# STUDIES ON DISEASES OF BAMBOOS AND NURSERY MANAGEMENT OF RHIZOCTONIA WEB BLIGHT IN KERALA

**THESIS**

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By

**MOHANAN CHORAN M.Sc.**

Division of Forest Pathology
Kerala Forest Research Institute
Peechi 680 653 Kerala, India

MAY 1994

# DECLARATION

I hereby declare that this thesis entitled **STUDIES ON DISEASES OF BAMBOOS AND NURSERY MANAGEMENT OF RHIZOCTONIA WEB BLIGHT IN KERALA** has not previously formed the basis of the award of any degree, diploma, associateship, fellowship or other similar titles or recognition.

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Peechi 680 653
May 1994

**MOHANAN CHORAN**

**Dr. Jyoti K. Sharma**
Scientist-in-Charge

Division of Forest Pathology
Kerala Forest Research Institute
Peechi 680 653 Kerala, India

# CERTIFICATE

This is to certify that the thesis entitled **STUDIES ON DISEASES OF BAMBOOS AND NURSERY MANAGEMENT OF RHIZOCTONIA WEB BLIGHT IN KERALA** embodies the results of original research work carried out by Mr. Mohanan Choran, under my guidance and supervision. I further certify that no part of this thesis has previously formed the basis of the award of any degree, diploma, associateship, fellowship or other similar titles of this or other University or Society.

Peechi 680 653
May 1994

**JYOTI K. SHARMA**

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# INTRODUCTION

# 1. INTRODUCTION

Bamboos are fast growing versatile plants of multiple end uses. For centuries, bamboos have been closely related to agriculture, cottage industries, arts, culture and day to day life of more than half of the world population. Their plethora of essential uses have led to the use of the terms such as 'poor man's timber', 'green gold', 'the cradle to coffin timber', etc. Until recent past, bamboos were categorized as 'minor forest produce' or treated even as weeds, because the other wood resources in the forest and their supply were plentiful. With the alarming shrinkage of forest resources, as well as restrictions on logging from natural stands the emphasis is being placed on raising fast growing multipurpose trees including bamboos. Recently, bamboos have been classified as 'non-timber woody resources' and they have now gained international recognition and priority in contrast to their previous categorization as 'minor forest produce. This elevated status attained is mainly due to their versatility, adaptability to different eco-climatic conditions and myriads of end uses.

Bamboos belonging to Bambusoideae of Gramineae consist of about 1250 species and 75 genera (Soderstrom and Ellis, 1988). Some are woody giants of 20 to 30 m in height and 15 to 20 cm dia whereas others are small semilignified plants; about 110 species belonging to 25 genera are herbaceous (Hsiung,1983,1991). Bamboos, perennial woody grasses of extremely gregarious habits, have aerial stems called culms and underground stem known as rhizome. Full sized culms are produced after 4 to 12 years depending on the species, and edaphic and microclimatic conditions.

The duration of vegetative growth and the incidence of flowering in bamboos vary among species. Flowering in most bamboos, which is only once in lifetime, is either sporadic or gregarious. Most bamboo species have a more or less sharply defined flowering cycle of roughly 1,3,7,11,15,30,48,60 or 120 years at the end of which all the plants of the same seed origin flower gregariously. Gregarious flowering is followed by the death of clumps. Though, majority of bamboos flower at long intervals of 25 to 60 years, annual flowering takes place in species like *Indocalamus wightianus* (Nees) Nakai (= *Arundinaria wightiana* Nees), *Bambusa atra* Lindl., etc. (Tiwari, 1991) and the plant does not die after flowering. There are species like *Dendrocalamus hamiltonii* Nees, *Gigantochloa* spp., *Oxytenanthera* spp., etc. which flower at irregular intervals.

## GEOGRAPHICAL DISTRIBUTION

It is estimated that about 21 million hectares of the earth is covered by bamboo forests. They are widely distributed through the tropical to temperate zones and from sea level to alpine elevation (3000-4000 m). Bamboos are commonly distributed at low elevations in the tropics and subtropics of Asia, America, Africa and Australia, where they grow either naturally in mixed forests or in plantations; Europe has no indigenous bamboo.

Geographically, bamboo distribution can be divided into three major regions: Asia-Pacific, America and Africa (Fig.1). The Asia-Pacific bamboo region is the largest which possesses more than 800 species and varieties of bamboos belonging to 45 genera and spread out in about 18 million hectares. In India, bamboos have an extremely wide range of distribution and they form a significant component of the deciduous, semievergreen and evergreen forests; they occur in all the

states, except Jammu and Kashmir spreading from tropical to temperate zones (Varmah and Bahadur, 1980).

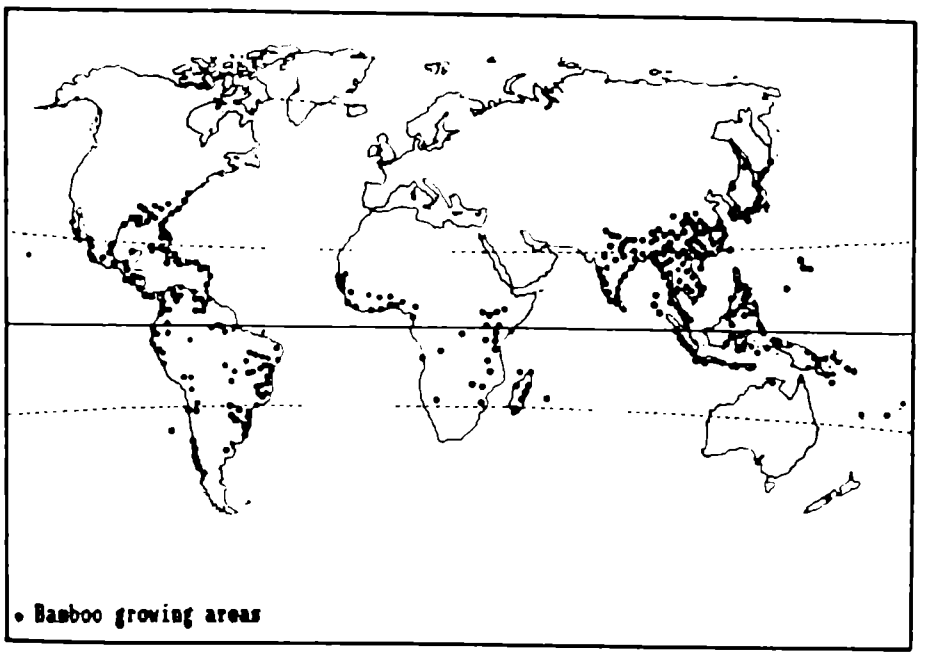



**Fig. 1: Geographical distribution of bamboos in the world**
(Source: Hsiung, 1991)

In India, there are about 128 species of bamboos belonging to 23 genera (Table 1.1) covering an area of 10.03 million hectares, which constitute around 12.8 percent of the total area of forest cover in the country (Tiwari, 1991). More than 50 percent of the recorded bamboos occur in eastern India. Other areas rich in bamboo resources are the Western Ghats, Andaman, Bastar region of Madhya Pradesh and Siwalik hills of Uttar Pradesh. In addition to the natural occurrence of bamboos in forests, they have been planted on a large-scale in many states. *Bambusa bambos* (L.) Voss (=*B. arundinacea* (Retz.) Willd.), *B. nutans* Wall., *B. vulgaris* Schrad, *Dendrocalamus hamiltonii* and *D. strictus* Nees are the common species raised in plantations.

Table 1.1: Bamboo genera and number of species occurring in India

| Sl. No. | Bamboo genus | No.of species | Sl. No. | Bamboo genus | No.of species |
|---|---|---|---|---|---|
| 1. | *Arundinaria* Michaux | 5 | 13. | *Oxytenanthera* Munro | 2 |
| 2. | *Bambusa* Schreber | 26 | 14. | *Phyllostachys* Seib.& Zucc. | 5 |
| 3. | *Chimonobambusa* Makino | 4 | 15. | *Pleioblastus* Nakai | 1 |
| 4. | *Dendrocalamus* Nees | 14 | 16. | *Psuedosasa* Nakai | 1 |
| 5. | *Dinochloa* Buse | 6 | 17. | *Pseudoxytenanthera* Soderstrom et Ellis | 4 |
| 6. | *Drepanostachyum* Keng | 9 | | | |
| 7. | *Gigantochloa* Kurz | 7 | 18. | *Schizostachyum* Nees | 18 |
| 8. | *Himalayacalamus* Keng | 1 | 19. | *Semiarundinaria* Makino | 1 |
| 9. | *Indocalamus* Nakai | 4 | 20. | *Sinarundinaria* Nakai | 1 |
| 10. | *Melocanna* Trin. | 2 | 21. | *Sinobambusa* Makino | 1 |
| 11. | *Neomicrocalamus* Keng | 3 | 22. | *Thamnocalamus* Munro | 2 |
| 12. | *Ochlandra* Thw. | 9 | 23. | *Thyrsostachys* Gamble | 2 |

## DISTRIBUTION OF BAMBOOS IN KERALA

Kerala State, situated between latitudes $8^{o}18'$ and $12^{o}48'$and longitudes $74^{o}52'$ and $77^{o}22'$, has an area of 38,863 $km^2$ which is about1.2 percent of the geographical area of India. Though, Kerala falls within the tropics, it has an equable climate. The annual rainfall varies from 750 mm to 6000 mm, the major portion of which occurs during the south west monsoon i.e., between June and August. The mean monthly temperature ranges from 17.5 to $29^{o}C$ and the mean monthly relative humidity from 75 to 92 percent.

Kerala has a forest cover of 9,400 $km^2$, which is 1.26 percent of the total forest area of India and 24 percent of the land area of the State. Bamboos form a significant component of the natural vegetation and occur in tropical evergreen, semievergreen and moist deciduous

forests, sub-tropical hills, and also as southern moist bamboo brakes. About 17 bamboo species belonging to five genera have been recorded in Kerala (Gamble, 1896; Mukteshkumar, 1990). Of these, *B. bambos, D. strictus, Pseudoxytenanthera bourdillonii* (Gam.) Naithani, *P. ritcheyi* (Munro) Naithani (=*Oxytenanthera monostigma* Bedd.), *Schizostachyum beddomei* (Fisch.) Majumdar (= *Teniostachyum wightii* Bedd.), *Ochlandra travancorica* (Bedd.) Benth. ex Gam., *O. scriptoria* (Dennst.) Fisch., *O. beddomei* Gam., *O. ebracteata* Raizada & Chatterji and *O. wightii* Fisch. are the naturally occurring species. In addition to these a large number of bamboo species have been introduced and cultivated.

Bamboos have also been raised in plantations as pure or mixed with forest species or as underplanting in old teak plantations. So far, an area of 3,400 ha has been brought under bamboo cultivation (Anon.,1990). Apart from this, bamboos are grown traditionally in homesteads and farmlands, accounting for a total of 310 ha in homesteads (Krishnankutty, 1991).

**Commercially exploited bamboos and their habitat**

*B. bambos, D. strictus* and *Ochlandra* species are the commercially exploited bamboos in the State. *B. bambos* prefers rich moist soil and grows on banks of perennial river and streams and moist valleys. It also occurs in extensive gregarious patches or as understorey in mixed forest. *D. strictus* is found naturally in tracts receiving as low as 750 mm of rainfall, mostly in dry tracts of Palakkade, Mannarkkad and Munnar Forest Divisions; sporadic occurrence is also noticed in moist deciduous and dry deciduous forests as pure patches or as understorey in mixed forests. *Ochlandra* species, popularly known as reed bamboos, occur as undergrowth in tropical evergreen, semi-evergreen, tropical moist deciduous forests, and also as pure reed brakes. Reed bamboos

are distributed often in pure patches where the canopy has been opened by shifting cultivation and felling of tree species (Basha, 1992).

As 'poor man's timber' bamboos play an important role in the rural economy of the State. They are used in the traditional cottage industries for making mats and baskets and about 30,000 people are directly or indirectly dependent on this industry for their livelihood (Nair, 1986; Muraleedharan and Rugmini, 1990). Apart from the traditional uses, bamboos form an important raw material for paper pulp and rayon industries in the State.

**Factors affecting the production of bamboos**

The productive potential of bamboo stands in the country is greatly affected by various climatic, biotic and abiotic factors viz., erratic rainfall, fire, grazing, unscientific harvesting, and pests and diseases. Among these fire is the most important one affecting the bamboo production. Crown fire and severe ground fire very often kills the rhizome and clump outrightly. Surface fire causes injuries on the base of the culms and rhizomes and predisposes the infection by decay fungi.

In the establishment stage, wild animals viz., pigs, rats and porcupines cause damage to the rhizomes and bases of the culms; hares and deers browse and trample the young bamboos. In the clump stage, monkeys, languors, wild elephants and bear cause heavy damages to the tender growing culms (Kadambi, 1949).

Bamboo stands are also attacked by various insects belonging to orders Coleoptera, Lepidoptera and Hemiptera. These include defoliators, borers, sap suckers of culms, leaf and developing seed.

Other pests include white ants which attack the rhizome, especially during the dry period (Singh, 1990; Mathew and Varma, 1990).

Bamboos are vulnerable to various diseases which affect them in nurseries, plantations as well as in natural stands. In India, rot and blight of emerging culms have already been identified as the limiting factor of the bamboo production in many bamboo growing areas, especially in the coastal belts of Orissa (Jamaluddin *et al.*, 1992). Similarly, foliage blight and rust have been recorded to pose threat to nursery as well as outplanted seedlings which are in the early establishment phase (Bakshi *et al.*, 1972; Harsh *et al.*, 1989). With the increased emphasis and priority on raising multipurpose tree species, large-scale planting of bamboos has been initiated recently in the State. Limited experience in raising the bamboo seedlings together with the lack of information on bamboo diseases and their control measures often resulted in partial to complete failure of many nurseries. Also, poor handling of bareroot seedlings for outplanting affected seriously the planting programme. This was clearly reflected by the large-scale mortality of outplanted young seedlings reported from many plantations. So far, no systematic attempt has been made to study the diseases affecting bamboos in nurseries, plantations and natural stands in the country. Hence, the present investigation was taken up to conduct a systematic study of the diseases affecting bamboos in Kerala in order to:

i. prepare a checklist of diseases in bamboo nurseries, plantations and natural stands and to identify their causal organisms,
ii. identify economically important diseases which may prove to be a constraint in bamboo production, and
iii. undertake detailed investigations on the management of economically important nursery disease(s).

The results of the disease survey are presented in the first part of the thesis and that of nursery management of web blight in the second part. Results of disease survey are discussed under each disease separately, while in respect of the management of web blight, separate discussions are provided for the laboratory and nursery trials.

# REVIEW OF LITERATURE

# 2. REVIEW OF LITERATURE

Bamboos, like many other forestry species, suffer from numerous diseases and disorders which affect the overall productivity of plantations and natural stands. A large number of diseases of bamboos have been reported from different countries, especially from those belonging to the three main bamboo growing regions. Diseases have been reported on seedlings in forest nurseries, clumps of various ages in plantations and in natural stands. Decay and rot of bamboos in stands, storage, and in service have also been recorded. However, the available information on bamboo diseases is widely scattered and it is not possible to make any assessment of their impact on bamboo cultivation.

Through an extensive literature search as far as all the information on diseases, decay and other disorders of bamboos from various bamboo growing countries has been gathered. In bamboos, both the above and underground parts are reported to be vulnerable to diseases at different phases of their growth. Since, the fungal genera and species associated with various diseases were subjected to frequent taxonomic revision, often new generic and specific names are found in the literature. However, the fungal names appeared in the original reports have been retained and used for the literature review. As far as possible author citation for fungal species as well as bamboo species have been provided. Details of various diseases recorded so far on bamboos are provided below.

To elucidate the present status of diseases and pathogens recorded on bamboos in Kerala State and India, the available information is

presented in Tables 2.1 and 2.2. This is followed by an overview of the diseases affecting bamboos recorded from various countries which provides details on pathogen, disease symptoms and incidence, control measures, and bamboo species affected, wherever available. The diseases are listed on the basis of the plant parts affected.

In Kerala, so far, a total of seven diseases affecting bamboos have been recorded. Fourteen fungi belonging to 11 genera have been found associated with these diseases (Table 2.1). Of these, 12 fungi were recorded only very recently (Balakrishnan *et al.*, 1990). There are no records on diseases affecting the bamboo seedlings in nurseries and culms in plantations.

**Table 2.1: Diseases of bamboos and their casual organisms recorded in Kerala**

| Disease | Fungal organism(s) associated | Bamboo species |
|---|---|---|
| Leaf and twig blight | *Ascochyta phaseolarum* Sacc. | *Bambusa bambos* |
| | *Fusarium equiseti* (Corda) Sacc. | *Ochlandra travancorica* |
| | *F.semitectum* Berk. & Rav. | *B. bambos* |
| Leaf spot | *Coniothyrium fuckelii* Sacc. | *O. travancorica* |
| | *Curvularia andropogonis* (Zim.)Boed. | *O. scriptoria* |
| | *C. lunata*(Wakker) Boed. | *Bambusa* sp. |
| | *Phyllachora malabarensis* Syd.& Butl. | *Bambusa* sp. |
| | *Taphrina deformans* Berk. & Rav. | *B. vulgaris* |
| Twig infection | *Apiospora indica* Theiss. & Syd. | *Bambusa* sp. |
| Culm infection | *Geotrichum* sp. | *B.bambos, B.vulgaris* |
| | *Fusarium* sp. | *Bambusa* sp. |
| Thread blight | *Pellicularia salmonicolor* (Berk. &. Br.) Dastur. | *O. travancorica* *O. scriptoria* |
| Shrinking and withering of culm | *Ganoderma* sp. | *Bambusa* sp. |
| Sooty mould | *Capnodium* sp. | *B. vulgaris* |

**Table 2.2: Diseases and their pathogens recorded on bamboos in India**

| Disease | Fungal organism (s) associated | Bamboo species | Reference(s) |
|---|---|---|---|
| Leaf blight | *Ascochyta phaseolarum* | BB | Balakrishnan *et al.*, 1990 |
| | *Drechslera rostrata* (Drech.)Rich. & Fraser | BB | Harsh *et al.*, 1989 |
| | *Exserohilum halodes* (Drech.)Leonard & Suggs | Bs | Bhat *et al.*, 1989 |
| Leaf spot | *Ascochyta bambusina* Rao | BN | Rao, 1962 |
| | *Annellophragmia coonoorensis*(Subr.) Subr. | BN | Sharma, 1971 |
| | *Balladyna butleri* Syd. | Bs | Sydow & Butler, 1911 |
| | *Cerodothis aurea* Muthappa | BB | Muthappa, 1969 |
| | *Coniothyrium fuckelii* | OT | Balakrishnan *et al.*, 1990 |
| | *Curvularia andropogonis* | OS | Balakrishnan *et al.*, 1990 |
| | *Curvularia lunata* | Bs | Balakrishnan *et al.*, 1990 |
| | *Diplozythiella bambusina* Died. | Bs | Sydow & Butler, 1916 |
| | *Endodothella bambusae* (Raben.)Theiss.& Syd. | Bs | Theissen & Sydow, 1915 |
| | *Fusarium equiseti* | OT | Balakrishnan *et al.*, 1990 |
| | *F. pallidoroseum* | MR,TD | Deka *et al.*, 1990 |
| | *F. semitectum* | Bs | Balakrishnan *et al.*, 1990 |
| | *Helminthosporium bambusae* Cooke | Bs | Cooke, 1892 |
| | *Hendersonula toruloidea* Nattrass. | BN | Rangaswami *et al.*, 1970 |
| | *Leptosphaeria graminium* Sacc. | Ds | Panwar & Gehlot, 1973 |
| | *Mycosphaerella bambusina*Syd. & Butler | Bs | Sydow. & Butler, 1911 |
| | *Periconia cookei* Mason & Ellis | Bs | Subramanian, 1954 |
| | *Petrakomyces indicus* Subr. & Ramkr. | Bs | Butler & Bisby, 1960 |
| | *Phyllachora bambusae* Syd. | Bs | Sydow & Butler, 1911; Theissen & Sydow, 1915; Parndekar, 1964 |
| | *Phyllachora dendrocalami* Awati & Kulk. | DS | Awati & Kulkarni, 1972 |
| | *Phyllachora graminis* (Pers.) Fuck. | As | Ananthanarayanan, 1964 |
| | *Phyllachora malabarensis* Syd. & Butler | Bs | Sydow & Butler, 1911 |
| | *Phyllachora shiraiana* Syd. | As<br>Bs | Sydow & Butler, 1911,<br>Uppal *et al.*, 1955 |
| | *Pseudorobillardia bambusae* Nagraj *et al.* | Bs | Butler & Bisby, 1960 |
| | *Rosellina congesta* Nine & Katumoto | Bs | Kar & Maity, 1971 |
| | *Taphrina deformans* | Bs | Balakrishnan, *et al.*, 1990 |
| | *Triglyphium bambusae* Roy | BT | Roy, 1966 |
| Leaf rust | *Dasturella bambusina* Mund. | Bs | Mandkur & Kheswala, 1943; Patel *et al.*, 1949; Nema & Mishra, 1965 |

Contd.

