
Mucor sp.	*B. bambos, D. strictus*	India, Thailand
Myrothecium sp.	*B. bambos, B. nutans, G. hasskarliana, T. siamensis*	India, Thailand
Mycelia sterilia	*D. strictus*	india
Nigrospora sp.	*B. bambos, D. strictus*	India
Nigrospora oryzae	*B. bambos, B. nutans, D. strictus, G. hasskarliana*	India, Thailand
Nodulisporium sp.	*B. nutans*	Thailand
Penicillium spp.	*B. bambos, B. nutans, B. tulda, D. strictus*	India, Thailand
Periconia spp.	*B. bambos, B. nutans, D. strictus, G. hasskarliana*	India, Thailand
Periconia tirupatiensis	*D. strictus*	India, Thailand
Phaeotrichochonis sp.	*B. bambos, B. nutans, D. strictus*	India, Thailand
Phoma sp.	*B. bambos, B. nutans, B. tulda, D. strictus*	India, Thailand
Phomopsis sp.	*B. nutans, B. tulda, D. strictus*	India, Thailand
Pithomyces sp.	*B. bambos, B. nutans, D. strictus, G. hasskarliana, T. siamensis*	India, Thailand
Prathoda longissima (= Alternaria longissima)	*B. bambos, D. strictus*	India, Thailand
Pseudomonas sp.	*B. bambos, B. tulda*	India
Rhizopus sp.	*B. bambos, B. tulda, T. siamensis*	Thailand
Stachybotrys sp.	*B. bambos, T. siamensis*	India, Thailand
Stachybotrys echinatus (=Memnoniella echinata)	*B. bambos, B. nutans, D. strictus, T. siamensis*	India, Thailand
Stachybotrys atra	*B. bambos*	India
Stemphylium sp.	*D. strictus*	India, Thailand
Torula sp.	*B. bambos, B. tulda*	India, Thailand
Trichoconiella padwickii (=*Trichoconis padwickii*)	*B. bambos, B. nutans, B. tulda, D. strictus, G. hasskarliana*	India, Thailand
Trichoderma harzianum	*B. bambos, B. tulda, D. strictus*	India
Xanthomonas sp.	*B. bambos, D. strictus*	India

APPENDIX IIE

Checklist of Bamboo Diseases and Pathogens in Bamboo Stands Reported from Different Countries in Asia (Diseases of Rhizomes and Roots)

Disease	Pathogen	Bamboo species affected	Country
Rhizome bud rot	*Globisporangium proliferum* (= Pythium middletonii)	*Bambusa bambos*	India
Rhizome and root rot	*Amylosporus campbellii*	*B. bambos,* Bamboo sp. *Dendrocalamus strictus*	India
	Serpula similis (=Merulius similis)	*Thyrsostachys oliveri, B. bambos*	India
	Sphaerostile bambusae	*B. bambos*	India
	Serpula eurocephala (= *Merulius eurocephalus*)	*B. bambos, D. strictus*	India
	Polyporus sp.	*Dendrocalamus strictus*	Pakistan
	Poria sp.	*D. strictus*	Pakistan
Decay of rhizome, root and basal culm	*Ganoderma lucidum*	*B. bambos, T. oliveri, Melocanna baccifera*	India
		Bamboo sp.	Philippines
		Bambusa sp.	Pakistan
	Amylosporus campbellii	*B. bambos,* Bamboo sp. *Dendrocalamus strictus*	India
	Coltricia bambusicola (=*Polyporus bambusicola*)	*B. bambos*	India
	Antrodia rhizomorpha (=*Poria rhizomorpha*)	*Melocanna baccifera*	India
	Rigidoporus microporus (=*Fomes lignosus*)	*Dendrocalamus giganteus*	Malaysia
	Rosellinia spp.	*Phyllostachys* spp.	China

* synonyms are given in parenthesis

Appendix IIIA

Checklist of Fungi Causing Decay and Deterioration of Bamboo Culms Reported from Different Countries in Asia (Decay and deterioration of Culms in Stands)