Table 2.2: contd.

| | | | |
|---|---|---|---|
| | *Dasturella divina* Mund. & Rhesw. | Ds | Mundkur & Rheswala, 1943; Thirumalachar *et al.*,1947; Cummins, 1971 |
| | *Dasturella* sp. | Bs | Rangaswami *et al.*, 1970 |
| | *Puccinia gracilenta* Syd.& Butler | Bs | Sydow & Butler, 1916 |
| | *Puccinia melanocephala* Syd. | As | Sydow & Butler, 1907, |
| | | ASE | Patel *et al.*, 1949, |
| | | Bs | Chowdury, 1948 |
| | *Puccinia xanthosperma* Syd. | Bs | Sydow & Butler, 1906 |
| Leaf and culm rust | *Tunicospora bagchii* Singh & Pandey | Ds | Sujan Singh & Pandey, 1971 |
| Bamboo blight | *Sarocladium oryzae* (Sawada) Gam. & Hawks | BN | Jamaluddin *et al.*, 1992 |
| Culm blight | *Geotrichum* sp. | BB,BV | Balakrishnan *et al.*, 1990 |
| Thread blight | *Corticium koleroga* (Cooke) Hohnel. | Bs | Rogers, 1943; |
| | *Pellicularia salmonicolor* | Os | Balakrishnan *et al.*, 1990 |
| Twig infection | *Apiospara indica* Theiss. | Bs | Butler & Bisby, 1931 |
| | *Coniosporium bambusae* (Thuem & Bolle) Sacc. | Bs | Sydow, 1932 |
| | *Craterellus cornucopioides* (L.) Fr. | BB | Banerjee, 1947 |
| | *Dacryopinax spathularia* (Schw.) Martin | BB | Banerjee, 1947 |
| | *Diplodia bambusina* Died. | Bs | Sydow & Butler, 1916 |
| | *Papularia sphaereosperma* (Pers.) Hohnel | Bs | Mason, 1933 |
| | | Bs | Sprague, 1950 |
| | *Penicillopsis bambusae* Nagraj & Govindu | Bs | Nagraj & Govindu, 1967 |
| | *Valsaria bambusae* Kapoor & Gill | Bs | Kapoor & Gill, 1961 |
| Smut on stem | *Ustilago shiraiana* P. Henn | Bs | Mundkur&Thirumalachar,1952 |
| Smut on spike | *Hypocrella seminamplexa* (Berk.) Sacc. | Bs | Berkeley, 1856 |
| | *Tilletia bambusae* Pavgi & Thirum. | Bs | Thirumalachar & Pavgi, 1968 |
| Ergot | *Claviceps* sp. | Bs | Ramakrishnan&Ramakrishnan,1949 |
| Root & stem rot | *Sphaerostilbe bambusae* Pat. | BB,Bs | Mathur, 1936 |
| | *S. hypococoides* Kalchlbr. & Cke. | Bs | Padhi, 1954 |
| Rhizome & root rot | *Amylosporus campbelli* (Berk.) Ryv. | DS | Tahir *et al.*, 1992 |
| | *Ganoderma lucidum* (Leyss.) Karst. | BB,Bs | Banerjee & Ghosh, 1942 |
| | *Merulius similis* Berk. & Br. | BB,BF,TO | Mitter & Tanden, 1932 |
| Witches'broom | Unknown etiology | DS | Bakshi et al.,1972 |

As *Arundinaria* sp., ASE *Arundinaria suberecta*, BB *B. bambos*, BF *B. flabellifer*, BN *B.nana*, BNT *B. nutans*, BV *B.vulgaris*, BT *B. tulda*, Bs *Bambusa* species, DS:*D. strictus*, MH: *Melocanna humilis*, OS *Ochlandra scriptoria*, OT *O. travancorica*,TD: *Teniostachyum dullooa*, TO: *Thyrsostachys oliveri*

Though, there are numerous records of diseases on bamboos from India, the details pertaining to their etiology, symptomatology and severity are meagre. Table 2.2 shows that 58 fungi belonging to 45 genera are associated with 14 diseases of different bamboos. Even though, the country is endowed with a large number of bamboo species distributed in different eco-climatic zones, the records of diseases are mainly on a few bamboo species. Most of these disease records are 50 to 90 years old.

## DISEASES OF RHIZOME AND ROOT

The bamboo rhizome is an underground portion of the stem, closely resembling to the culm and its branches in basic structure, which form the above ground portion of the stem. True roots develop from the closely spaced nodes of the underground rhizomes, 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 some other adverse factor may check the growth and prevent the production of the culm. Each bud has as many as 35 or more telescoped internodes with an equal or larger complement of scales. The buds on rhizomes start growing just before the monsoon, so that they appear above ground with the onset of or during the monsoon.

*Merulius similis* Berk. & Br. has been reported as one of the most potential rhizome and root rot pathogens of bamboos causing considerable damage to the clumps. It has been recorded on *B. bambos* and *B. flabellifer* from West Bengal (Bose, 1919; Banerjee, 1947). Mitter and Tandon (1932) have also reported this fungus as the causal organism of rhizome decay of *Thyrsostachys oliveri* Gamble in Uttar Pradesh. Sporocarps of the fungus develop on the exposed parts of the affected rhizome and also on the humus around the infected clumps.

*Amylosporus campbelli* (Berk.) Ryv. causing root and rhizome rot of *D. strictus* has been recently recorded from Madhya Pradesh (Jabalpur) (Tahir *et al.*, 1992).

Decay of roots, rhizome and basal stem of *B. bambos* and other bamboo species in Uttar Pradesh, West Bengal and Assam has been recorded to be caused by *Fomes lividus* (Kalchbr.) Sacc., *Serpula similis* (Berk. & Br.) Ginns., *Polyporus anthelminticus* Berk. & Br., *P. zonalis* Berk. and *P. bambusicola* P. Henn. (Mitter and Tandon, 1932; Banerjee, 1947; Anon., 1950; Bagchee, 1954; Bakshi *et al.*, 1963; Bakshi, 1971).

Root rot of *Melocanna baccifera* (Roxb.) Kurz and *M. bambusoides* caused by *Poria rhizomorpha* Bagchee has been reported from northern Bengal and Assam (Bagchee, 1954; Spaulding 1961). The fungus occurs as saprophyte in the soil forming abundant rhizomorphic strands on decaying roots and it becomes parasitic on poor and badly drained soils causing brown cuboidal rot (Bakshi, 1971). From Malaysia, white root rot of *Dendrocalamus giganteus* Munro caused by *Fomes lignosus* (Klotzch) Bres. has been recorded ( Hilton, 1961). *Ganoderma lucidum* (Leyss.) Karst., a serious root rot pathogen of world wide distribution, has been recorded on *B. bambos* and *Bambusa* sp. causing root rot in Uttar Pradesh and West Bengal (Banerjee and Ghosh, 1942). *Ganoderma* root rot of bamboos has also been recorded from the Philippines and Pakistan (Bakshi, 1957; Spaulding, 1961). The sporophores of the fungus develop on the affected bamboo culms at the ground level and on the exposed rhizomes. In India, the fungus is widespread in occurrence and attacks a large number of broad leaved, sub-temperate tree species. It is normally endemic in natural forests, and does not cause serious damage. However, when the forests are clear felled, *G. lucidum* quickly spreads to residual roots and stumps to build up high inoculum potential. Raising new plantations in such

sites without clearing the infected residual stumps and roots causes severe damage to the susceptible species. The lateral spread of the disease takes place through root contact. Besides these, a large number of fungi have been recorded on bamboos causing decay and rot in different parts of the country. However, many of these early records are probably on fallen culms, twigs and branches of unidentified bamboo species (Patil *et al.*, 1980; Shukla *et al.*, 1988).

## DISEASES OF CULMS AND FOLIAGE

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 the last of all. The newly emerged tender culms (20-30 cm high) are completely covered by imbricate sheaths with no internodes seen outside. The new culms grow rapidly and reach their full height of 8 to 25 m within 60-90 days depending on the species, clump vigour, edaphic and microclimatic conditions. These newly emerging culms of bamboos are generally susceptible to diseases.

### BAMBOO BLIGHT

Bamboo blight is an important disease which affects the village groves of four species of bamboos viz., *Bambusa bambos, B. balcooa* Roxb., *B. tulda* Roxb. and *B. vulgaris* throughout Bangladesh (Gibson, 1975; Rahman, 1978; Boa, 1987a,b). The disease was first recorded in 1970 by Rahman and Zethner (1971) as a potentially serious problem of village bamboos in Bangladesh. 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. Bamboo blight occurs mostly in well established older clumps, aged more than 8 to 10 years. Culms which survive the first growing season remain healthy and the spread of the disease between clumps of bamboos is slow. The initial symptoms of blight are premature death of culm sheath and partial collapse of the fragile apical region. Later, wet rotten patches develop on the internodes often associated with insect damage. These necrotic patches spread rapidly in the cheesy and juicy (*sic*) 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. Mining insects are suspected to help in spreading the disease. The spread of infection from one area to another is rather slow. Even though, the disease has been studied in detail symptomatically, its etiology is still poorly understood. Various fungal organisms viz., *Acremonium strictum* W. Gam., *Coniothyrium fuckelii* Sacc., *Sarocladium oryzae* (Sawada) W. Gams & D. Hawks, *Fusarium* spp., *Pteroconium* sp., *Arthrinium* sp., etc. have been found to be associated with the blighted culms (Rahman, 1978; Rahman and Khisha, 1981; Boa and Rahman, 1983,1987; Boa, 1987a,b). However, pathogenic connection between a fungus or a group of fungi and the blight disease has not been adequately demonstrated (Boa, 1987a,b). Recently, *Sarocladium oryzae*, the rice sheath blight pathogen has been reported as the principal fungus associated with the bamboo blight in Bangladesh (Boa and Brady, 1987).

In India, bamboo blight caused by *S. oryzae* has been recorded on *Bambusa nutans* Wall. ex Munro in coastal belts of Orissa (Gupta *et al.*, 1990; Jamaluddin *et al.*, 1992). The development of the disease was found to be related to the climatic conditions of the area. High humidity and temperature favour the infection. Boa and Rahman (1987b) considered poor stand management, climatic and soil factors, and insect and fungus attack responsible for the development of the

disease. Boa and Rahman (1987b) and Boa and Brady (1987) worked out an integrated control measure of the disease which included removal of blighted culms, burning of debris of clumps in April before the onset of rain and application of fungicides (Dithane M-45 and Copper oxychloride) as soil drench. Jamaluddin *et al.*, (1992) have also suggested cultural measures and fungicidal application for controlling the bamboo blight in Orissa. These include application of Bavistin (0.16%) and Dithane M-45 (0.3%) in combination or Fytolan (0.3%) and also light burning of the debris in March for minimizing the inoculum.

In Jiangsu, Anhui, Fujian, Zhejiang and Shanghai provinces of China, bamboo shoot blight caused by *Ceratosphaeria phyllostachydis* Zhang has been recorded (Zhang, 1982; Lin, 1988). The fungus attacks newly emerged shoots of *Phyllostachys edulis* Makino and *P. pubescens* Mazel ex. H. Lahaie and causes withering of twigs, branches and whole shoot. Severe infection has been recorded to cause heavy losses of bamboos in Guangfang county of China Poor resistance of the bamboo species and prevalence of favourable climatic conditions were the factors identified for the fast spread and severity of the disease (Xu *et al.*, 1989). Since 1983, control measures have been adopted to check this disease. Suggested control measures include thorough cleaning of diseased branches and culms in the groves and also spraying of fungicides viz., carbendazim, thiophanate methyl or Bordeaux mixture (1:100) once in ten days for two to three times successively (Lin, 1988; Xu *et al.*, 1989).

## BAMBOO WILT

Recently, a wilt disease of *Dendrocalamus latiflorus* Munro caused by *Fusarium semitectum* Berk. & Rav. has been recorded in Nanping and Fujian provinces of China (Xie *et al.*, 1987). The cold injury has been

reported as the important predisposing factor to induce the infection. Selection of plantation site and cold resistant bamboo species had satisfactory effects in controlling the wilt disease. In U.S.S.R., *Phyllostachys* spp. are reported to be affected with shoot wilt caused by *Coniosporium bambusae* (Thuem. & Bolle.) Sacc. (Beradze, 1972, 1973). A bacterial wilt of Taiwan giant bamboo, *Sinocalamus latiflorus* (Munro) McClure caused by *Erwinia sinocalami* Lo, Ghon & Huang has been reported from Taiwan (Lo, *et al.*, 1966; Hsieh, 1984).

**CULM ROT**

A disease which affects the young emerging culms called 'dried out culm buds' has been reported from Bangladesh (Banik, 1984; Boa and Rahman, 1987); due to infection the newly emerged shoots fail to develop into culms. No pathogen could be isolated from the affected culm buds. A similar basal culm rot caused by *Fusarium solani* (Mart.) Sacc. has been reported from China on *Phyllostachys viridis* (Young) McClure and by *F. moniliforme* Sheld. on *P. pubescens* (Chen, 1982).

In Indonesia, a culm rot of *Bambusa* sp., *B. bambos, Gigantochloa apus* Schult. f. Kunz. caused by *Encoelia helvola* (Fr.:Fr.) Karst. was recorded as early as in 1926 by Overeem. In U.S.A., culm rot of *Bambusa vulgaris* caused by *Sclerotium rolfsii* Sacc. was recorded. (Anon., 1960; Lan, 1980). A culm rot of *Bambusa* sp. caused by *Clavaria* sp. has been recorded from Thailand (Giatgong, 1980).

**LEAF AND CULM RUST**

More than 22 rust fungi have been recorded on leaves and culms of various bamboo species from different countries (Table 2.3).

Table 2.3: Bambusicolous rust fungi recorded from different countries

| Rust fungus | Bamboo species affected | Country reported |
|---|---|---|
| *Dasturella divina* | *B. bambos, B. vulgaris,* | |
| | *D.hamiltonii,D.longispathis,* | India |
| | *D. strictus, Oxytenanthera* sp., | Japan |
| | *T.oliveri, B. multiplex, B.oldhami,* | |
| | *B. shimadai, D.latiflorus* | Australia |
| *D. bambusina* | *Bambusa* sp. | India |
| *Puccinia arundinariae* | *Arundinaria tecta* | U.S.A. |
| *P. bambusarum* | *Arundinaria* sp. | Peru |
| *P. gracilenta* | *Bambusa* sp. | India |
| *P. hikawaensis* | *Sasa kesuzu* | Japan |
| *P. kusunoii* | *Nipponobambusa* sp., *Phyllostachys* sp., | Japan |
| | *Pseudosasa* sp., *Sasa* sp., *Sasaella* sp. | China |
| | *Semiarundinaria* sp., *Sinobambusa* sp. | Taiwan |
| *P. kwanhsienensis* | *Bambusa* sp. | China |
| *P. longicornis* | *Nipponobambusa* sp., *Pseudosasa* sp., | China |
| | *Sasa* sp., *Sasaella* sp. | Japan |
| *P. melanocephala* | *Arundinaria* sp. | India, China |
| *P. nigroconoidea* | *Phyllostachys* sp. | China |
| *P. phyllostachydis* | *Phyllostachys* sp. | U.S.A., Hawai,Japan,China |
| *P. sasicola* | *Sasa borealis* | Japan |
| *P. tenella* | *Bambusa* sp. | Hongkong, China |
| *P. xanthosperma* | *Bambusa* sp. | India |
| *Uredo bambusae-nane* | *Bambusa nana* | India, Singapore |
| *U. dendrocalami* | *D. strictus* | Sri Lanka |
| *U. ditissima* | *D. latiflorus, Schizostachyum* | Philippines |
| | *lumampao* | Taiwan |
| *U. ignava* | *Bambusa* sp., *Dendrocalamus* sp., | Central & South America, |
| | *Schizostachyum* sp. | West Indies, Africa,China |
| *U. ochlandrae* | *Ochlandra stridula* | Sri Lanka |
| *Stereostratum* | *Bambusa* sp., *Chimonobambusa*sp. | China, Japan |
| *corticioides* | *Phyllostachys* sp., *Sasa* sp., | Pakistan |
| | *Semiarundinaria* sp. | |
| *Tunicospora bagchi* | *D. strictus* | India |

*Dasturella divina* (Syd.) Mund. & Khes. which is widespread in India, affects many bamboo species, viz.,*B.bambos, B.vulgaris, D.*

*hamiltonii* Nees *D. longispathus* Kurz, *D. strictus, Oxytenanthera* sp., *T. oliveri* ( Mundkur and Kheswala, 1943; Thirumalachar *et al.*, 1947; Sujan Singh and Bakshi, 1964; Sathe, 1965; Bakshi and Singh, 1967). *Dasturella divina* is a heteroecious rust having alternate hosts, *Randia candolleana* W & A. and *Xeromphis spinosa* (Thumb.) Keay on which it produces pycnia and aecia; on bamboos uredinial and telial stages occur. This rust has also been recorded from Australia, Japan and Taiwan (Itoi *et al.*, 1978; Hsieh, 1984, 1987). *Dasturella bambusina* Mundk. & Khesh., a closely related species to *D. divina* has been recorded on *Bambusa* sp. in Maharashtra (Mahabaleswar) and Madhya Pradesh (Jabalpur) (Mundkur and Kheswala, 1943; Ramakrishnan, 1951; Patel *et al.*, 1951; Nema and Mishra, 1965; Rangaswami *et al.*, 1970).

About 13 species of *Puccinia* have been recorded on different bamboos. Various records of rust on bamboos are as follows: *Puccinia arundinariae* Schw. on *Arundinaria tecta* (Walt) Muhl. from U.S.A.; *P. bambusarum* Arth. on *Arundinaria* sp. from Peru; *P. hikawaensis* Hirat. f. & S. Uchida on *Sasa kesuzu* Munro & Okam from Japan; *P. kusonoii* Diet. on *Nipponobambusa* sp., *Phyllostachys* sp., *Pseudosasa* sp., *Sasa* sp., *Sasella* sp., *Semiarundinaria* sp., and *Sinobambusa* sp. from China, Japan and Taiwan (Cummins, 1971); *P. kwanhsienensis* Tai on *Bambusa* sp. from China (Cummins, 1971), *P. longicornis* Pat. & Hariot on *Nipponobambusa* sp., *Pseudosasa* sp., *Sasa* sp., and *Sasella* sp. from China and Japan; *P. melanocephala* H. Syd. & P. Syd. on *Arundinaria* sp. from China and U.S.A.; *P. nigroconoidea* Hino & Cumm. on *Phyllostachys* sp., from China; *P. phyllostachydis* S. Kusano on *Phyllostachys* sp. from U.S.A., Hawai, Japan and China; *P. sasicola* Hara ex Hino & Katumoto on *Sasa borealis* Makino, *S. kesuzu* Muroi & Okam. from Japan; *P. tenella* Hino & Katumoto on *Bambusa* sp. from Hongkong and China (Anon., 1960; Spaulding, 1961; Cummins, 1971; Reid, 1978; 1984; Kobayashi and Guzman, 1988).