Pathogen	Bamboo species affected	Country
Amauroderma rugosum	*Bambusa bambos, Dendrocalamus strictus*	India
Amylosporus campbellii *(= Polyporus anthelminticus)*	*D. longispathus, D. strictus, B. bambos, Thyrsostachys oliveri*	India
Anthostomella bambusae	*B. bambos*	India
Apiospora indica	*Bambusa* sp.	India
Arthrinium arundinis *(=Coniosporium bambusae)*	*Bambusa* sp., *Ochlandra* sp.	India
Arthrinium phaeospermum	*Bambusa* sp.	India
Astrocystis mirabilis	*Bambusa* sp., *Phyllostachys* sp.	India, Japan
Auricularia auricula-judae	*Bambusa* sp.	India
Belonopsis graminea	*Bambusa* sp.	India

Biscogniauxia capnodes	*Bambusa* sp.	India
(=Hypoxylon nummularium var. merrillii)		
Bondarzewia berkleyii	Bamboo sp.	India
Chaetomium globosum	*Phyllostachys reticula, Bamboo* sp.	China, Japan, India
Clathrus delicatus	*Bambusa* sp.	India
Clypeosphaeria crenulata	*Bambusa* sp.	India
Coriolus fibula(=Polystictus fibula)	*Bambusa bambos*	India
Cyathus limbatus	*Bamboo* sp.	India
Cyathus striatus	*Bamboo* sp.	India
Craterellus cornucopioides	*B. bambos*	India
Daldinia sp.	*Bambusa* sp.	India
Daldinia concentrica	*Bamboo* sp.	Thailand
Dacryopinax spathularia	*Bambusa bambos*	India
Diatrype chlorosarca	*Bamboo* sp.	India
Dictyoarthrinium quadratum	*Bamboo* sp.	India
Didimobotryum atrum	*Bambusa* sp.	India
Didymostilbe kamatii	*Bambusa* sp.	India
Diplodia bambusina	*Bambusa* sp.	India
Earliella scabrosa(=Trametes corrugata)	*Bambusa* sp.	India
Edmundmasonia bulbosa	*Bambusa* sp.	India
Encoelia helvola	*B. bambos, Bambusa* sp.	Indonesia
Flavadon flavus(=Irpex flavus)	*Bambusa* sp.	India
Fomes hypoplastus	*Bambusa bambos*	India
Fomes pectinatus	*Bambusa* sp.	India
Guepinia ramosa	*Bambusa bambos*	Inida
Gymnopilus dilepis(= Flammula dilepis)	*B. bambos*	India
Heteroepichloe bambusae	*Bambusa* sp.	India
(= Epichloe bambusae)		
Hjortstamia percomis(=Stereum percome)	*Bambusa* sp.	India
Hymenoscyphus tetracladius	*Bambusa* sp.	India
(=Articularia tetracladia)		
Hypoxylon bambusae	*B. bambos*	India
Hypoxylon fuscopurpureum	*Bambusa* sp., *Phyllostachys* sp.	India, Japan
Hypoxylon perforatum	*Bambusa* sp.	India
Hypoxylon pithecolobii	*B. bambos*	India
Hypoxylon rubiginosum	*Bambusa* sp.	India
Kretzschmariella culmorum	*D. strictus*	India
(= Hypoxylon culmorum)		
Lasiodiplodia theobromae	*Bambusa* sp.	India
(= Botryodiplodia theobromae)		
Lenzites adusta	*Bambusa* sp.	India
Leptosporomyces adnatus	*Bambusa* sp.	India
(=Corticium adnatum)		
Loweporus lividus(= Fomes lividus)	*Bambusa* sp.	India
Nectria sp.	*Bamboo* sp.	Pakistan
Nigroporus durus(= Fomes durus)	*Bambusa bambos*	India
Niptera bambusae(= Belonopsis bambusae)	*Bambusa sp.*	India
Phaeoisaria clematidia	*Bambusa bambos*	India
Phellinus gilvus(= Polyporus gilvus)	*Bambusa* sp.	India
Polyporus sp.	*Dendrocalamus* sp.	India
Polystictus steinheilianus	*Bambusa bambos*	India
Pycnoporus sanguineus		
(= Polystictus sanguineus)	*Bambusa bambos*	India