In India, three species of *Puccinia* have been recorded on bamboos from different states. *P. gracilenta* Syd. & Butler was reported from West Bengal (Darjeeling) producing dirty brown sori on leaves of *Bambusa* sp. *P. melanocephala* was recorded from Assam and Maharashtra. The rust produces dark brown streaks on leaves of *Arundinaria suberecta* Nees, *Arundinaria* sp. and *Bambusa* sp. Another rust, *P. xanthosperma* Syd., producing yellowish brown to dark brown sori on leaves of *Bambusa* spp. has been recorded from Uttar Pradesh (Mussoorie) (Sydow and Butler, 1907; Butler and Bisby, 1960; Bakshi and Singh, 1967).

Five species of *Uredo* viz., *Uredo bambusae-nanae* Yen, *U. dendrocalami* Petch, *U. ditissima* Cumm. (=*Puccinia ditissima* H. Syd.), *U. ignava* Arth. and *U. ochlandrae* Petch have been recorded on different species of bamboos. *U. bambusae-nane* was recorded on *Bambusa nana* Roxb. from Singapore; *U. dendrocalami* and *U. ochlandrae* on *D. strictus* in Sri Lanka and China (Spaulding, 1961); *U. ditissima* on *D. latiflorus, Schizostachyum lumampao* (Bloe.) Merr. in the Philippines and Taiwan; *U. ignava* on *Bambusa* sp., *Dendrocalamus* spp., *Schizostachyum* sp. in West Indies, Central and South America, Africa, Malaysia and China (Cummins, 1971; Spaulding, 1961).

*Stereostratum corticioides* (Berk. & Br.) Magn., an important rust pathogen affecting the culms of bamboos, has been recorded from China, Japan and Pakistan (Spaulding, 1961; Zhu *et al.*, 1983). The rust affects species of *Bambusa, Chimonobambusa, Phyllostachys, Pseudosasa, Sasa* and *Semiarundinaria*. In China, the rust poses major problem in plantations of *Phyllostachys glauca* McClure and *P. propingua* McClure. The incidence of the diseases has affected bamboo production, including edible bamboo shoots and the development of bamboo industry (Zhu, 1988c). Alternate host of the rust is not known and the source of fresh infection is wind dispersed urediniospores which infect the

culm. Since 1978, the rust has spread rapidly in Jiangsu, Nanjing, Weiqiao, Zhejiang and Anhui Provinces of China. The incidence of rust infection recorded ranges from 30 to 90 percent (Zhu and Zhang, 1987). Control measures, including fungicidal application, against the culm rust have been developed in China. Chemical treatment was found effective in controlling the rust infection if the fungicides was applied in March before the development of urediniospores. Coating the diseased portion with 1:1 coal tar and diesel oil mixture was also found promising in controlling the rust (Zhu and Zhang, 1988). Further it was suggested that felling and removing the seriously damaged culms and chemical treatment in the groves for 3 to 4 years successively was necessary to minimize the disease incidence (Zhu and Zhang, 1987, 1988; Zhu, 1988b,c; Chen *et al.*, 1989).

*Tunicospora bagchi* Singh & Pandey causing twig blight of *D. strictus* is recorded from Uttar Pradesh (Dehra Dun) (Sujan Singh and Pandey, 1971; Bakshi *et al.*, 1972). The rust attacks the leaf sheath resulting in death of leaves and twigs above the region of infection. The rust sori were observed throughout the year on the host (Bakshi, 1976). Orange-yellow uredinia appear in September. Telia also develop along with uredinia and continue their growth upto August next year and form continuous and concentric rings all along the leaf sheaths.

**THREAD BLIGHT**

*Corticium koleroga* (Cooke) Hohnel. (=*Pellicularia koleroga* Cooke), causing thread blight of leaves and lesions on culms of *Dendrocalamus* sp. and *Bambusa* sp., has been recorded from Karnataka and Kerala (Rogers, 1943). The fungus forms mycelial strands which creep over the surface of stem and leaves. The infection is usually severe in humid areas. A similar infection of *Ochlandra* species caused by

*Pellicularia salmonicolor* (Berk. & Br.) Dastur. has been recorded recently from Kerala by Balakrishnan *et al.*(1990).

## FOLIAGE BLIGHT

Recently, a serious foliage blight of bamboos in nurseries and plantations, caused by *Drechslera rostrata* (Drech.) Richardson & Fraser has been recorded in Madhya Pradesh (Jabalpur) (Harsh *et al.*, 1989). The disease appears by the end of rainy season in September and persists till leaf fall. In nurseries, high incidence and intensity of the disease affect the seedling growth seriously. High humidity, shade and low temperatures (20-27$^{o}$C) favour the disease development and spread. In young plantations the disease incidence was high but restricted to the lower leaves. Application of fungicides such as Difolatan (0.2%), Fytolan (0.4%) are suggested for controlling the disease (Harsh *et al.*, 1989). A similar foliage blight caused by *Exserohilum halodes* (Drech.) Leonard & Suggs on *Bambusa* sp. has been reported from Karnataka (Dharward) (Bhat *et al.*, 1989). Foliage blight of *Phyllostachys* sp. caused by *Fusarium* sp., with more than 30 percent incidence has been reported in Fujian Province of China (Kuai, 1987). The infection begins to appear in March and continues till July. Initially, withering of leaf tips and margins occurs, followed by defoliation.

## LEAF SPOT DISEASES

There are several records of the occurrence of leaf spot diseases on bamboos. A large number of them are mere records and detailed investigations have been carried out only on a few of the diseases. In India, a number of *Phyllachora* spp. have been recorded on bamboos in

forest nurseries, plantations and natural stands. Abundant characteristic black spots develop on necrotic tissues on the upper surface of the leaf and rarely on the lower surface. The following species of *Phyllachora* are associated with leaf spots of bamboos in different localities. *Phyllachora bambusae* Syd. & Butler was recorded on *B. bambos* from Maharashtra (Bombay, Mahabaleswar and Ganapati Pula) (Parndekar, 1964), Awati and Kulkarni, 1972), from Kerala (Kannoth) (Sydow and Butler, 1911); *P. dendrocalami* Awati & Kulk. on *D. strictus* from Maharashtra (Mahabaleswar and Ganapati Pula) (Awati and Kulkarni, 1972); *P. graminis* (Pers.) Fuck. on *Arundinaria* sp. from Maharashtra (Pune) (Ananthanarayanan, 1964); *P. malabarensis* Syd. & Butler on *Bambusa* sp. from Kerala (Wynad) (Butler and Bisby, 1960); *Phyllachora* sp. on *Bambusa* sp. from Kerala, and on *B. bambos* from Tamil Nadu (Butler and Bisby, 1960; Rangaswami *et al.*, 1970); *P.shiraiana* Syd. on *Arundinaria* sp. from Assam (Wahjain) and on *Bambusa* sp. from Maharashtra (Bombay) (Uppal *et al.*, 1955). *Phyllachora* spp. causing tar spot disease has also been recorded from other countries. *Phyllachora arundinaria* and *P. chusqueae* have been recorded on *Arundinaria tecta* and other bamboo species in U.S.A. (Anon., 1960). Leaf spots of *Bambusa ligulata, B. vulgaris* var. *striata* (Lodd.) Gamble, *Dendrocalamus asper* Backer, *D. giganteus* Munro, *D. pendulus, Gigantochloa cingulata, G. latifolia, G. levis* (Blanco) Merr., *G.rostrata, G. scortechinii*, caused by *Glomerella cingulata* (Stonem.) Spauld & Schrenk. and *Colletotrichum* sp., have recently been reported from Malaysia (Azmy and Maziah, 1990). Leaf spots caused by *Colletotrichum graminicola* (Ces.) Wils. has been recorded earlier on *Arundinaria* sp. in U.S.A. (Anon., 1960).

Numerous other leaf spot diseases of minor importance are caused by *Ascochyta bambusina* Rao on leaves of *B. multiplex* (Lour.) Raeusch ex Schult. from Maharashtra (Pune) (Rao, 1962); *A. phaseolarum* Sacc. on *B. bambos* from Kerala (Balakrishnan *et al.*, 1990) and on leaves of

*Bambusa* sp. from Karnataka (Coorg) (Rangaswami, *et al.*, 1970); Grey leaf spot of *B. nutans* Wall. ex Munro caused by *Hendersonula toruloidea* Nattrass; brown leaf spot of *Melocanna humilis* Kurz and *Teniostachyum dullooa* Gam. caused by *Fusarium pallidoroseum*; foliage chlorosis of *D. strictus* caused by *Paecilomyces lilacinus* from North eastern states of India (Deka *et al.*, 1990); *Balladyna butleri* Syd. on leaves of *Bambusa* sp. causing black spots in Assam (Khasi Hills) (Butler and Bisby, 1960); *Alternaria* sp. on leaves of *Bambusa* sp. from Karnataka (Coorg) (Rangaswami *et al.*, 1970); *Leptosphaeria graminium* Sacc. on *Dendrocalamus* sp. from Shillong (Panwar and Gehlot, 1973); *Endodothella bambusae* (Rabenth.) Theiss & Syd., and *Helminthosporium bambusae* Cooke on *B. spinosa* and *Triglyphium bambusae* Roy on *B. tulda* Roxb. from Assam (Cooke, 1892; Roy, 1966); *Periconia cookei* Mason & M.B. Ellis on leaves of *Bambusa* sp. from Uttar pradesh (Mussoorie) and Karnataka (Anekal) (Sprague, 1950; Rangaswami *et al.*, 1970); *Petrakomyces indicus* Subram. & Ramkr., *Pseudorobillardia bambusae* Nag Raj *et al.*, *Diplozythiella bambusina* Died., on leaves of *Bambusa* sp. from Uttar Pradesh (Dehra Dun) (Butler and Bisby, 1960); *Meliola bambusicola* Hansf. causing black mildew on leaves of *Bambusa* sp. (Browne, 1968). A large number of fungi causing leaf infection of minor importance have been reported from U.S.A. Some of these are *Cercosporidium compactum* (Berk. & Curtis) Deighton, *C. graminis* (Fuckel) Deighton, *Volutella tecticola* Atk., *Stagonospora simplicor* Sacc. & Braid., *Mycosphaerella arundinariae* (Atk.) Earle, *Cladosporium herbarum* (Pers.:Fr.) Link., *C. oxysporum* Berk. & Curtis, *Alternaria* sp., *Helminthosporium* sp., etc. (Anon., 1960; Morgan-Jones, 1978; Alfieri *et al.*, 1984). Various other fungi causing leaf lesions of minor importance have also been recorded on bamboos from India, China, Japan, U.K., U.S.A., etc. (Thirumalachar and Pavgi 1952; Bagchee and Singh, 1954; Anon., 1960; Butler and Bisby, 1960; Browne, 1968, Ellis, 1971; Itoi *et al.*, 1978, 1979; Sutton, 1980; Deka *et al.*, 1990).

## WITCHES' BROOM

Witches' broom disease affecting the new culms, branches and foliage has been reported on different species of bamboos from China, Taiwan, Japan, and Indonesia. *Balansia take* (Miyake) Hara has been recorded as the causal agent of witches' broom of various species of bamboos, especially *Phyllostachys viridis* and *P. glauca* McClure in China and Taiwan. In Hunan Province, the disease incidence was upto 95 to 100 percent. Serious infection caused slow growth of bamboos and low sprout production. Typical symptoms of witches' broom of bamboo were shortening of the internodes of the diseased branches and clustering of the lateral branches. The infected branches grew continuously when the current shoot ceased to grow. The leaves become small in size and appeared to be bud scale in shape. Numerous knots were formed together with fine slender sprouts which appeared like a trailing plant. The fungal fructification developed on the terminal end of the shoots got infected first. Until next year the brooms were gradually formed and became densely aggregated (Zhu and Huang, 1988; Zhu, 1989a,b). The pathogen over-wintered on infected branches and produced conidia on the spring sprouts and formed the source of new infection. The conidia spread through rain splash. Infection occurred on new shoots and spread of the disease was recorded only on the above ground parts of shoots; rhizome system was found free from infection. Lin and Wu (1987) reported association of a bacteria like organism and *B. take* with the witches' broom of *Phyllostachys aurea* Carriere ex. A. & C. Riviere. Other pathogens identified to cause witches' broom of bamboos are *Epichloe bambusae* on *Bambusa vulgaris, Dendrocalamus asper* Schult. f. Backer ex Heyne, *Gigantochloa* spp. in Indonesia and *Loculistroma bambusae* on *Phyllostachys* spp. in China, *Aciculosporium take* Miyake in Taiwan (Shinohara, 1965; Chen, 1970, 1971; Nozu and Yamamoto, 1972; Kao and Leu, 1976; Lin and Wu, 1987).

## LITTLE LEAF DISEASE

A little leaf disease of *D. strictus* has been recorded from Andhra pradesh, Karnataka and Tamil Nadu (Nayar and Ananthapadmanabha, 1977). The affected clump became stiff and pointed with the appearance of a stiff brush; the internodes became shortened and the leaves diminished in size. Swelling developed at the nodal and diseased clumps dried up in the advanced stages of infection. Though, bamboos have been considered as the possible collateral host of sandal spike pathogen causing littling of leaf and brooming, no conclusive evidence was available. Bakshi *et al.*(1972) recorded a little leaf disease in bamboo nurseries and young plantations in Bihar (Ranchi), as a disease of unknown etiology. The incidence of the disease was found to be about 43.7 percent. The infected plants produced excessive branches in clusters at the nodal region forming typical witches' broom.

## MOSAIC DISEASE

Recently, a mosaic disease affecting the cultivated species of bamboos with patchymorph type of rhizome has been reported from Taiwan (Lin *et al.*, 1979). Bamboo mosaic virus (BaMV), previously acronymized as BoMV, which is a tentative member of the potexvirus group, is considered as the causal agent (Lin *et al.*, 1977,1979). *B. oldhamii* Munro and *D. latiflorus* Munro were the most susceptible species having recorded disease incidence of more than 70 percent (Lin and Chen, 1991). Characteristic symptoms included mosaic on the leaves and brown internal streaking of shoots and young culms. The emerging shoots had hard texture and were of low quality for eating and canning. In Taiwan, where bamboo is normally vegetatively propagated, the use of nonindexed, infected plants as propagating materials greatly aid in

the spreading of the disease. Bamboo mosaic disease is now considered to be a limiting factor in the production of vegetable bamboos in Taiwan (Lin *et al.*, 1993).

## CULM AND FOLIAGE SMUT

Smut infection caused by *Ustilago shiraiana* P. Henn. on various bamboo species has been recorded from China (Zhu, 1988a). The disease kills the infected shoots and recurs year after year. In India, *U. shiraiana* is known to cause witches' broom and swelling of bamboo shoots. The disease appears to affect adversely the growth of shoots (Bakshi and Singh, 1967).

## OTHER DISEASES OF CULMS

Some other culm diseases of different bamboo species have also been recorded from different countries. A culm canker of *Bambusa* sp., caused by *Hypoxylon rubiginosum* (Pers.) Fr. has been recorded in India (Bagchee and Singh, 1954), and culm blight of *Phyllostachys bambusoides* Sieb. et Zucc. and *P. nigra* var. *henonsis* (Mitf.) Murol caused by *Colletotrichum hsienjenchang* from Japan (Spaulding, 1961). Die-back of culms caused by *Papularia vinosa* (Berk. & Curtis) Mason has been recorded on *Bambusa* sp. and *Phyllostachys* sp. from U.S.A. (Anon., 1960; Alfieri *et al.*, 1984). The main cause of mortality of *D. strictus* culms in North Pakistan was found to be die-back caused by *Poria* sp., *Polyporus* sp. and *Rhizoctonia* sp. (Sheikh *et al.*, 1978).

## CULM SHEATH INFECTION

In the early phase of development of culms, culm sheath protects the young internodes from injuries. However, severe injuries and infection on young culm sheath often transfer the infection to the growing culm. A severe culm sheath infection of *Phyllostachys* sp. caused by *Shiraia bambusicola* has been recorded in China by Tai (1932) and *Discocurtisia arundinariae* (Berk. & Curtis) Nanf. on *Arundinaria* sp. in U.S.A. (Anon., 1960).

## STAINS, STRIPES AND SPOTS

Many fungi cause stains on culms, particularly when the clumps have low resistance to infection or when the culms have been subjected to excessive humidity and poor light conditions. Sometimes these stains give a decorative appearance to the culms and such bamboos are highly prized in China and Japan for the manufacture of decorative panels, musical instruments, etc. The best known stain causing fungi are: *Lembosia tikusiensis* on *Phyllostachys nigra* (Lodd.) Munro, *Asterinella hiugensis* Hino & Hidaka on *Phyllostachys bambusoides*, *Phragmothyrium semiarundinariae* on *Semiarundinaria narikisae*, *Miyoshiella macrospora* on *Bambusa shimadai* Hyata, *Miyoshiella fusispora* on *Arundinaria narihara*, and *Micropeltis bambusicola* on *Sasa paniculata* Makino et Shibata. Culm sooty stripes caused by *Papularia arundinaria*, *Arthrinium* state of *Apiospora montagnei* Sacc. have been recorded on *Bambusa* sp. from India (Thirumalachar and Pavgi, 1950; Bagchee and Singh, 1954). *A. montagnei* has also been recorded on *Melocanna bambusoides* Trin. from Pakistan (Khan, 1961), and on *Bambusa* sp. and *Phyllostachys* sp. from U.S.A. (Anon., 1960). *Scolecotrichum graminis* and *Selenophoma donacis* causing brown stripes and spots on

culms of *Arundinaria tecta* (Walter) Muhl. and other bamboos (*sic*) have been reported from U.S.A. (Anon., 1960). Other fungi causing culm spots and blemishes on *Arundinaria* spp. recorded from U.S.A. include: *Aulographium arundinariae* Cooke, *Botryosphaeria arundinariae* Earle, *B. festucae* (Lib.) Arx & Muller, *Didymosphaeria arundinariae* Ellis & Everh., *Eutypa consobrina* (Mont.) Rappaz, *Hypocrella tuberiformis* (Berk. & Rav.) Atk., *Lophodermium arundinaceum* (Schrad. :Fr.) Chev. (Anon., 1960). *Guignardia bambusae* Miyake & Hara, *Diplodia bambusae* Ellis & Langl., *Pseudoseptoria donacis* (Pass.) Sutton, *Hendersonia* sp., *Cylindrosporium bambusae* Miyake & Hara, *Placostroma bambusae* (Turconi) Sprague, etc. are recorded on *Bambusa* sp. as causing culm spots in U.S.A. (Sprague, 1950; Anon., 1960; Alfieri *et al.*, 1984).

A purple-spot disease on culms of 2-to 3-year-old *Phyllostachys viridis* resulting in death of culms has been reported from Nanshan village in Yuyao city in China (Anon., 1987). The infection manifests initially as yellow mottled spots on the base of culm which later turn to purple-brown with dark shade at the ground level. The leaves turn yellow and fall-off; the twigs wither and finally the whole culm dies. The disease was found serious in forest areas with water logging. The etiology of the disease has not yet been proved.

## INFECTION OF INFLORESCENCE AND SEEDS

Fungal infection of spikes of *Bambusa* sp. by *Hypocrella semiamplexa* (Berk. & Cooke) Sacc. and *Tilletia bambusae* Thirum. & Pavgi has been reported from India (Berkeley, 1856; Thirumalachar and Pavgi, 1968). *Ustilago* attacks young spikelets and black spores often completely replace the seed, causing smut. Only those seeds which are not infected fully attain maturity, but they contain spores. Such seeds on germination do not produce healthy seedlings. Severe *Ustilago*

infection of bamboo seeds has also been reported in U.S.A. and restrictions have been imposed on imports of reproductive materials of bamboos (Patterson and Charles, 1916). Many instances of infestation by *Hypocreopsis phyllostachydis* causing ergot of various Indian bamboos imported into the United States, and of *Phyllostachys* spp. in Japan have been reported. From India, ergot of *Bambusa* sp. caused by *Claviceps* sp. has been recorded from Nilgiris (Ramakrishnan and Ramakrishnan, 1949).

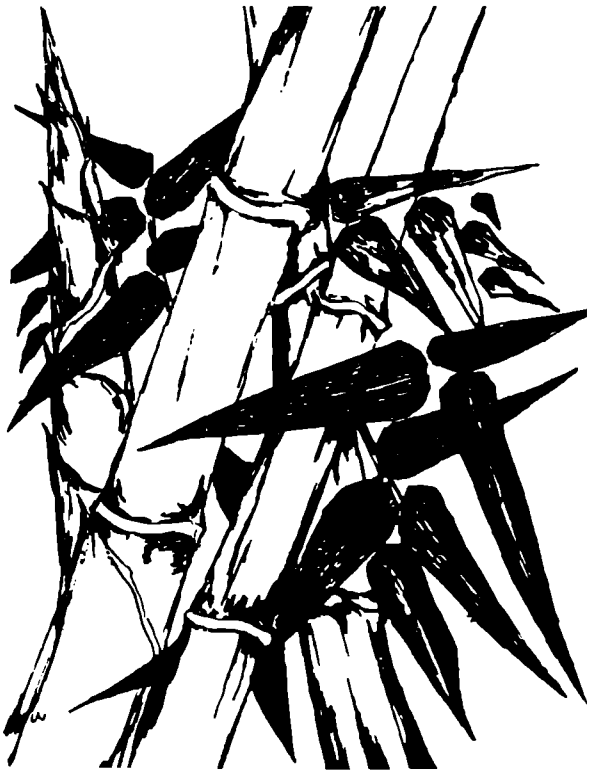
Bamboo seeds are attacked by fungi and bacteria during their different developmental stages in the plant as well as after the seed fall. Seeds also get infected during the storage and subsequent handling prior to sowing (Mohanan and Sharma, 1991). In tropical humid areas, bamboo seeds are reported to be colonized by several field and storage fungi and many of them are reported to be potential pathogens which may pose problem in nurseries (Mohanan, 1990). Studies on seed microflora of *B. bambos, B. nutans, D. strictus, Gigantochloa haskarliana* (Kurz.) Back. ex K. Heyne and *T. siamensis* Gamble in Thailand revealed a total of 48 species of fungi (Pongpanich and Chalermpongse, 1986). Of these nine were parasitic which caused diseases in nurseries. Many spermoplane as well as seed-borne fungi have been recorded on stored seeds of different bamboo species from Thailand (Chalermpongse *et al.*, 1984; Anantachote, 1987; Pongpanich, 1990). In India, Mohanan (1990) reported 19 fungal and two bacterial organisms associated with stored seeds of *B. bambos* and *D. strictus*, of which seven were potential seed-borne pathogens capable of causing infection of nursery seedlings. Namdeo *et al.* (1989) studied the seed pathology of *D. strictus* and suggested seed treatment with Ceresan @ 4 g/kg to control the spermoplane microflora.

The foregoing review of literature on bamboo diseases makes amply clear that there is a dearth of knowledge on diseases of bamboos in

nurseries which directly affect the planting stock and subsequently the success of the plantation. Though, various organisms associated with diseases of bamboos have been reported, their pathogenic status have not been confirmed. In many instances even the etiology and symptomatology of the disease are not adequately described. More importantly, the information on incidence and severity of the diseases are lacking which makes difficult to assess the impact of the disease(s) on the bamboo productivity.

Though, a few diseases such as leaf blight, leaf rust and witches' broom (Bakshi *et al.*, 1972; Harsh *et al.*, 1989; Bhat *et al.*, 1989) have been recorded in bamboo nurseries, no efforts were made to control them, except for the leaf blight caused by *Drechslera rostrata*, recently recorded by Harsh *et al.* (1989). Harsh *et al.* (1989) have reported application of Difolatan (0.2%) and Fytolan (0.4%) to control the leaf blight of *Bambusa* sp.

Since, the web blight of bamboos caused by *Rhizoctonia solani*, a disease recorded in the present study, is a new disease record, no literature is available on the pathogen affecting bamboo seedlings. Literature pertaining to various aspects on characterization of *R. solani*, its management in nurseries by cultural control, biocontrol and chemical control, etc. is provided under the Chapter on "Management of Rhizoctonia web blight".



# MATERIALS AND METHODS

# 3. MATERIALS AND METHODS

## DISEASE SURVEY

### SELECTION OF STUDY AREAS AND SAMPLING PROCEDURES

A reconnaissance survey was made in various bamboo plantations and bamboo natural stands in the State to ascertain their distribution and disease potential. Based on this survey, representative plots were selected in 22 localities for detailed investigations (Fig. 2; Table 3.1). Three plots each of 50 x 50 m were selected for bamboos at random in each of 17 localities; while 20 x 20 m plots were selected for reed bamboos in each of the five areas. In addition, bamboo preservation plots, trial plots, botanical garden, Bambusetum, bamboo brakes were also identified and selected for the study (Table 3.2).

All the clumps in each plot were selected and paint-marked. New culms produced in each clump during the growing season were marked with different colours to differentiate them year-wise. The selected plots were visited at least twice a year, during June to September and December to May and observations recorded on Disease Data Sheets. Information was also gathered on location of bamboo nurseries being raised in the State from 1987 onwards from various Forest Divisions. As far as possible most of the nurseries were visited (Table 3.3) frequently between December to June, when the seedlings were at different stages of growth. Experimental bamboo nurseries raised at KFRI, Peechi during the years 1988-1991 and at Chandhanathodu, Wynad during 1991-1992 were also surveyed intensively for seedling diseases and their management. Bamboo species surveyed in nurseries,

plantations, natural stands, Bambusetum, preservation plots, etc. are given in Table 3.4.

**Table 3.1: List of representative plots selected in bamboo natural stands and plantations in Kerala for disease survey during 1987 - 1991**

| Sl. No. | Locality | Forest Division | Year of planting | Bamboo species |
|---|---|---|---|---|
| **Natural stands** | | | | |
| 1. | Thirunelly | Wildlife Divn. Wynad | | *Bambusa bambos* |
| 2. | Muthanga | Wildlife Divn. Wynad | | *B. bambos* |
| 3. | Noolpuzha | Wildlife Divn. Wynad | | *B. bambos* |
| 4. | Periya | North Wynad | | *Ochlandra scriptoria* |
| 5. | Anamari | Nilambur | | *B. bambos* |
| 6. | Agaly | Mannarkkad | | *Dendrocalamus strictus* |
| 7. | Thakarapady | Mannarkkad | | *D. strictus* |
| 8. | Goolikadavu | Mannarkkad | | *D. strictus* |
| 9. | Watchumaram | Vazhachal | | *O. travancorica* |
| 10. | Vazhachal | Vazhachal | | *O. scriptoria* |
| 11. | Marayoor | Munnar | | *B. bambos* |
| 12. | Chinnar | Munnar | | *D. strictus* |
| 13. | Pachakanam | Ranni | | *O. travancorica* |
| 14. | Kottoor | Trivandrum | | *O. ebracteata.* |
| **Plantations** | | | | |
| 1. | Nilambur | Nilambur | 1987 | *B. bambos* |
| 2. | Nadukani | Nilambur | 1970 | *D. strictus* |
| 3. | Mundoor | Palakkade | 1973 | *T. oliveri* |
| 4. | Irumpupalam | Trichur | 1986 | *B. bambos* |
| 5. | Palappilly | Chalakkudy | 1986 | *B. bambos* |
| 6. | Ezhattumugam | Vazhachal | 1986 | *B. bambos* |
| 7. | Kollathirumedu | Vazhachal | 1986 | *B. bambos* |
| 8. | Kaliyar | Kothamanagalam | 1986 | *B. bambos* |

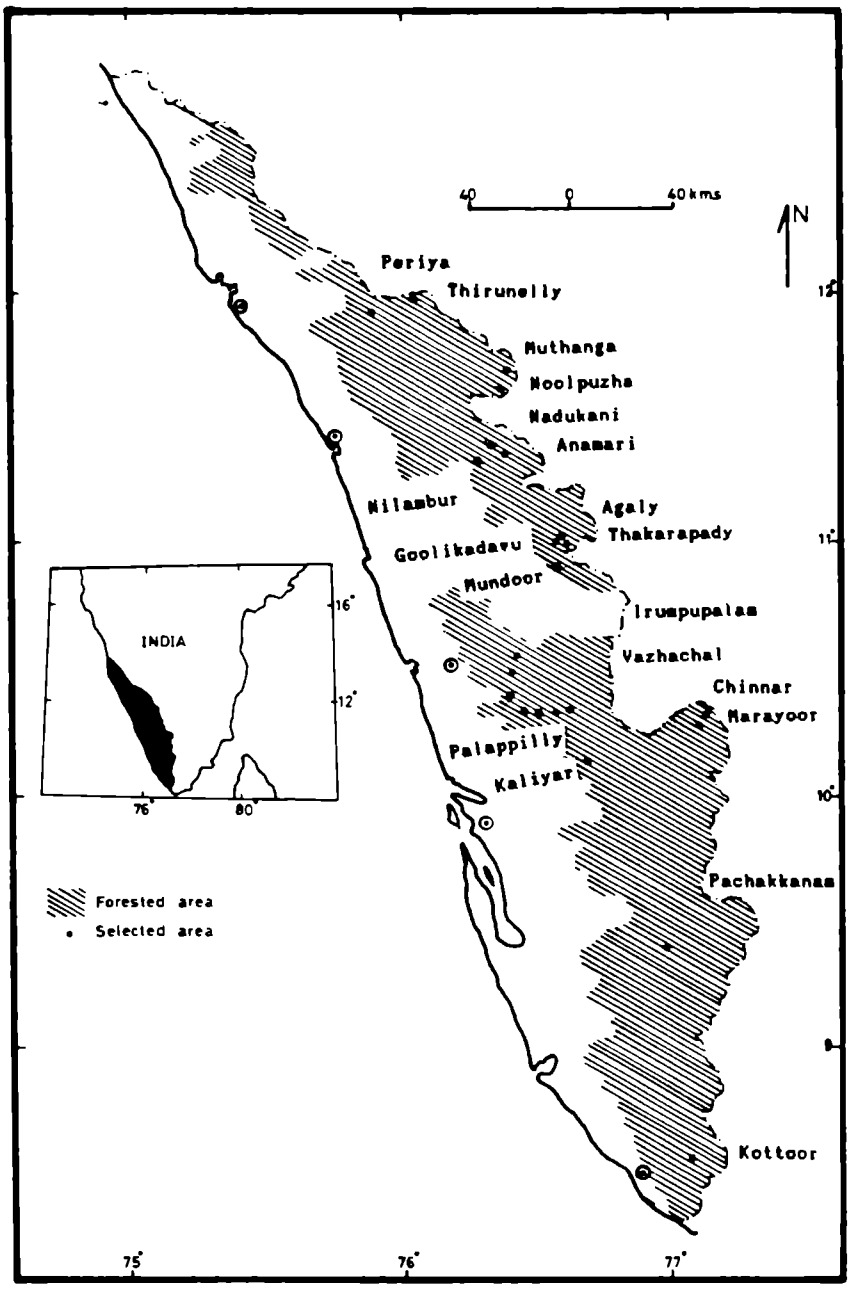



Fig. 2. Bamboo growing areas in Kerala selected for the disease survey.

Table 3.2: List of trail plots, preservation plots, Bambusetum, etc. surveyed in addition to the representative plots

| Sl.No. | Locality | Forest Division | Bamboo species |
|---|---|---|---|
| 1. | Bambusetum (KFRI Sub-centre, Nilambur) | Nilambur | BB.BBL,BG,BP,BT,BVE BV,DB,DH,DL,DS,OS,OT, OXM,OXS,TO,TS |
| 2. | Trial Plot (KFRI campus, Peechi) | Trichur | BB,BBL,BV,DS,DL OS,OT,TO |
| 3. | Preservation Plot (Chauzhiakode) | Trivandrum | BB,OE,OS,OT,OE |
| 4. | Preservation Plot (Mallana) | Malayattoor | BB |
| 5. | Botanic Garden(Calicut Univ.) | | BB,BV,BVE |
| 6. | Palakkayam | Nilambur | OXM |
| 7. | Ambumala * | Nilambur | DL |
| 8. | Millpalam, Kulathupuzha * | Trivandrum | Ts |
| 9. | Peruvannamuzhy | Calicut | OS,OT |
| 10. | Sholayar | Vazhachal | OT,OTH,BB |
| 11. | Munnar | Munnar | As |
| 12. | Thattekad @ | Malayattoor | BB |
| 13. | Pachila @ | Kothamangalam | BB |
| 14. | Mullaringad | Kothamangalam | BB |
| 15. | Edamalayar | Malayattoor | OT |
| 16. | Pooyamkutty | Malayattoor | OT,OTH |
| 17. | Adimaly | Munnar | OT,OTH |
| 18. | Adirappally | Vazhachal | OS,OT |
| 19. | Rakky | Ranni | OT |
| 20. | Vadasserikkara @ | Ranni | BB |
| 21. | Nelliampathy | Nenmara | OT |
| 22. | Arippa * | Trivandrum | BB,OT |
| 23. | Devikulam | Munnar | BP |
| 24. | Aramba | Thenmala | BB,OT |
| 25. | Orukomban | Parambikulam | BB,OT |
| 26. | Anavay | Mannarkkad | BB,DS |
| 27. | Kadukuman | Mannarkkad | BB,DS |

* Trial plots; @ 2 to 3 years old plantation; As: *Arundinaria* sp.; BB:*B.bambos*, BBL:*B.balcooa*; BG:*B.glaucescens*; BP:*B.polymorpha*; BT:*B.tulda*; BVE:*B.ventricosa*; BV:*B.vulgaris*; DB:*D.brandisii*; DH:*D.hamiltonii*; DL: *D.longispathus*; DS: *D.strictus*; OS: *O.scriptoria*; OE:*O.ebracteata*; OT:*O.travancorica*; OTH: *O. travancorica* var. *hirsuta*; OXM: *O. monostigma*; OXS: *O. stocksii*; TO: *T. oliveri*; TS: *T. siamensis*; Ts: *Thyrsostachys* sp.

**Table 3.3: List of bamboo nurseries surveyed during 1987-1992**

| Sl. No. | Locality | Forest Division | Year | No. of seedbeds | Bamboo species |
|---|---|---|---|---|---|
| 1. | Vadavukodu | Ernakulam Social Forestry | 1987-'88 | 12 | BB |
| 2. | Kalamassery | Ernakulam S.F. | 1987-'88 | 10 | BB |
| 3. | Dhoni | Palakkade | 1987-'88 | 15 | DS |
| | | | 1988-'89 | 10 | DS |
| 4. | Peechi | Trichur | 1988-'89 | 12 | BB,OS*,OT* |
| | | | 1889-'90 | 10 | BB,PP* |
| | | | 1990-'91 | 11 | BB,DL |
| 5. | Nilambur | Nilambur | 1988-'89 | 20 | BB,DS |
| | | | 1989-'90 | 22 | BB,DS |
| 6. | Pattikad | Trichur | 1987-'88 | 40 | BB |
| 7. | Pallappilly | Trichur | 1990-'91 | 20 | BB,DM*,OW* |
| | | | 1991-'92 | 10 | BB,DS,DB |
| 8. | Pariyaram | Chalakkudy | 1989-'90 | 12 | BB |
| 9. | Kulanjithodu | Ranni | 1989-'90 | 50 | BB |
| 10. | Vadasserikkara | Ranni | 1990-'91 | 40 | BB |
| 11. | Niravilpuzha | South Wynad | 1990-'91 | 100 | BB |
| | | | 1991-'92 | 50 | BB |
| 12. | Thettamala | South Wynad | 1991-'92 | 50 | BB |
| 13. | Periya | South Wynad | 1990-'91 | 20 | BB |
| | | | 1991-'92 | 25 | BB |
| 14. | Vattapoyil | South Wynad | 1991-'92 | 18 | BB |
| 15. | Begur | South Wynad | 1990-'91 | 100 | BB |
| 16. | Paneli | Malayattoor | 1990-'91 | 50 | BB |
| | | | 1991-'92 | 50 | BB |
| 17. | Pezhad | Malayattoor | 1990-'91 | 40 | BB |
| | | | 1991-'92 | 20 | BB |
| 18. | Chandhanathodu | Cannanore | 1991-'92 | 20 | BB,DS,DB,TS |

* Container seedlings.

BB:*B.bambos*; DB: *D.brandsii*; DS: *D.strictus*; DM: *D.membranaceus*; DL: *D.longispathus*; OS: *Ochlandra scriptoria*; OT: *O.travancorica*; OW: *O.wightii*.TS: *Thyrsostachys siamenisis*; PP: *Phyllostachys pubescens*

Table 3.4: List of bamboo species surveyed in Kerala during 1987-1992

| Sl. No. | Bamboo species | Occurrence |
|---|---|---|
| 1. | *Arundinaria* Michaux. sp. | NS |
| 2. | *Bambusa balcooa* Rox. | BM,PP |
| 3. | *B. bambos* (L.) Voss | N,PN,PP,BM |
| 4. | *B. glaucescens* (Willd.) Sieb. ex Munro | BM |
| 5. | *B. polymorpha* Munro | BM,PP |
| 6. | *B. tulda* Roxb. | BM |
| 7. | *B. ventricosa* Kurz. | BM,BG |
| 8. | *B. vulgaris* Schrad | BM,BG,PP |
| 9. | *Dendrocalamus brandsii* Kurz. | BM |
| 10. | *D. hamiltonii* Nees | BM,PP |
| 11. | *D. longispathus* Kurz. | BM,PP |
| 12. | *D. membranaceus* Munro | BM,N |
| 13. | *D. strictus* Nees | N,PN,BM,PP |
| 14. | *O. ebracteata* Raizada & Chatterji | NS |
| 15. | *Ochlandra scriptoria* (Dennst.) Fisch. | NS,BM |
| 16. | *O. travancorica* (Bedd.)Benth.ex Gam. | NS,BM,PP |
| 17. | *O. travancorica* Benth.var. *hirsuta* Gam. | NS |
| 18. | *O. wightii* Fisch. | N |
| 19. | *Oxytenanthera monostigma* Bedd. | BM,NS,PP |
| 20. | *Phyllostachys pubescens* Mazel ex Lahaie | N |
| 21. | *Thyrsostachys oliveri* Gamble | PN,BM,PP |
| 22. | *T. siamensis* Gam. | N |
| 23. | *Thyrsostachys* sp. | PP |

N: Nursery; NS: Natural stand; PN: Plantation; PP: Preservation plot; BM: Bambusetum; BG: Botanic garden

## DISEASE INDEXING

Observations on disease incidence, severity, spread, symptoms and nature of damage caused to seedlings, etc. were recorded in bamboo nurseries. The incidence of a disease was recorded either by counting the number of disease patches and the approximate area covered by them

or percent seedlings affected for a given density of seedlings in a seedbed (Sharma and Mohanan, 1991a). Infected seedlings were counted separately in transplant and containerbeds. A disease scoring scale (Table 3.5) was used for assessing the severity of seedling diseases.