Pseudohydnum gelatinosum *(= Tremellodon gelatinosum)*	*Bambusa bambos*	india
Rigidoporus lineatus(= Polyporus zonalis)	*Bambusa* sp.	India
Rigidoporus microcarpus(=Fomes lignosus)	*Dendrocalamus giganteus*	Malaysia
Rosellinia bonarerensis	*Drepanostachyum falcatum*	India
Rosellinia congesta	*Bambusa* sp.	India
Rosellinia spacidea	*Thamnocalamus spathiflorus*	India
Schyzophyllum commune	*B. bambos, Bamboo* sp.	Japan,India
Tetraphragmia nilgirensis *(=Arthrobotryum nilgiriense)*	*Bambusa* sp.	India
Thelephora palmata	*Bamboo* sp.	India
Trabutia sp.	*Bambusa* sp.	India
Trametes apiara(= Hexagonia apiara)	*B. bambos*	India
Trametes cingulata	*Bambusa* sp.	India
Trametes flavida(=Daedalia flavida)	*B. bambos, D. strictus, T. oliveri*	India
Trametes versicolor	*Phyllostachys* sp., *Phyllostachys reticulata*	Japan

Appendix IIIB

Checklist of Fungi Causing Decay and Deterioration of Bamboo Culms Reported from Different Countries in Asia (Decay and deterioration of Culms in Storage)

Pathogen	Bamboo species affected	Country
Alternaria alternata	*Dendrocalamus giganteus, D. membranaceus D. brandisiiB. intermedia,Leptocanna chinensis*	China
Antrodia rhizomorpha (=*Poria rhizomorpha*)	*Bambusa bambos, D. strictus*	India
Arecophila bambusae	*Bamboo* sp.	Hongkong
Arecophila coronata (=*Amphisphaeria coronata*)	*Bamboo* sp.	Hongkong
Arthrinium arundinis (=*Apiospora montagnei*)	Bamboo sp.	India, Pakistan, China
Arthrinium sp.	Bamboo sp.	China
Arthrinium phaeospermum	Bamboo sp.	China
Aspergillus sp.	*B. blumeana, Bambusa* sp.	Philippines, Japan
Atrosphaeriella fuscomaculans	*Phyllostachys nigra* var. *henonis*	Japan
Atrosphaeriella fusispora	*Phyllostachys* sp.	Thailand
Bambusicola bambusae	*Bamboo* sp.	Thailand
Bambusicola irregulispora	*Bamboo* sp.	Thailand
Bambusicola massarinia	*Bamboo* sp.	Thailand
Bambusicola splendida	*Bamboo* sp.	Thailand
Chaetosphaerulina bambusae	*Bamboo* sp.	India
Chaetomium globosum	Bamboo sp.	China, India, Japan
Chaetomium sp.	Bamboo sp.	China
Cochliobolus sp.	*Dendrocalamus hamiltonii*	India
Cyathus limbatus	*B. bambos, D. strictus*	India
Cladosporium sp.	Bamboo sp.	China, Japan
Cyphellophora sessilis (= *Phialophora sessilis*)	Bamboo sp.	China
Daedalea flavida	*Bamboo* sp.	India
Daldinia childiae	Bamboo sp.	Thailand

Daldinia concentricaDaldinia sp.	*D. hamiltonii*	India
Earliella scabrosa (=*Trametes persoonii*)	*Bambusa* sp.	India
Ellisembia leptospora (= *Sporidesmium leptosporum*)	*Bambusa* sp.	India
Favolus sp.	*Bambusa* sp.	Thailand, India
Favolus grammocephalus (= *Polyporus grammocephalus*)	*B. bambos, D. strictus*	India
Favolus tenuiculus (= *Polyporus tenuiculus*)	*B. bambos, D. strictus*	India
Flavodon flavus	*B. bambos, D. strictus*	India
Fibroporia vaillantii (= *Poria vaporaria*)	*P. edulis, P. nigra, D. latifolius*	Japan
Fomes hypoplastus	*Bambusa* sp.	India
Fomitopsis palustris (= *Tyromyces palustris*)	*P. edulis, P. nigra, Chimonobambusa quadrangularis*	Japan
Fomitopsis pinicola	*Bambusa* sp.	Thailand
Fusarium spp.	Bamboo sp.	Japan
Gloeophyllum sepiarium	Bamboo sp.	Thailand
Gloeophyllum striatum (= *Lenzites striata*)	*B.bambos, D. strictusB. blumeana, Schizostachyum lumampao*	India, Philippines
Gloeophyllum subferruginosum	Bamboo sp.	Thailand
Gymnopilus delipes (= *Flammula delepes*)	*Bambusa* sp.	India
Irpex consors	Bamboo spp.	Japan
Irpex lacteus	*Phyllostachys pubescens/heterocycla/edulis, P. lithophila, P. nigra, D. latifolius, Chimonobambusa quadrangularis*	Japan
Lacellina graminicola	Bamboo sp.	India
Lasiodiplodia sp.	*D. hamiltonii*	India
Leiotrametes lactinea (= *Trametes lactinea*)	Bamboo spp.	Thailand
Lentinus sp.	Bamboo spp.	Thailand
Leptosphaeria sp.	*D. hamiltonii*	India
Leptosphaeria lelebe	*Bambusa multiplex*	Japan
Longipedicella aptrootii (=*Didymella aptrootii*)	*Bamboo* sp.	Malaysia, Hongkong, Philippines
Microascus brevicaulis (=*Scopulariopsis brevicaulis*) *B. intermedia, Leptocanna chinensis*	*D. giganteus, D. membranaceus,D. brandisii,*	China
Neokalmusia brevispora (= *Phaeosphaeria brevispora*)	*Sasa* sp.	Japan
Nigrospora sp.	*D. hamiltonii*	India
Nigroporus durus(= *Fomes durus*)	*B. bambos, D. strictus*	India
Oxyporus cervinogilvus (= *Poria diversipora*)	*Bamboo* spp.	India
Perenniporia sp.	*Dendrocalamus hamiltonii*	India
Pestalotiopsis mangifolia (=*Pestalotia mangifolia*)	*D. giganteus, D. membranaceus, D. brandisii, B. intermedia, Leptocanna chinensis*	China
Penicillium sp.	*B. blumeana, B. vulgaris* var. *striata*	Philippines
Phellinus gilvus	*B. bambos, D. strictus*	India
Pleurotus sp.	*B. bambos, D. strictus*	India

Polystictus steinheilianus	Bamboo sp.	India
Poria sp.	*Sasa lumampao*	Philippines
Pseudotetraploa curviappendiculata (=*Tetraploa curviappendiculata*)	*Sasa* sp.,*Sasa kurilensis*	Japan
Pseudotetraploa javanica (= *Tetraploa javanica*)	*Sasa* sp.	Japan
Pseudotetraploa longissima (= *Tetraploa longissima*)	*Pleioblastus chino*	Japan
Pycnoporus sanguineus	*Bamboo* sp.	Thailand
Pyronellaea	*D. hamiltonii*	India
Rigidoporus lineatus (= *Polyporus zonalis*)	Bamboo spp.	India
Roussoella hysterioides	*Bamboo* sp.	Hongkong
Schyzophyllum commune	*Bamboo* spp.	India, Vietnam, Thailand
Scopulariopsis sphaerospora	*Bamboo* sp.	Japan
Sphaerostibe bambusae	Bamboo spp.	India
Sporidesmium nilgirense	Bamboo spp.	India
Stibella fimetaria (= *Stilbum erythrocephalum*)	Bamboo spp.	India
Tetraploa aristata	Bamboo sp.	India
Thelephora palmata	Bamboo sp.	India
Thelephora cingulata	Bamboo spp.	Thailand
Trametes cervino-gilvus	Bamboo sp.	Thailand
Trametes coccinea (= *Pycnoporus coccineus*)	*P. nigra, P. edulis, D. latifolius*	Japan
Trametes elegans(= *Lenzites elegans*)	*B. bambos, D. strictus*	India
Trametes ljubarskyi (= *Haploporus ljubarskyi*)	Bamboo spp.	Thailand
Trametes versicolour (= *Polyporus versicolour*)	*P. edulis, P. nigra, D. latifolius*	Japan
Tremella fuciformis	*Bambusa bambos*	India
Trichoderma sp.	Bamboo spp.	Philippines
Trichoderma sp.	*Dendrocalamus hamiltonii*	India
Tubercularia latertia (= *Stilbum lateritium*)	Bamboo spp.	India
Xylaria spp.	*Phyllostachys* spp., *Phyllostachys reticulata*	Japan, Thailand
	Bambusa sp.	India

INDEX I: Hosts

(Current names of bamboo species are given in italics; synonyms are in normal type)

INDEX II: Pathogen & Disease

(Accepted names of fungi are given in italics; synonyms and disease names are in normal type)