**Table 3.5: Disease index to assess the severity of diseases in nurseries, plantations and natural stands**

| Disease severity | Damping-off | Web blight | Foliage infection | Culm and branch infection | Disease severity rating |
|---|---|---|---|---|---|
| Nil | Nil | Nil | Nil | Nil | 0 |
| low (L) | 1-25 damped-off patches in 12x1 m seedbed | 1-25 infection foci in 12x1 m seedbed | upto 25% of the foliage affected | upto 25% of the culm and branches affected; >10% die-back of branches | 1 (0.1-1) |
| medium (M) | 26-50 damped-off patches in 12x1 m seedbed | >25-50 infection foci in 12x1 m seedbed | >25-50% of the foliage affected; >10% defoliated prematurely | >25-50% of the culm and branches affected; >25% die-back of shoot | 2 (1.1-2) |
| severe (S) | >50 damped-off patches in 12x1 m seedbed | >50 infection foci in 12x1 m seedbed; infection still spreading | >50-75% or more foliage infected; >25% defoliated prematurely | >50-75% of the culm and branches affected; >50% of die-back of shoot infection spreading | 3 (2.1-3) |

Disease severity of foliage diseases, branch infection, culm necrosis, etc. in bamboo natural stands and plantations, was rated on a numerical scale (0-3) of disease rating index (Table 3.5). The average severity index of a disease (DSI) in a plantation/natural

stand was calculated from the sum of total number of clumps of each disease severity rating (DSR) in all the plots multiplied by the disease severity index (0-3) and dividing it by the total number of clumps assessed (N) as given in the following formula (Sharma *et al.*, 1985).

$$DSI = \frac{nL \times 1 + nM \times 2 + nS \times 3}{N}$$

Where, nL, nM, nS represent total number of clumps with low, medium and severe disease severity; 1, 2, 3 disease severity index (DSI) for low, medium and severe respectively and N, the total number of clumps assessed in all the observation plots.

For emerging and growing culm diseases, number of healthy, diseased, deformed and emerged culms died each year, were counted separately for each clump from the plot and percent incidence calculated. The percent incidence of a particular disease in an area/ plantation was calculated from the total number of culms/clumps affected (nd) and total number of culms/clumps observed in all the plots as follows:

$$\text{Percent incidence} = \frac{nd}{N} \times 100$$

## COLLECTION OF INFECTED MATERIALS AND ISOLATION OF CAUSAL ORGANISM

Infected materials viz., seedlings, foliage, stem, culm, culm sheath, branch, rhizome, roots, etc., collected from nurseries and field, were brought to the laboratory in separate clean polythene bags and stored in a refrigerator. Isolation of the causal organisms from the disease specimens was carried out within one to two days of collection.

**Culture media used for isolation and maintenance of isolates**

Potato dextrose agar (PDA) and malt extract agar (MEA) were used as general media for isolation and maintenance of fungi. Oat meal agar (OMA), Lima bean agar (LBA), Rose bengal agar (RBA), Potato sucrose agar (PSA) were also used for selective isolation of various fungi. Nutrient agar medium (NAM) was used for isolating and maintaining bacteria. All the culture media (dehydrated) used in the study were supplied by Himedia, Bombay.

SMC medium (Saglio *et al.*, 1971) was used for isolation of MLO. The medium contained PPLO broth base, 34 g; tryptone, 10 g; glucose, 1 g; fructose, 1 g; sorbitol 70 g; sucrose, 10 g; fresh yeast extract, 100 ml; horse serum, 200ml; phenol red (1%) 2ml; double distilled water, 574 ml. All the ingredients, except horse serum and yeast extract were dissolved in distilled water and autoclaved at 15 p.s.i. for 15 min. Horse serum and yeast extract were filter-sterilized separately passing through Millipore filter (pore size 0.45 µm), and phenol red solution separately autoclaved, were aseptically added to the broth base; pH of the medium was adjusted to 7.2. Five millilitre of the medium was transferred aseptically to screw cap culture bottles. For isolation of fungal pathogen, the disease specimens were surface sterilized using either mercuric chloride (0.01%) or sodium hypochlorite (5%) solutions.

**Inoculation and incubation procedures for isolation of MLO from diseased tissues**

Nodal shoots of diseased *D. strictus* with highly shortened internodes were cut into 1.0 to 1.5 cm in length and immediately surface sterilized in 2.5 percent sodium hypochlorite solution for 2

to 5 min (Ghosh *et al.*, 1985a). The stem bits were rinsed in sterile distilled water, dipped in 75 percent ethyl alcohol for 15 sec and flamed quickly. The surface sterilized bits were then placed in sterile Petri dishes containing 2 ml of culture medium and cut into small pieces. The pieces were macerated and squeezed using forceps to release the inoculum into the medium. This source inoculum was then added to 20 ml of fresh medium and thoroughly mixed and filtered through Millipore filter (0.45 µm) to remove possible bacterial contamination. Half millilitre of the final inoculum was then added to 5 ml of fresh medium and inoculated into a screw cap culture bottle. In order to prevent the antispiroplasma action of plant tissues, the primary culture was serially diluted tenfold in fresh medium at two days'intervals (Ghosh *et al.*, 1985a). The bottles were incubated at 25 ± 2°C and observed for growth of MLO indicated by colour change of the medium from red to yellow.

**Identification of causal organism**

Identification of pure culture of microorganisms isolated from various disease specimens was attempted up to specific level wherever possible on the basis of their cultural and morphological characters. For authentic identification or confirmation, the cultures and herbarium specimens bearing fructifications were referred to IMI, Kew, U.K. The colour standard of Kornerup and Wanscher (1978) was used for describing the fungus. The identified cultures were subcultured regularly and stored at 25± 2°C.

**Microtomy and histopathology**

To study the histopathology of little leaf disease of *D. strictus* and also the morphological details of fructifications of various fungi

such as pycnidia, perithecia and rust sori, appropriate specimens were selected and their sections (2-8 µm) cut using Minotome cryomicrotome (IEC, USA). Samples of internodal region from young shoots affected with little leaf diseased as well as those of healthy *D. strictus* plants were selected for histopathological studies. Samples were fixed in Formalin acetic -acid-alcohol (FAA) (Johnston and Booth, 1989). Sections were cut using cryomicrotome, mounted in distilled water and viewed under Leitz Dialux 20 microscope. Phloem tissues were examined for any deformities.

**Dienes' staining reaction**

Free hand-cut sections of internodal region from young shoots of little leaf diseased and healthy *D. strictus* were taken. The sections were stained with 0.2 percent solution of freshly prepared and filtered Dienes' stain (methylene blue, 2.5 g; azure II, 1.25 g; maltose, 10.0 g; sodium carbonate, 0. 25 g; distilled water, 100 ml) (Deeley *et al.*, 1979) for ten minutes, then washed and mounted in distilled water and viewed under Leitz Dialux 20 microscope.

**Fluorescence microscopy**

Aniline blue, a fluorochrome used for detecting callose in the phloem of mycoplasma infected plant tissues (Hiruki and Shukla, 1973) was used in fluorescence microscopy. Free hand-cut sections of little leaf diseased as well as healthy tissues of *D. strictus*, immediately heat killed in boiling water for ten minutes, were stained in 0.01 percent aniline blue in 1/15 M phosphate buffer (Ghosh *et al.*, 1985a,b). Stained sections were viewed under Leitz Dialux 20 Fluorescence microscope and photographs taken.

Hoechst 33258, a DNA binding fluorochrome (Russel *et al.*, 1975) was also used in fluorescence microscopy. Free hand-cut sections were fixed in 3.0 percent glutaraldehyde in cacodylate buffer at 4°C for 6 h. Sections were washed in 0.1 M phosphate buffer and stained in Hoechst 33258 prepared in 0.1 M phosphate buffer containing 100 $\mu g\ ml^{-1}$ for 15 to 20 min and viewed under Leitz Dialux 20 Fluorescence microscope.

**Transmission electron microscopy**

Two millimetre bits of juvenile shoot and petiole from diseased and healthy *D. strictus* plants were fixed in 2.5 percent glutaraldehyde buffered with 0.1 M sodium cacodylate, pH 7.0, for 24 h at 4°C. Sections were washed thoroughly in the same buffer and post fixed in 2 percent osmium tetroxide in 0.1 M cacodylate buffer for 5-6 h. After washing with cacodylate buffer (30 min), and distilled water, the sections were dehydrated in acetone series and embedded in Epon 812 (Morris, 1965).

Ultrathin sections were cut with LKB III Microtome using glass knife and differentiated with aquous uranyl acetate (0.5%) and lead citrate for 10 to 15 min in each stain (Reynolds, 1963); sections were viewed under Zeiss transmission electron microscope (TEM) and photographs taken.

**Staining**

Lactophenol cotton blue 0.1 percent (anhydrous lactophenol, 67.0 ml; distilled water, 20.0 ml; cotton blue, 0.1 g), glycerol aniline blue 0.2 percent (glycerol (50%), 100 ml; aniline blue, 0.2 g) were

used for staining the fungal specimens. Pyridoxin (50%) was used for clearing the whole mount (Sharma and Mohanan, 1991a).

## PATHOGENICITY TEST

### Damping-off, web blight, stem and root infection

For seedling diseases viz., damping-off, web blight, stem and root infection caused by *R. solani*, the soil sterilized at 15 p.s.i. for 15 min was infested with the inoculum of the test isolates (*R. solani*)(2:100) in aluminium trays (30 x 30 x 5 cm) separately. Inoculum of *R. solani* was raised on corn-meal sand medium (corn-meal, 1000 g; washed sand, 1000 g; water, 1500 ml) in wide-mouth culture bottles for 18 days, air-dried and powdered using Remi Automixer. Sieved forest soil was sterilized at 15 p.s.i. in large aluminium buckets for 4 h for two consecutive days and transferred to aluminium trays (2 kg tray$^{-1}$). Inoculum of *R. solani* was added (20 g tray$^{-1}$) to the soil, mixed well and watered. The trays were kept covered with a paper and incubated for two weeks for allowing the inoculum to become active and grow. Seeds of *B. bambos* and *D. strictus* (7 g tray$^{-1}$), were sown at the rate of 1 kg per standard bed.

For testing the pathogenicity of *Fusarium moniliforme* and *F. oxysporum*, causing seed rot and pre-emergence damping-off, seeds of *B. bambos* were soaked (10 min) in conidial suspension ($10^8$ spore ml$^{-1}$) of the test pathogens separately, prepared from 7-day-old PSA culture. The treated seeds were air-dried for 15 min and stored in sterilized flasks for 24 h. The seeds were sown in sterilized soil in Aluminium trays. A thin layer of sterilized soil was covered over the broadcast sown seeds. The trays were watered regularly. Seedling emergence, symptoms of the disease, disease incidence and spread were monitored

and observations recorded. Isolations were made from the infected seed/seedlings and pathogenicity of the isolates confirmed.

**Foliage disease**

The pathogenicity of fungi viz., *Bipolaris maydis, B. urochloae, Bipolaris* sp., *Exserohilum rostratum, E. holmii, Fusarium pallidoroseum, Dactylaria* sp., *Colletotrichum gloeosporioides, Alternaria alternata, Curvularia pallescens,* etc. causing foliage diseases was confirmed in artificial inoculation trials employing 10- to 60-day-old *B. bambos* and *D. strictus* seedlings raised in sterilized forest soil in trays (30 x 30 x 5 cm and 90 x 60 x 25 cm) or on polyurethane foam sheet (20 x 10 x 1cm) (Chacko, 1983). Container seedlings (10- to 11-month-old) were also used in pathogenicity trial. Conidial suspension ($10^4$spore $ml^{-1}$) of test fungus was prepared in sterile distilled water separately. One drop of Tween 20 was added in 100 ml of conidial suspension and sprayed uniformly on the bamboo seedlings separately using atomizer connected to a vacuum pump. The inoculated seedlings were transferred to a humidity chamber, maintained at 90 to 100 percent r.h. and incubated for 10 to 15 days. In the case of *Bipolaris* spp. and *Exserohilum* spp. inoculated seedlings as well as controls were removed from the humidity chamber after two days of incubation and kept under direct sun light. Observations on the appearance of leaf infection and its subsequent spread were recorded regularly. The pathogenic nature of the isolates was confirmed which on being reisolated from the respective infected tissues.

**Rhizome rot and rhizome bud rot**

In the case of rhizome rot and rhizome bud rot, one year-old *B. bambos* seedlings, raised in large metallic trays (90 x 60 x 25 cm)

containing sieved sterile soil, were used for pathogenicity trials. Pathogenicity of isolates of *Rhizostilbella hibisci* and *Pythium middletonii* causing rhizome rot, and rhizome bud rot respectively was confirmed by inoculating the rhizome. The soil beneath the seedling was removed carefully and the intact rhizome washed with sterile water. The rhizome buds were inoculated with and without injuries made with a sterile scalpel blade. Suspensions in sterile water containing spores and macerated mycelia, of *R. hibisci* and *P. middletonii* prepared from 10-day-old PDA culture of the former and 7-day-old OMA culture of the later were brushed separately on the rhizome buds. The inoculated rhizomes were covered with sterile soil and watered moderately. The inoculated seedlings were observed regularly for the development of disease symptoms. Appropriate controls, where only sterile water was used in place of spore/mycelial suspension were also maintained along with the inoculated plants. After one month of inoculation, the plants were uprooted gently and the rhizomes washed in running water. Foliage symptoms, discoloration on the rhizome, internal necrosis, etc. were recorded. Isolations were made from the apparently infected regions of the rhizome buds to confirm the pathogenic nature of the isolates.

**Rot of emerging and growing culms, and necrosis of culm internodes**

For confirming the pathogenicity of the fungi associated with the diseases of emerging and growing culms, artificial inoculations were carried out on the emerging shoots with different test fungi. The growth of *B. bambos* (3-year-old), raised in large metallic trays was monitored regularly and the culms emerging from the underground rhizome noted. When the culms just emerged out, the soil around them was carefully removed. The culms were wound inoculated by pricking with a sterile needle on the intact culm sheeth and spraying the

wounds with the conidial suspensions ($10^4$ conidia $ml^{-1}$) of *F. moniliforme* var. *intermedium* and *Sarocladium* sp., prepared in sterile distilled water; inoculation was also done without injury. Inoculation of growing culms of *B. bambos* and *D. strictus*, of 1.5 to 2 m height was carried out using spore suspension ($10^4$ conidia $ml^{-1}$) of *F. equiseti* by spraying on the wounds made on the culm sheath at the node with sterile needle; the inoculated area was covered with polythene sheet and provided with a moistened sterile cotton pad inside. Appropriate controls were also maintained by spraying with sterile distilled water. Pathogenicity of *Curvularia lunata* causing necrosis of culm internodes in *T. oliveri* was also carried out similarly. The growing culms of *T. oliveri* were injured with sterile scalpel blade at the node and sprayed with conidial suspension ($10^4$ conidia $ml^{-1}$) of the fungus prepared from 10-day PDA culture. The inoculated area was covered with polythene sheet and in order to maintain high humidity around the inoculated area, moistened cotton pad was kept. Observations on the development of symptoms and its spread were recorded frequently. Isolation of the fungus from the diseased tissue was made after 30 to 35 days of inoculation and pathogenicity of the isolates confirmed.

*Field trial*

A field trial was carried out at Thenkodum (Kaliyar Forest Range) in a teak plantation (1979) where bamboo was raised at an espacement of 10 x 10 m during 1986 and large-scale mortality of out planted bamboos recorded during 1987. The pathogen associated with the disease was identified as *Pythium middletonii*. One hectare area was planted during June, 1988 with 18-month-old *B. bambos* container seedlings, in pits of 30 x 30 x 30 cm at an espacement of 10 x 10 m to assess the natural infection of rhizome caused by *Pythium middletonii*.

*Screening of tetracycline for little leaf disease recovery*

Twelve clumps of *Dendrocalamus strictus* affected with little leaf disease were selected in natural stands at Thakarapady (Mannarkkad Forest Divn.) for tetracycline therapy. Tetracycline-hydrochloride tree injection formula (Pfizer Ltd., Thane) (1.0 g 500 $ml^{-1}$) (Ghosh *et al.*, 1985a) was applied as foliar spray (50 ml $shoot^{-1}$) on the selected culms. The treated portion, nodes including nodal shoots was covered with a polythene sheet for a day and later removed. Observations on the remission of symptoms, if any, were recorded at fortnightly interval for six months.

# MANAGEMENT OF RHIZOCTONIA WEB BLIGHT

## LABORATORY TRIALS

### CHARACTERIZATION OF *RHIZOCTONIA SOLANI* ISOLATES

#### Anastomosis group (AG) testing and determination of nuclear condition

Authentic tester isolates of *R. solani* belonging to various anastomosis groups (AG) (Table 3.6) were obtained from Dr. Akira Ogoshi, Hokkaido University, Japan. Anastomosis was tested by opposing isolates of *R. solani* on sterilized glass slides (76 x 26 mm) sprayed with 1.5 percent water agar (Yokoyama and Ogoshi, 1986). A total of 56 *R. solani* isolates recovered from bamboo seedlings were tested. *R. solani* isolates causing other than web blight disease, e.g. damping-off and seedling wilt were also included in the test to ascertain whether AG differs from those of causing web blight. Mycelial disks (5

mm dia) removed from the margin of actively growing 4-day-old PDA cultures of *R. solani* bamboo isolates and authentic AG isolates of *R. solani* were placed three centimetre apart on the same sterilized microscope slide. The slide was placed over a U shaped sterile glass tube kept in the Petri dish having moistened sterile blotter disk (90 mm dia). The setups were incubated in the dark at 25°C for 24 to 48 h. The process of hyphal attraction and fusion was observed by using Leitz Dialux 20 microscope. Aniline blue (0.2%) in 50 percent glycerol slightly acidified with HCl (Tu and Kimbrough, 1973) was used to stain the fungal hyphae and also to observe the nuclear condition.

**Table 3.6: Tester isolates of *Rhizoctonia solani* employed in the AG determination of bamboo isolates of *R. solani***

| AG & ISG[a] | Isolate | Origin | Location | Year of isolation |
|---|---|---|---|---|
| AG-1 IA | CS-Ka Hokkaido Univ. | Rice | Hokkaido, Japan | 1961 |
| AG-1 IB | B-19 Hokkaido Univ. | Sugar beet | Hokkaido, Japan | 1954 |
| AG-1 IC | BV-7 Natl.Inst.Agri.Sci. | Sugar beet | Hokkaido, Japan | 1961 |
| AG-2-1 | PS-4 Hokkido Univ. | Pea | Tokushima,Japan | 1973 |
| AG-2-2 IIIB | C-96 Oniki | Mat rush | Fukuoka, Japan | 1972 |
| AG-2-2 IV | RI-64 Ibaraki Agri.Exp.Statn. | Sugar beet | Ibaraki, Japan | 1960 |
| AG-3 | ST-11-6 Hokkaido Univ. | Potato | Hokkaido, Japan | 1981 |
| AG-4-HG I | AHI Hokkaido Univ. | Peanut | Chiba, Japan | 1968 |
| AG-5 | GM-10 Hokkaido Univ. | Soybean | Nagano, Japan | 1970 |
| AG-6-HG-I | OHT1-1 Kuninaga | Soil | Hokkaido, Japan | 1977 |
| AG-7 | HO-1556 Homma | Soil | Kagawa, Japan | 1979 |
| AG-BI | TS-2-4 Kuninaga | Soil | Hokkaido, Japan | 1977 |

[a] Anastomosis group and intraspecific group

*(Courtesy: Dr. Akira Ogoshi, Hokkaido University, Japan)*

**Cultural characters, linear growth and relative virulence**

Fifty six *R. solani* isolates recovered from diseased bamboo seedlings were designated in five groups, based on their similarity in colony colour, production of aerial mycelium and sclerotia on potato dextrose agar medium (PDA). From each of these groups one isolate of *R. solani* was selected. These five isolates were employed in detailed investigations on growth and cultural characters, relative virulence, and carbon and nitrogen utilization.

Linear growth and cultural characters of these five *R. solani* isolates viz., RS1 (KFRI 797), RS2 (KFRI 131), RS3 (KFRI 11 S2), RS4 (KFRI CN3) and RS5 (KFRI 787) were studied on PDA. For each isolate, and medium, there were three replicates of flat bottomed assay Petri dishes (90 mm dia), containing 15 ml of the medium. Each dish was inoculated with a mycelial disk taken from the margin of a 5-day-old culture of *R. solani* isolate and incubated at 25 $\pm$ 2 $^{o}$C. From each replicate dish, diameter growth was recorded after 14 h of incubation at 4 h interval. Cultural characters such as colony color, type of aerial mycelium, sclerotial production, etc. were recorded after ten days of growth. The development of sclerotia was rated according to relative abundance and density of sclerotia in the agar medium as: 0: absent; 1: poor (widely scattered); 2: numerous (moderate); 3: good (abundant); 4: excellent (closely aggregated).

Relative virulence of five *R. solani* isolates was tested in soil sterilized at 15 p.s.i. for 15 min. It was infested with the inoculum of each test isolate at two inoculum levels, 2:100 and 2:1000 in aluminium trays (30 x 30 x 5 cm) separately. Inoculum of *R. solani* was prepared as described under pathogenicity trial and the soil was infested with two inoculum levels separately. Trays were sown separately with 7 g of seeds, equivalent to a seed rate of 1

kg/standard bed, and watered regularly. Seedling emergence, disease incidence, spread and symptoms of disease were monitored and observations recorded. Data were subjected to appropriate statistical analyses and comparison of relative virulence of RS isolates made.

## Utilization of carbon and nitrogen sources

Effect of ten carbon sources viz., D-galactose, D-arabinose, D-ribose, D-raffinose, D-cellobiose, D-maltose, D-mannose, D-glucose, D-sucrose, D-fructose and 13 nitrogen sources viz., L-alanine, L-arginine, L-asparagine, L-glutamic acid, L-methionine, D-L-phenyl alanine, L-tyrosine, Ammonium nitrate, Ammonium sulphate, Potassium sulphate, Potassium nitrate, Sodium nitrate and Urea on mycelial growth of five representative bamboo isolates of *R. solani* was compared in 25 ml synthetic liquid medium in stationary 250 ml Erlenmeyer flasks. The basal synthetic medium consisted of Na $NO_3$, 2.0g; Mg $SO_4$. 7 $H_2O$, 0.5g; $KH_2$ $PO_4$, 1.0g; KCL, 0.5g; and sterile distilled water 1000 ml. One millilitre of micronutrients from stock solution containing $Mn^{+2}$, 0.05 mg; $Zn^{+2}$, 0.2 mg; $Fe^{+3}$, 0.1 mg was added to one litre of the basal medium. The initial pH of the medium was adjusted to 6.5 with 5N HCl or 0.3 M $K_2HPO_4$ before sterilization. Each carbon source was added separately to the basal medium at the rate equivalent to 10 g of dextrose per litre.

For studying the effect of various N sources on growth, dextrose was taken as C source in the basal medium. The nitrogen components were added separately in quantity necessary to provide 277 mg of nitrogen per litre. The pH of the medium was adjusted to 6.5 with 0.3 M $K_2$ $HPO_4$ or 5 N HCl.

The media were sterilized through a Millipore filter (pore size 0.45 μm) and each flask was seeded with a single 5 mm dia mycelial disk cut from the advancing margin of 5-day-old culture of *R. solani* isolates on PDA at 25 ± 2°C.

The cultures were incubated at 25 ± 2°C for 18 days. The mycelial weights were determined after filtering the medium through Whatman filter paper No. 41 (90 mm dia), washing with distilled water, drying at 40°C for 24 h in a temperature controlled oven and weighing them in Sartorius Electronic Balance. The mycelial growth (weight) of the isolates was rated as follows poor: up to 50 mg; fair: > 50-75 mg; good: >75-100 mg; very good: >100-125 mg; excellent: >125 mg. The data were subjected to ANOVA and Cluster analyses.

### *In vitro* evaluation of fungicides

#### *i. Poison-food technique (PFT)*

Fungicides viz., carbendazim, PCNB, captafol, mancozeb, MEMC, thiram, metalaxyl + mancozeb (Ridomil), thiophanate-methyl, carboxin and zerlate were evaluated at different concentrations (Table 3.7) against five *R. solani* isolates (RS1,RS2,RS3, RS4,RS5), employing poison-food technique (PFT). To obtain a desired concentration, appropriate quantity of fungicide was added to the sterilized double strength PDA medium of 40 to 45°C and its equal quantity poured in sterile flat bottomed assay Petri dishes. Mycelial disks, 4 mm dia taken from the periphery of actively growing 5-day-old cultures, were inoculated at the centre of each Petri dish and incubated at 25 ± 2°C. Three replicates for each concentration were kept and a control was maintained without fungicide. Observations on colony diameter were recorded on seventh day of incubation from each replicate. The

percent inhibition of growth in each treatment was calculated by the following equation (Vincent, 1927) and the mean calculated.

$$I = \frac{100\ (C - T)}{C}$$

where I, inhibition over control, C, growth in control and T, growth in treatment.

### *ii. Soil fungicide screening technique (SFST)*

The soil-fungicide screening technique (SFST) described by Zentmeyer (1955) and Corden and Young (1962) modified by Sharma and Mohanan (1991a,b) was used for evaluating the efficacy of fungicides. Fungicides viz., MEMC, PCNB, carboxin, carbendazim, and metalaxyl+mancozeb (Ridomil) at different concentrations were screened against five *R. solani* isolates (RS1,RS2,RS3,RS4,RS5) (Table 3.7). Air-dried forest soil was sieved through a sieve (5 mesh $cm^{-2}$) and autoclaved for 45 min at 15 p.s.i. After cooling, 10 g of soil was placed in sterile glass vial of 30 mm dia and 8 mm length. A culture disk (8 mm dia) punched from an actively growing 5-day-old colony of *R. solani* was transferred over the soil. Another 10 g of sterile soil was placed over the disk. Ten millilitre of fungicide solution prepared in sterile water was gently poured over the soil surface using a sterile pipette; each concentration had three such vials. In control vials sterile distilled water was poured. The mouth of the vial was covered with aluminium foil. The vials were incubated for 24 h at 25 $\pm$ 2$^{o}$C. After incubation, the soil along with the mycelial disk from the vials was emptied gently and the mycelial disk removed with sterile forceps. The disk was washed in three changes of sterile water to remove the adhering soil particles and transferred to Petri dish containing PDA with the mycelial surface of the disk facing the

medium. Observations on the diameter growth of the colony were recorded after seven days. Percent inhibition of growth in each treatment was calculated using the equation of Vincent (1927).

**Table 3.7: List of fungicides evaluated against *R. solani* employing PFT and SFST**

| Sl. No. | Trade name | Common name | Chemical name | % Conc. (a.i.)used |
|---|---|---|---|---|
| 1. | Bavistin | carbendazim | methyl benzimidazole -2-yl-carbamate | 0.025,0.05, 0.1,0.2 |
| 2. | Brassicol | PCNB | pentachloronitrobenzene | 0.05,0.1,0.2,0.3,0.5 |
| 3. | Difolatan | captafol | cis-N-(1,1,2,2,-tetra-chloroethylthio) -3a,4, 7,7a-tetrahydrophthalimide | 0.05,0.1,0.2 |
| 4. | Dithane M-45 | mancozeb | Manganese ethylenebis-dithiocarbamate + Zn ions | 0.05,0.1,0.2 |
| 5. | Emisan-6 | MEMC | 2-methoxyethyl mercuric chloride | 0.001,0.003, 0.006, 0.008 |
| 6. | Hexathir | thiram | tetramethylthiuram disulphide | 0.05,0.1,0.2 |
| 7. | Ridomil | metalaxyl + mancozeb | (+)-methyl-N- (2-methoxy acetyl)-N-(2,6-xylyl) DL alaninate + mancozeb | 0.025,0.05,0.1, 0.2 |
| 8. | Topsin M | thiophanate methyl | 1,2-di-(3-methoxycarbonyl -2-thioureido) benzene | 0.05,0.1,0.2 |
| 9. | Vitavax | carboxin | 2,3-dihydro-6-methyl-5-phenylcarbamoyl-1,4,-oxathin | 0.025, 0.05,0.1 0.2 |
| 10. | Ziram 80 | zerlate | Zinc dimethyldithio carbamate | 0.05,0.1,0.2 |

**Screening of antagonistic organisms against *R. solani* isolates**

***i. Isolation of* Trichoderma *species***

Soil samples (25 g) from *B. bambos* nurseries at Pezhad, Paneli (Malayattoor Forest Div.) and Periya (South Wynad Forest Div.) were collected, air-dried, compacted and used for isolation of *Trichoderma* spp. on rose bengal agar medium (Martin, 1950), by the soil plate technique (Warcup, 1950). *Trichoderma harzianum* and *T. viride* isolated from nursery soil were made into pure cultures. In addition, cultures of *T. harzianum* and *T. viride* were also obtained from Biocontrol Laboratory, Tamil Nadu Agricultural University (TNAU), Coimbatore. One isolate each of *T. harzianum* and *T. viride* from bamboo nursery soil at Pezhad, Paneli and Periya and one isolate each of the two species obtained from TNAU, Coimbatore were used in screening trials against *R. solani* isolates viz., RS1, RS2, RS3, RS4, RS5.

***ii. Petri dish bioassay***

Antagonistic behaviour of isolates of *T. harzianum* and *T. viride* selected above was studied in Petri dish assay technique against *R. solani* bamboo isolates. The ability to inhibit the growth of *R. solani* isolates and or colonize the isolates was taken as indication of antagonism. Disk (5 mm dia) taken from actively growing 5-day-old PDA colony of *R. solani* was plated at one side of the sterile PDA medium in 90 mm Petri dish and opposite side with the test isolates of *T. harzianum* or *T. viride* separately. The Petri dishes were incubated at 25 $\pm$ 2$^{o}$C for seven days and observations recorded on antagonism, predation, lysis of mycelium, etc.

*iii. Slide culture*

Four isolates each of *T. harzianum* and *T. viride* were tested against *R. solani* bamboo isolates employing slide culture technique for antagonistic behaviour. Mycelial disks (5 mm dia) from the margin of actively growing 4-day-old culture of *R. solani* isolates and those of antagonistic fungi were placed four centimetre apart on the sterilized microscopic slide coated with 1.5 percent water agar. The inoculated slides were placed over a U shaped glass tube kept in the Petri dish (120 mm dia) having moistened sterile blotter disks. The setups were incubated at 25 $\pm$ 2$^{o}$C for 2-to 3-days. The process of antagonism, coiling, parasitism, lysis, cell degradation, etc. were observed under Leitz Dialux 20 microscope. Percentage of hyphal interaction (HI) was calculated by following the formula:

$$\text{Percent HI} = \frac{A}{B} \times 100$$

where, A is the sum of parasitized *R. solani* hyphae in 15 microscopic field (40 x 10x) and B is the sum of *R. solani* hyphae in 15 microscopic field. The most efficient antagonists (mycoparasites) among *T. harzianum* and *T. viride* were selected.

*iv. Seedling bioassay*

a. Soil amendment with *Trichoderma harzianum* and *T. viride*

*Trichoderma* spp. were mass cultured using Tapioca rinder substrate (Kausalya Gangadharan and Jeyarajan, 1988). Powdered tapioca rinder (200 g) was mixed with 750 ml water, filled in polypropelene bags (30 x 20 cm) and sealed by flaming. These sealed bags were steam

sterilized at 15 p.s.i. for 2 h on two successive days. Ten millimetre dia disks of *T. harzianum* (TH4) and *T. viride* (TV3), cut from actively growing 5-day-old cultures, were transferred to each bag aseptically after opening the bag separately. The bags were resealed by flaming and incubated for 20 days at 25 $\pm$ 2$^{o}$C.

Inoculum of *R. solani* isolates was prepared as described under pathogenicity trial. Twenty gram of inoculum was added to sterile forest soil (2 Kg) 1:100 (W/W) in aluminium trays (30 x 30 x 5 cm), thoroughly mixed and watered. The trays were covered with a paper and incubated for two weeks. In the infested soil, promising antagonistic fungi (*T. harzianum* (TH4) and *T. viride* (TV3)), raised on tapioca rinder medium, were added separately at the rate of 20 g per kg of soil. The soil was mixed thoroughly and incubated for seven days. *B. bambos* seeds were sown at the rate of 1 kg per standard bed i.e., 7 g per tray. A thin layer of sterile soil was put over the sown seeds to cover the seeds. All the treatments were replicated thrice. Controls were maintained without adding the antagonistic fungus in the soil infested with *R. solani*. Observations on percent seedling emergence, incidence of disease and spread in various treatments were recorded for 45 days.

**b. Seed treatment with *Trichoderma harzianum* and *T. viride***

*Trichoderma harzianum* (TH4) and *T. viride* (TV3) were grown on PDA medium for 10 days and the spore suspensions ($2x10^{8}$ spores $ml^{-1}$) prepared separately in sterile distilled water. The spore suspension (400 ml) containing 0.5 percent carboxy methyl cellulose (CMC), a sticker, was added to 350 g of *B. bambos* seeds, mixed thoroughly by shaking vigorously and then air-dried (20 min). These treated seeds were sown at the rate of 7 g per tray (30 x 30 x 5 cm) in soil

infested with *R. solani* (2:100). All the treatments were replicated thrice. Control sets without the antagonistic organisms were also maintained. Observations on percent seedling emergence, disease incidence, symptoms, and spread were recorded for 45 days.

## NURSERY TRIALS

### EXPERIMENTAL SITE AND PREPARATION OF NURSERY BEDS

The study was conducted in a forest nursery at Chandhanathodu in Wynad District of northern Kerala. Chandhanathodu, 800 m above mean sea level, receives an annual rainfall of 6000 mm or more. The area records very high relative humidity throughout the year with mean minimum and maximum daily temperatures 13$^{o}$C and 32$^{o}$C, respectively. The soil of the nursery site is well drained, loamy, medium deep and acidic (pH 6.6). The soil of the area was thoroughly worked and 80 experimental seedbeds of 3 x 1 x 0.3 m were prepared at an espacement of 60 cm.

### Cultural control of web blight

A total of 36 beds were randomly selected in the nursery for studying the effect of various cultural treatments for controlling web blight. Treatments viz., two levels of moisture regime (W1,W2), shade with coconut leaf thatch (CLT) and without shade (NS), three seed rates (SR1,SR2,SR3), were given. All the 12 treatment combinations were replicated thrice (Table 3.8).

Table 3.8: Various treatments of seed rate, water regime and shade tried for the cultural control of web blight

| Sl. No. | Treatment combination | Sl. No. | Treatment combination | Sl. No. | Treatment combination |
|---|---|---|---|---|---|
| 1. | SR1W1NS* | 5. | SR3W1NS | 9. | SR2W1S |
| 2. | SR1W2NS | 6. | SR3W2NS | 10. | SR2W2S |
| 3. | SR2W1NS | 7. | SR1W1S | 11. | SR3W1S |
| 4. | SR2W2NS | 8. | SR1W2S | 12. | SR3W2S |

* SR1: 0.25 Kg seed/bed; SR2: 0.50 Kg seed/bed; SR3: 0.75 Kg seed/bed; W1: 30 l water/bed/day; W2:60 l water/bed/day; S: coconut leaf thatch shade (CLT); NS:no shade.

*i. Soil moisture regime*

Two soil moisture regimes viz., 10 l $m^{-2}$ (W1) and 20 l $m^{-2}$ (W2) per day were regulated by appropriate frequency of watering, which was four to five times a day during the first fifteen days' of sowing and two to three times after 30 days' of emergence of seedlings.

*ii. Shading*

For shade treatment, conventional coconut leaf thatch (CLT), was used. Of the 36 seedbeds, 18 were provided with CLT shade and the others without shade (NS). Light intensity over the beds under CLT and open was measured using an Integrating Photometer (LICOR, USA) at hourly intervals from 07.00 to 17.00 h during the study period. For comparison, light intensity over the seedbeds under coir mat (CM) shading in other experiments was also measured.

*iii. Seedling density*

Effect of seedling density on incidence and spread of web blight was studied by using different seed rates for sowing. Beds were broadcast sown at the rate of 1 Kg, 2 Kg and 3 Kg per standard bed, i.e., 0.25 Kg, 0.50 Kg and 0.75 Kg/bed. Seeds of *B. bambos* were cleaned and percent germination ascertained (96%) by blotter method (ISTA, 1966). Cleaned seeds were transferred to gunny bags and soaked in stream water overnight. The beds were broad-cast sown and covered with 2 to 3 mm thick layer of fine sieved soil.

**Biocontrol of web blight**

*i. Soil solarization*

Soil solarization was done by covering the seedbeds with thin polythene sheets. Four beds were selected randomly and watered profusely to make the soil moist. Then each bed was covered with a polythene sheet (4.50 x 2.50 m) and edges sealed with mud on all sides. As far as possible the beds were kept moist constantly by drenching the soil with water on all the sides of the beds in the morning and evening. Soil thermometers were inserted in the beds at different depths (2.5, 5.0 and 15.0 cm) and soil temperatures were recorded during 08.00 to 19.00 h at 1 h interval. The polythene sheets were removed after 18 days and the beds were sown with bamboo seeds at the rate of 0.5 Kg per bed and watered at the rate of 30 litre per bed per day.

*ii. Treatment with antagonistic organisms*

**Soil amendment**

Antagonistic organisms viz., *Trichoderma harzianum* (TH4) and *T. viride* (TV3) were mass cultured on tapioca rinder medium (Kausalya Gangadharan and Jeyarajan, 1988) and 20-day-old cultures were used for soil inoculation. Inoculum of *T. harzianum* and *T. viride* was applied separately at the rate of 150 g $m^{-2}$ to six beds selected at random in the nursery; the inoculum was mixed thoroughly with the top layer of soil (5 cm depth). The treated nursery beds were watered regularly (30 l per bed per day) and sown (0.50 Kg per bed) after 7 days of applying the antagonistic fungi.

**Seed treatment**

For seed treatment spore suspensions of *Trichoderma harzianum* (TH4) and *T. viride* (TV3) were prepared in distilled water ($2 \times 10^8$ spores $ml^{-1}$) and added five percent CMC as stcker. Bamboo seeds (3 Kg), soaked in water overnight, were used for the antagonistic fungal seed-coating; half the quantity of water soaked seeds was coated with *T. harzianum* and the other half with *T. viride* spores by soaking for 10 min in 1.5 l of the respective spore suspensions. The spore-coated seeds were air-dried for 30 min and broad-cast sown separately in three nursery beds, each at the rate of 0.5 Kg per bed. The beds were watered at the rate of 30 litre per bed per day.

## Chemical control of web blight

### *Fungicidal treatment*

For conducting field screening of fungicides against web blight 21 seed beds were selected randomly and six fungicides viz., MEMC, mancozeb, carbendazim, metalaxyl + mancozeb (Ridomil), thiram, and carboxin were applied as soil and foliar drench at the rate of 15 l of fungicidal solution per bed. A randomized block design was followed throughout the experiment. Schedule of fungicide treatments and dosages used are given in Table 3.9. There were three replicate seedbeds for each treatment. Three control beds without any treatment were also maintained. Seeds were sown at the rate of 0.50 Kg per bed and watered 30 l per bed per day.

**Table 3.9: Schedule of fungicide treatment in the bamboo nursery at Chandhanathodu**

| Fungicide | Days after emergence | | |
|---|---|---|---|
| | 7 | 21 | 42 |
| | Concentration (% a.i.) | | |
| MEMC | 0.003 | 0.003 | 0.003 |
| Mancozeb | 0.2 | 0.2 | 0.2 |
| Carbendazim | 0.2 | 0.2 | 0.2 |
| Ridomil | 0.2 | 0.2 | 0.2 |
| Thiram | 0.2 | 0.2 | 0.2 |
| Carboxin | 0.2 | 0.2 | 0.2 |

Recording observations on seedling infection and growth of seedlings

*i. Disease incidence and severity*

Incidence and severity of web blight were recorded from the seedbeds under various treatments. Observations were recorded daily till 44 day of emergence of seedlings and later at weekly or fortnightly intervals. The incidence and progress of web blight was recorded by counting the number of disease foci (patches) (Sharma and Mohanan, 1992). The foci were serially numbered using aluminium labels. At each observation, foci were marked by placing coloured reed bamboo splinters at the periphery of the patch so as to ascertain whether the focus was expanding further. In the case of expanding foci, splinters painted with different colours were inserted at the new periphery. At each observation total number of seedlings affected in each focus (patch) was recorded. A quadrat, 20 x 20 cm was used to count the number of seedlings affected in a focus. From the cumulative number of foci and the total number of seedlings affected, area under the disease progress curve (AUPDC) (Smith *et al.*, 1988) and growth rate of disease was calculated in each treatment combination.

$$AUDPC = \sum_{i=1}^{n-1} (Y_{i+1} + Y_i) /2 \times (t_{i+1} - t_i)$$

where $t_i$= time in days, i = 0 to n, and $Y_i$ = number of foci or number of diseased seedlings on day i. Growth rate was calculated using exponential model, $Y_t = Y_o^{ert}$ (van der Plank, 1963,1968; Kranz, 1974). In cases where disease severity was nil, 0.001 was added to all such observations before transforming them to log scale.

*ii. Growth of seedlings*

Six beds were selected randomly and three of them were provided with CLT shade and three left without shade (NS). Watering was done at the rate of 30 l/bed/day upto 20 days of seedling emergence and later 40 l/bed/day. Data on emergence of seedlings, development of leaves, rhizome and new shoots were recorded. Seedling biomass (root and shoot biomass) was assessed at 10 days interval in seedbeds under CLT and without shade from 20th day of emergence up to 80 days. One hundred seedlings from each treatment were carefully uprooted, washed to remove the soil particles adhered to the root system, air-dried for seven days and shoot and root parts weighed separately.

Meteorological data

Data on rainfall and ambient temperature for the year 1991 were gathered from weather station (Navarathna Estate, Chandhanathodu) located near the experimental nursery.

Soil temperature at a depth of 10 cm in seedbeds under differnt shade and moisture regime was recorded using soil thermometers, for 52 days of seedling emergence. Wet and dry bulb temperatures in the nursery were recorded daily at 08.00 h, 12.00 h and 17.00 h and respective r.h. was deduced. Daily maximum and minimum temperatures were also recorded in the nursery.

Soil water potential was measured in the seedbeds using Tensiometer (WIKA, Germany). Tensiometers were installed at 15 cm soil depth in each seedbeds under different moisture regimes (W1,W2) and shade treatments (CLT,NS). Observations on soil water potential in the seedbeds were recorded during 08.00, 12.00 and 18.00 h.

**Statistical analyses**

The data generated from different experiments were subjected to statistical analyses. Analysis of variance (ANOVA) was employed for studying the effects of different factors. Comparison of treatments was made through Duncan's Multiple Range Test (DMRT). Regression equations were fitted through method of least squares. Cluster analysis was employed for grouping treatments with multiple characters. All the analyses were carried out using SPSS / PC+ ver.2.0 (Norusis, 1988).

# RESULTS AND DISCUSSION

# 4. RESULTS AND DISCUSSION

## DISEASE SURVEY

### BAMBOO NURSERIES

In Kerala, usually 12- to 18- month-old bareroot or container seedlings are used for outplanting. Bamboo seedlings are raised by the Forest Department by following the usual forest nursery prescriptions. Usually, bamboo nurseries are raised during the month of December-January. Bamboo seeds collected during the current seeding year or properly stored seeds having high germinability are sown at the rate of 500 g to 1.5 Kg per standard seedbed (12 x 12 x 0.25 m). In many localities, seeds pre-treated by soaking overnight in water are used for sowing. Shade regulation over the nursery beds and watering are done as in the case of other forestry species. After 40 to 50 days of growth, the seedlings are either transplanted into polythene containers (18 x 12 cm) filled with forest soil or in the newly raised transplanting beds, at an espacement of 15 x 15 cm. Outplanting of one-year-old bareroot or container seedlings is carried out after the onset of South-West monsoon i.e., during the month of June-July.

A total of 27 bamboo nurseries comprising of 10 to 100 standard beds, raised at 18 different localities in Kerala, were surveyed for the occurrence of diseases during 1987-1992 (see Table 3.3 under Materials and Methods). Altogether 13 seedling diseases were recorded in bamboo nurseries with which 14 fungi were found associated consistently (Table 4.1). Most of these diseases were prevalent in almost all the bamboo nurseries surveyed, while a few were restricted to certain nurseries. However, the severity of each disease varied

from nursery to nursery depending on the local climatic factors, bamboo species raised, seedling density, nursery practices adopted, etc.

**Table 4.1: Checklist of nursery diseases of bamboos recorded in Kerala during 1987-1992**

| Sl. No. | Disease | Pathogen(s) | Bamboo species affected |
|---|---|---|---|
| 1. | Damping-off | | |
| | i. Pre-emergence damping-off | *Rhizoctonia solani* | BB,DS,DB,TS* |
| | | *Fusarium moniliforme* | |
| | | *F. oxysporum* | |
| | ii. Post-emergence damping-off | *R. solani* | BB,DS,DB,TS |
| 2. | Seedling spear rot | *R. solani* | BB,DS |
| 3. | Seedling wilt | *R. solani* | BB,DS |
| 4. | Web blight | *R. solani* | BB,DS,DB,TS |
| 5. | Leaf rust | *Dasturella divina* | BB,DS,DB,OT,TS |
| 6. | Bipolaris leaf blight | *Bipolaris maydis* | BB,DS,DB,DM,TS,OW |
| | | *B. urochloae* | PP |
| | | *Bipolaris* sp. | BB |
| 7. | Exserohilum leaf spot | *Exserohilum rostratum* | BB,DS |
| | | *E. holmii* | BB,PP |
| 8. | Dactylaria leaf spot | *Dactylaria* sp. | BB,DS,DB,OW,TS |
| 9. | Colletotrichum leaf spot | *Colletotrichum gloeosporioides* | BB,DS |
| 10. | Curvularia leaf spot | *Curvularia pallescens* | BB,BV,DL,TO,OS |
| 11. | Alternaria leaf tip blight | *Alternaria alternata* | BB,DS |
| 12. | Seedling rhizome rot | *Rhizostilbella hibisci* state of *Nectria mauritiicola* | BB |
| 13. | Leaf stripping and stunting | Unknown etiology (possibly a virus) | BB |

*BB:*B.bambos*; DS:*D.strictus*; DB:*D.brandisii*; DL:*D.longispathus*; DM:*D.membranaceus*;TS:*T.siamensis*; OS:*O.scriptoria*; OT:*O.travancorica*; OW: *O. wightii*; PP:*P.pubescens*.

## *DISEASES IN BAMBOO NURSERIES*

### 1. DAMPING-OFF

#### Occurrence

Damping-off has been recognized as a significant problem in bamboo nurseries in Kerala causing considerable loss of seed and seedlings. The disease, both pre- and post-emergence damping-off was recorded in *B. bambos* nurseries raised at Periya (South Wynad Forest Divn.), Chandhanathodu (Cannanore Forest Divn.), Paneli (Malayattoor Forest Divn.), Pattikad and Peechi (Trichur Forest Divn.), Nilambur (Nilambur Forest Divn.), Kulanjithodu (Ranni Forest Divn.) and in *D. strictus* nursery at Dhoni (Palakkade Forest Divn.) during 1987-1992. In these nurseries, different seed rates ranging from 750 g to 1.5 Kg per standard seedbed were used. In addition, the seedbeds were provided shade with thatched coconut leaves or with 'jungle leaves' and over watered. Pre-treatment of seeds was done in all the nurseries except in a nursery at Kulanjithodu where severe damping-off was recorded (Table 4.2).

Disease incidence was found to be low in all the nurseries except at Dhoni during 1987-'88, and at Kulanjithodu, during 1989-'90 where respectively medium and severe infections were recorded. Damping-off was also recorded in seedlings of *D. strictus, D. brandisii* and *T. siamensis* in a nursery at Chandhanathodu during 1991-'92.

#### Symptoms

In bamboo nurseries sown with good quality seeds but provided with either excessive or thick shade and frequent watering often poor

seedling emergence was recorded even after 7- to 12 days of sowing. The disease occurred in patches in the seedbeds. The size and number of the patches and the seedling emergence depended upon the severity of the infection. When a thin layer of top soil over the patch was removed gently, a large number of well-filled seeds covered with fungal mycelium and powdery fungal spore mass were observed. The seed decay and pre-emergence damping-off were characterized by the rotting of the well-filled viable seeds and also the just emerged radicle. In nurseries situated at Dhoni and Kulanjithodu, partial failure of nursery was recorded due to the poor seedling emergence on account of damping-off. Post-emergence damping-off was characterized by the development of water-soaked greyish brown lesions on the emerging plumule near the soil level. The lesions spread and became necrotic which resulted in collapse of the affected plumule.

**Table 4.2: Severity of damping-off in bamboo nurseries at different localities in Kerala surveyed during 1987-1992**

| Sl. No. | Locality | Bamboo species | 1987-'88 | | 1988-'89 | | 1989-'90 | | 1990-'91 | | 1991-'92 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | DSI | DSR | DSI | DSR | DSI | DSR | DSI | DSR | DSI | DSR |
| 1. | Periya | BB[1] | | | | | | | 0.80 | L | 0.64 | L |
| 2. | Chandhanathodu | BB | | | | | | | | | 0.95 | L |
| 3. | Pattikad | BB | | | 0.40 | L | | | | | | |
| 4. | Paneli | BB | | | | | | | 0.50 | L | 0.40 | L |
| 5. | Peechi | BB | | | 0.50 | L | 0.40 | L | 0.36 | L | | |
| 6. | Dhoni | DS | 1.13 | M | 0.75 | L | | | | | | |
| 7. | Nilambur | BB | | | 0.55 | L | 0.22 | L | | | | |
| 8. | Kulanjithodu | BB | | | | | 2.10 | S | | | | |

[1] DSI Disease severity index; DSR Disease severity rating; L: low; M: medium; S: severe; BB: *B. bambos*; DS: *D. strictus*

**Causal organisms**

Three fungi were found causing damping-off of bamboo seedlings.

1. *Rhizoctonia solani* Kühn state of *Thanatephorus cucumeris* (Frank) Donk (IMI No.350658).
2. *Fusarium moniliforme* Sheld. (IMI No.322571).
3. *Fusarium oxysporum* Schlecht.

*Rhizoctonia solani* was isolated mostly from the damped-off seedlings which caused radicle and plumule rot. While *Fusarium moniliforme* and *F. oxysporum* caused mainly pre-emergence damping-off and seed decay.

***Cultural characters***

1. *Rhizoctonia solani*: Colony on Potato dextrose agar (PDA) fast growing, yellowish brown in colour, mostly submerged with scanty aerial mycelium; hyphae septate, 7.0-8.8 µm dia; sclerotia widely scattered, light brown, small, 0.25-0.75 µm dia.

2. *Fusarium moniliforme*: Colony on Potato sucrose agar (PSA) fast growing, salmon to pale orange; microconidia fusoid to clavate, 6-12 x 1.5-2.4 µm, 0-septate, occasionally becoming 1-septate and produced in chains from subulate lateral phialides 22-28 µm long; macroconidia and chlamydospores absent.

3. *Fusarium oxysporum*: Colony on PSA white with pale violet tinge on the reverse; microconidia ellipsoid, cylindrical, straight or slightly curved, 6-12 x 2.2-3.4 µm, produced from simple short lateral phialides; macroconidia abundant, 3 to 5 septate, 28-56 x 3-5 µm; chlamydospores globose, formed singly or in pairs, intercalary or on short lateral branches.

**Pathogenicity test**

Seeds of *B. bambos* sown in *R. solani* infested soil showed comparatively poor emergence (57%) than those in control (96%). Though, seedling emergence occurred after four days of sowing in both control and *R. solani* infested soil, germination completed in control within seven days of sowing, while it took 12 days in treated soil.

Infection of radicle and just emerged plumule was observed in *R. solani* infested soil which consequently resulted in post-emergence damping-off. Post-emergence damping-off occurred within one to two days of emergence as water-soaked greyish brown lesions on the plumule at the soil level. Severe infection on the emerging radicle and plumule often led to the development of abnormal incurved seedlings which later succumbed. When a thin top layer of the seedbed soil was removed gently, the ungerminated well-filled decayed seeds were found covered with the mycelium of *R. solani*. *R. solani* was reisolated from the infected radicle, decayed seeds and damped-off seedlings.

*B. bambos* seeds coated with conidia of *Fusarium moniliforme* and *F. oxysporum* separately and sown in Aluminium culture trays showed slightly low percent of seedling emergence (89) as compared to controls (96). Seedling emergence occurred after four days of sowing and completed within seven days in *Fusarium* treated seeds as well as in controls. Only pre-emergence damping-off occurred in both the *Fusarium* infested soils as evidenced by the low per cent seedling emergence. Upon a closer examination, ungerminated well-filled seeds treated with both *F. moniliforme* and *F. oxysporum* found decayed. The decayed seeds were covered with white cottony fungal mycelium bearing powdery spore mass over the whole seed surface. Infection of the just emerging radicle and plumule as greyish brown lesions was observed less frequently in seedlings infested with *F. moniliforme* and *F. oxysporum*. *F. moniliforme* and *F. oxysporum* were reisolated from the decayed seeds, decayed radicle and plumule.

**Discussion**

Damping-off, the first disease to appear in the seedbed nurseries affects seedlings both before emergence (pre-emergence damping-off)

and after emergence (post-emergence damping-off) within 2- to 15-days after sowing; the development of the disease chiefly depends upon the microclimatic conditions prevailing in the nursery. Though, almost all the nursery-grown forestry species are susceptible to damping-off fungi, the seeds of species which germinate quickly and seedlings grow fast possibly sustain less damage from damping-off than slow emerging and slow growing species (Duryea, 1984). This is also true in the case of bamboos as the seed germinates quickly and the seedling grows rapidly. The over all incidence and damage caused by damping-off are comparatively less in bamboo seedlings than those recorded for other forestry species. (Bakshi *et al.*, 1972; Sharma *et al.*, 1985; Mehrotra, 1990). Pre-sowing seed treatment is also known to play an important role in minimizing the incidence and development of damping-off (Bakshi, 1976). In the case of bamboo seeds, overnight soaking in water which possibly reduces the spermoplane microflora, and subterranean exposure of seeds prior to germination, facilitate to minimize the incidence of damping-off. This explanation holds good for the severe damping-off during the year 1989 recorded in a nursery at Kulanjithodu, sown without pretreating the seeds.

*Fusarium moniliforme* and *F. oxysporum* are associated only with the pre-emergence damping-off, while *R. solani* causes mainly post-emergence damping-off of bamboo seedlings. The only indication of pre-emergence damping-off in nursery beds is the presence of sparse and patchy germinating seedlings. But it is confirmed by digging up seeds that have not emerged and observing them for decay. A possible evidence of seedborne nature of Fusarium pre-emergence damping-off has been provided by the seed pathological studies on stored seeds of *B. bambos* and *D. strictus*, which reveal occurrence of *Fusarium* spp. in high frequency affecting seed germination and seedling growth (Mohanan, 1990a).

*Fusarium* spp. and *R. solani* have been recognized as the important damping-off pathogens in forest nurseries throughout the world (Brown and Wylie, 1991; Ferreira and Muchovej, 1991; Sutherland, 1991; Ray, 1991; Borja and Austara, 1991; Arentz, 1991; Perrin, 1991). In India, *R. solani* has emerged as the most important damping-off pathogen in forest nurseries, especially in high rainfall areas (Bakshi *et al.*, 1972; Sharma *et al.*, 1985; Mehrotra, 1990); however, *Fusarium* spp. were recorded less frequently in forest nurseries in the country (Bakshi, 1976; Sharma *et al.*, 1985). The present findings are in conformity with the earlier works cited above, as in bamboo nurseries also *R. solani* has become the principal damping-off fungus, whereas *F. moniliforme* and *F. oxysporum* are of minor importance and cause only seed decay and pre-emergence damping-off.

Damping-off in bamboo nurseries occurs in patches; the number of patches and their size, the rate of spread and seedling mortality depend largely on the cultural practices adopted in the nursery as well as the *R. solani* strain in the given population. These observations gain support from the previous works which clearly indicate that the fungi causing damping-off do not usually attack seedlings unless conditions for their development on the host are favourable or the conditions for the growth of seedlings are poor (Leach, 1947; Griffin, 1958; Rowan *et al.*, 1972). As in the case of bamboos, *R. solani* has been reported to be capable of infecting the seedlings at their different growth phases and causing various disease symptoms.

Excessive soil moisture due to over watering, dark shade, high seedling density and high organic soil contents are the main factors contributing to initiation and spread of damping-off (Roth and Riker, 1943; Vaartaja, 1952; Gibson, 1956; Sharma and Mohanan,1991a). Some of these factors are also found to be responsible for the high

incidence of damping-off in bamboo seedlings. Though, this disease can not be considered as an economically important one, for raising disease-free nursery stock pre-sowing seed treatment and regulation of moisture regime in the seedbeds should form part of the nursery management.

## 2. SEEDLING SPEAR ROT

### Occurrence

The disease was observed in *B. bambos* nurseries at Kulanjithodu during 1989-'90, Periya and Niravilpuzha (Wynad Forest Divn.) during 1990-'91, Chandhanathodu during 1991-'92 and in *D. strictus* nursery at Dhoni during 1988-1989. Infection of emerging spear-like plumule occurred within two to five days of emergence. The overall disease incidence was found low in all the nurseries. However, in *B. bambos* nursery at Chandhanathodu, the disease incidence was severe in seedbeds without any shade, sown with high seed rate of 3 Kg per standard bed and watered insufficiently. In seedbeds where the seeds were covered with a thick layer (>0.5 cm) of soil generally the disease incidence was very high.

### Symptoms

The disease manifested as small irregular water-soaked lesions on emerging spear-like plumule near the soil level or at the pointed apical portion. The lesions coalesced and spread rapidly from base to the apex or from tip downwards covering the entire spear which subsequently became necrotic. The infected spears failed to grow further and expand to form leaves and dried up in due course. Disease occurred in patches in seedbeds and the advanced stage of infection

could easily be detected as the infected seedlings in patches gave a burnt-up appearance.

**Causal organism**

*Rhizoctonia solani* Kühn state of *Thanatephorus cucumeris* (Frank) Donk (IMI No. 350658).

**Pathogenicity test**

In artificial inoculation trials seedlings of *B. bambos* emerged on the fourth day of sowing in both *R. solani* treated soil as well as control. Characteristic spear rot was observed in the infested soil on the emerging seedling plumule near the soil level as greyish brown water-soaked lesions with dark brown margin. The lesions spread very quickly in linear fashion towards the tip of the elongating spear and within three days the entire infected spear became necrotic. Infection at the tip of the spear emerging through the soil was also observed, where downward spread of the infection noticed. In control no infection was recorded. *R. solani* was reisolated from the infected seedlings.

**Discussion**

Seedling spear rot caused by *R. solani* is the disease which affects emerging plumule. It is a new disease recorded for the first time on bamboos. Symptomwise, the disease appears to be an extension of the damping-off which was probably delayed by the unfavourable soil conditions. The disease was recorded only in five out of 27 nurseries surveyed where a thick layer of soil was spread over the seeds and the seedbeds received less water. Longer period of subterranean condition of the emerging plumule due to thick layer of soil, high soil

temperature and water stress may have possibly enhanced the chance of infection by *R. solani*. This circumstantial evidence clearly suggests that the development of spear rot depends mainly on the nursery management practices. Occurrence of this new disease in bamboos confirms the earlier observation that *R. solani* is highly diverse in its characteristics in producing different disease symptoms under different microclimatic conditions (Baker, 1970).

### 3. SEEDLING WILT

#### Occurrence

The disease was recorded in 20- to 40-day-old *B. bambos* and *D. strictus* seedlings at Chandhanathodu nursery during 1991-'92 and in 40- to 50-day-old container seedlings of *B. bambos* in a Social Forestry nursery at Kalamassery (Ernakulam Social Forestry Divn.) during 1987-1988. At Chandhanathodu, seedling wilt was observed in seedbeds both provided with and without shade, having high seedling density (3.0 Kg seeds per standard bed) and watered copiously. In both the nurseries, disease incidence was found to be low.

#### Symptoms

Initially, the infection occurred as water-soaked, greyish brown lesions on the seedling stem near the ground level. The infection spread upward and caused lesions on leaf sheath, basal leaves and stem; the juvenile leaves were free from the infection. The infected areas on the stem became dark brown in colour and necrotic, which later coalesced and became constricted. Affected seedlings showed symptoms of physiological wilting. Due to loss in turgidity, the seedlings showed rolling up of the entire foliage from 11.00 AM

onwards, especially those in seedbeds under direct sun light and less frequently watered. Bending and breaking up of the seedling stem often occurred at the constricted area and epicormic roots developed from the lower portion of this cankered area. The wilted seedlings rarely showed browning and decay of feeder roots. Production of small yellowish brown sclerotial bodies on the affected basal part under high humidity was also noticed. Severe infection usually resulted in high mortality of seedlings, either in distinct patches or scattered all over the seedbed. The infection continued for 30- to 40 days in seedbeds depending on the microclimatic conditions prevailing in the nursery. In seedbeds provided with shade, the infected seedlings could be detected easily during the early morning hours. However, by the middle of the day in the shaded seedbeds and from 11.00 AM onwards in the seedbeds without shade, the symptoms of physiological wilting and rolling up of the leaves became evident.

**Causal organism**

*Rhizoctonia solani* Kühn state of *Thanatephorus cucumeris* (Frank) Donk (IMI No.350659); anastomosis group - AG2-2IV.

**Discussion**

Seedling wilt of bamboos caused by *R. solani* is recorded in bareroot and container seedlings affecting young 20- to 40-day-old seedlings. The pathogen affects the conducting tissues of root and stem and rarely the foliage is affected. This indicates the specificity of the fungus on host tissues. *R. solani* is already known for its complex nature due to the presence of different strains which can affect all the tissues of 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

(Baker, 1970). The *R. solani* strain, which caused seedling wilt, was found to be belonging to the anastomosis group AG2-2IV. Isolates of *R. solani* AG-2-2 are generally considered to cause root and crown rots of sugar beet and corn (Anderson, 1982; Summer and Bell, 1986; Ogoshi, 1987; Windels and Nabben, 1989); they also have been reported to cause foliar diseases and seedling decay of soybean, and sheath blight of mat rush (Ogoshi, 1987; Liu and Sinclair, 1991,1992). In Kerala, *R. solani* has been recorded to cause seedling wilt and root rot of *Eucalyptus grandis* Hills ex Maiden, *E. tereticornis* Sm. and *Casuarina equisetifolia* (Sharma *et al.* 1984b; Mohanan and Sharma, 1989, 1993).

## 4. WEB BLIGHT

### Occurrence

Web blight of bamboo, a widespread seedling disease in Kerala, was recorded from 23 seedbed nurseries in 15 localities in the State during 1987-1992 (Table 4.3). Disease was also recorded in *B. bambos, D. strictus, D. brandisii,* and *T. siamensis* seedlings in a experimental nursery raised at Chandhanathodu during 1991-'92. Severity and spread of infection largely depended on the microclimatic conditions prevailing at the nursery site and also the cultural practices adopted in the nursery. In all the nurseries surveyed, disease severity was found to be low except at Niravilpuza, Kulanjithodu, Periya, Begur, Paneli and Pezhad, where disease severity index (DSI) ranged between 1.04-1.25 and disease severity rating (DSR) was medium (Table 4.3). The disease affected 20- to 30-day-old bamboo seedlings and continued further depending on the favourable microclimatic conditions prevailing in the nursery. Severe infection affected considerably the availability of the transplanting stock.

Table 4.3: Severity of web blight in bamboo nurseries at different localities in Kerala surveyed during 1987-1992

| Sl No. | Locality | Bamboo species | DSI* | DSR | Year |
|---|---|---|---|---|---|
| 1. | Vadavukodu | BB | 0.33 | L | 1987-1988 |
| 2. | Kalamassery | BB | 0.30 | L | 1987-1988 |
| 3. | Dhoni | DS | 0.40 | L | 1987-1988 |
| | | | 0.30 | L | 1988-1989 |
| 4. | Peechi | BB | 0.50 | L | 1988-1989 |
| | | | 0.60 | L | 1989-1990 |
| | | | 0.54 | L | 1990-1991 |
| 5. | Nilambur | BB | 0.40 | L | 1988-1989 |
| | | | 0.63 | L | 1989-1990 |
| 6. | Pattikad | BB | 0.93 | L | 1987-1988 |
| 7. | Pariyaram | BB | 0.75 | L | 1989-1990 |
| 8. | Kulanjithodu | BB | 1.04 | M | 1989-1990 |
| 9. | Vadasserikkara | BB | 0.76 | L | 1990-1991 |
| 10. | Niravilpuzha | BB | 1.05 | M | 1990-1991 |
| | | | 1.16 | M | 1991-1992 |
| 11. | Thettamala | BB | 0.82 | L | 1991-1992 |
| 12. | Periya | BB | 1.25 | M | 1990-1991 |
| | | | 1.24 | M | 1991-1992 |
| 13. | Begur | BB | 1.04 | M | 1990-1991 |
| 14. | Paneli | BB | 1.12 | M | 1990-1991 |
| | | | 1.18 | M | 1991-1992 |
| 15. | Pezhad | BB | 0.93 | L | 1990-1991 |
| | | | 1.20 | M | 1991-1992 |

*DSI: Disease severity index; DSR: Disease severity rating; L: low; M: medium; BB: *B.bambos*; DS: *D.strictus*.

**Symptoms**

Infection appeared in 20- to 30-day-old bamboo seedlings as water-soaked lesions on the stem near the soil level. Later, the infection spread rapidly affecting the entire shoot, except one to two juvenile leaves. Infected stem and foliage became discoloured, greyish brown to dark brown, within two to five days of infection. Leaf necrosis was

initiated either from the leaf tip and proceeded towards the base of the leaf or from the leaf margins towards the midrib.

The disease spread very rapidly within the seedlings through the fast growing mycelial strands of the fungus. Incitation and spread of disease between seedlings was mainly through the physical contact of the diseased foliage with the healthy neighbouring seedlings. The disease usually occurred as small patches comprising of 5 to 10 seedlings in the seedbed which increased in size as more and more seedlings got affected gradually under favourable microclimatic conditions. The individual infection focus in the seedbed spread and merge with other foci leading to formation of large disease patches of upto 30 cm dia. The disease was recorded in seedbeds provided with or without shade. However, high disease incidence and its rapid spread was usually observed in seedbeds having high seedling density and those watered copiously. Infected foliage showed shades of greyish brown, purplish grey, and pastel green discolouration which later turned into necrotic areas. Complete necrosis often led to withering of the foliage. Under high humidity, especially during the early morning hours fungal mycelium, which arose from the soil epiphytically, grew over the affected seedlings entangling their foliage and stem. Yellowish brown sclerotia of the fungus developed on the decayed basal foliage and stem. The affected seedlings were killed outright within 10 to 20 days of infection leaving large circular to irregular patches of dried up seedlings in seedbeds (Plate 1a,b).

**Causal organism**

*Rhizoctonia solani* (IMI Nos. 350660, 350661, 350662, 350659); anastomosis groups - AG1-IA, AG1-IC, AG2-2IV.


Plate 1. Web blight of bamboo seedlings (*Bambusa bambos*) caused by *Rhizoctonia solani*. a: A view of the seedbed nursery showing diseased and dried up *B. bambos* seedlings, b: A close up of severely affected seedlings with the web blight disease.

**Discussion**

Among the nursery diseases of bamboos recorded, web blight caused by *R. solani* is the most widespread and economically important. The disease occurs in almost all the bamboo nurseries surveyed and the severity varies considerably depending on the microclimatic conditions prevailing in the nursery. Though, web blight affects 20- to 30-day-old seedlings, the disease continues (90- to 120-days) till the microclimatic conditions in the nursery are favourable for the growth and development of the fungus. Heavy and incessant rain for a couple of days followed by an overcast weather for 5- to 6-days form the ideal conditions for the disease to become severe. High density of seedlings, thick shading over the seedbeds and free water on seedlings also influenced greatly the development and spread the disease.

In forest nurseries in India, web blight caused by *R. solani* has earlier been recorded in Khasi pines (*Pinus kesiya* Royle ex Gord. (Mehrotra, 1989), *Casuarina equisetifolia* Forst in Kerala (Mohanan and Sharma, 1989, 1993), and a large number of broad leaved forest species viz., *Ailanthus triphysa* (Dennst.) Alston, *Azadirachta indica* A. Juss., *Bombax ceiba* L., *Cassia nodosa* Ham., *Ceiba pentandra* (L.) Gaertn., *Derris robusta* Benth., *Eucalyptus* spp., *Gmelina arborea* L., *Melia azedarach* L., *Michelia champaka*, (L.) Piers., *Paraserianthes falcataria* (L.) Nielson in different parts of the country (Sharma and Sankaran, 1984; Sharma *et al*, 1984b,c,1985; Florence *et al*., 1985; Mehrotra, 1989; 1990; Mohanan and Sharma, 1993; Ali, 1993). In bamboos, *R. solani* causing web blight belong to AG1-IA, AG1-IC, and AG2-2IV.

Disease management measures for web blight has been suggested for other forestry species which include sanitation, modification of cultural practices and use of fungicides. Sanitary measures

recommended were disposal of leaf litter in the nursery and seggregation of diseased seedlings, soon after their detection for preventing the lateral spread of the disease which occurs through contact of the overlapping foliage of the adjoining seedlings (Mehrotra, 1989; Sharma and Mohanan, 1991a). Regulation of the shade over the nursery beds and also watering quantity and frequency to check the disease and reducing the seedling density in the seed beds were suggested by Sharma and Mohanan (1986). Fungicides viz., carbendazim, mancozeb, MEMC, PCNB, carboxin were suggested for the control of the *R. solani* web blight in different tree species (Sharma and Sankaran, 1984; Mehrotra, 1990; Sharma and Mohanan, 1992; Ali, 1993). The factors influencing the disease development and spread, and cultural, biological and chemical control measures are discussed in detail under the chapter on 'Management of Rhizoctonia web blight'.

## 5. LEAF RUST

### Occurrence

Leaf rust of bamboo seedlings is widespread in nurseries in Kerala; the disease was recorded from almost all the nurseries surveyed during the study. Rust appeared during the month of August affecting 4- to 8-month-old bareroot as well as container seedlings; infection continued till late May. Rust was recorded on seedlings of *B. bambos*, *D. strictus*, *D. brandisii*, *Oxytenanthera monostigma*, *Ochlandra travancorica*, *O. scriptoria* and *T. siamensis*. Of these *B. bambos* and *D. strictus* were the most susceptible species. Though, rust occurred in all the nurseries surveyed, the severity of infection was found low to medium except in a *B. bambos* nursery at Chandhanathodu during 1991-'92. Severe infection occurred in 8-month-old seedlings and 14 seedbeds were completely devastated by the

disease. Medium infection was recorded in *B. bambos* nursery at Pezhad and Paneli during 1990-'91, Nilambur during 1989-'90 and Periya and Thettamala during 1991-'92.

**Symptoms**

Infection usually appeared during the month of August on the mature leaves in the form of greyish brown minute flecks; usually, the juvenile leaves did not get any infection. The small flecks coalesced and formed spindle-shaped dark brown pustules with pale halo around. Mature leaves were found more susceptible to infection than younger ones; higher density of uredinia was observed on the former than the latter. Uredinia, yellowish brown in colour, developed in the flecks on the adaxial surface of the leaves. Development of uredinial sori was observed rarely on the abaxial surface. In severe cases, the adaxial surface of the entire leaf lamina became completely covered with uredinia imparting yellowish brown colour. The rust infection continued till late May. Dark brown teliosori developed either in mature uredinial sori or separately on the adaxial surface in linear rows during January. Necrosis and withering of mature leaves occurred due to severe rust infection.

**Causal organism**

*Dasturella divina* (Syd.) Mundk. & Khesw.(IMI Nos. 322078, 322081).

Uredinia yellowish brown with pale yellow, incurved, thick-walled paraphyses, 42-70 x 8.2-10.6 µm; urediniospore 25-30 x 18-23 µm, ellipsoid, obovoid or nearly globoid, wall 1.6-2.0 µm thick, golden yellow to brownish, echinulate, pores indistinct, 4-6, equatorial. Telia blackish brown, usually in groups arranged in linear rows, subepidermal, erumpent, aparaphysate, mostly 150-200 µm thick; teliospores yellowish brown, catenulate, arranged basipetally, 3-6 spores, cuboid or oblong, smooth, 13-28 x 10.0-16.2 µm, spore wall 1.2-1.6 µm thick at sides, 3.0-11.6 µm at the apex.

## Discussion

*Dasturella divina* causing leaf rust is widespread in bamboo nurseries in the State. Seedling mortality due to rust infection was recorded only in a nursery at Chandhanathodu, Wynad during 1991-'92, where cent percent rust incidence occurred. Seedlings were completely killed due to heavy infection in 14 out of 80 seedbeds. This clearly indicates the potential of the leaf rust in causing mortality of bamboo seedlings. It is interesting to note that bamboo seedlings were raised for the first time in Chandhanathodu nursery and during the past 20 years no bamboo was raised in that locality. Also, there are no bamboo stands in nearby areas which may have served as the reservoir of the inoculum. *D. divina* is recorded as a heteroecious rust having an alternate host *Randia* spp.(=*Catunaregum* spp.) on which it produces pycnia and aecia (Bakshi *et al.*, 1972). However, no alternate host of the bamboo rust could be detected in the natural forest which surrounded the nursery. Under these conditions it is not clear that how such a severe rust infection recorded at Chandhanathodu. From India, so far, two species of *Dasturella* viz., *D. divina* (=*D. oxytenantherae* Sathe) and *D. bambusina* have been recorded on different bamboos (Mundkur and Kheswala, 1943; Sathe, 1965; Bakshi and Singh, 1967; Rangaswami *et al.*,1970). Of these, *D. bambusina* differs from *D. divina* mainly in the number of teliospores per chain and depth of telial coloumn. Though, rusts collected from different bamboo species in the State also showed variation in morphological characters of urediniospores and teliospores, these characters were not reliable in diffferentiating them into separate species. *D. divina* has also been recorded from Australia, Japan and Taiwan (Cummins, 1974; Hsieh, 1984; Johnson, 1985). This is the first record of rust on bamboos from Kerala as well as first record of *D. divina* on *T. siamensis* from India. Since, the leaf rust can cause considerable loss to the nursery stock, detailed studies on epidemiology, disease

cycling and possible control measures are warranted.

## 6. BIPOLARIS LEAF BLIGHT

### Occurrence

Leaf blight, affecting both young and mature leaves of 2- to 18-month-old bamboo seedlings, was found widespread in the nurseries surveyed. The infection appeared in young seedlings during the months of March-April and it continued till outplanting of seedlings. The disease was recorded in bareroot as well as container seedlings of *B. bambos* at Pattikad during 1987-'88, Nilambur during 1988-1990, Peechi during 1988-'91, Kulanjithodu during 1989-'90, Pariyaram during 1989-'90, Paneli, Pezhad and Periya during 1990-'92, Vadasserikkara during 1990-'91, Thettamala, Niravilpuzha, Vattapoyil and Chandhanathodu during 1991-92. In addition, various other species of bamboos were also found affected by the disease: *D. strictus* at Dhoni during 1987-'89, *Phyllostachys pubescens* at Peechi during 1989-'90, *D. brandisii, D. strictus* and *T. siamensis* at Chandhanathodu during 1991-'92, *D. membranaceus* and *O. wightii* at Palappilly during 1991-'92. In all the nurseries, disease severity was found low. However, in Chandhanathodu nursery, during the months of December to January when cool nights alternate with hot days severe infection was encountered. The disease incidence was higher in beds exposed to direct sunlight than those provided with shade. In thickly shaded beds seedlings located in the extreme end of the beds, which were exposed to direct sunlight, had higher disease incidence.

### Symptoms

The disease manifested as minute, spindle-shaped water-soaked lesions on both young and mature leaves, which later turned into dark

brown to dull violet lesions with greyish brown centres. Lesions coalesced and formed large necrotic areas. Necrosis of leaf tissues started from the leaf tip downwards or from the leaf margins towards the midrib (Plate 2). Usually, dark brown cross bands occurred in the necrotic area. The colour of the lesions, spread, etc. depended on the bamboo species affected, leaf maturity, and the pathogen species associated. Under high humidity, sporulation of the fungus was observed and spores were produced as dark greyish black mass in the necrotic tissues on the adaxial surface of leaf.

**Causal organisms**

Three species of *Bipolaris* were found causing the leaf blight:

1. *Bipolaris maydis* (Nisikado & Miyake) Shoem. anamorph of *Cochliobolus heterostrophus* (Drech.) Drech.(IMI No. 326944).
2. *Bipolaris urochloae* (Putterill) Shoem. (IMI No. 326947)
3. *Bipolaris* sp. (IMI Nos. 326946, 326947).

Since, the expression of symptoms varied depending upon the species of *Bipolaris* involved, detailed symptoms produced by each species are given below.

*B. maydis* was isolated from *B. bambos* seedlings in nurseries at Paneli, Pezhad, Periya, Thettamala, Niravilpuzha, Chandhanathodu and Peechi; from *D. membranaceus* and *O. wightii* seedlings in nursery at Palappilly and from *D. brandisii, D. strictus* and *T. siamensis* seedlings in a nursery at Chandhanathodu. *B. maydis* produced dark brown lesions with greyish brown centre.

*B. urochloae* was isolated from 8-month-old *Phyllostachys pubescens* seedlings in a nursery at Peechi. *B. urochloae* produced dark brown to


Plate 2. Foliar infection caused by *Bipolaris* spp. a: *Bambusa bambos* leaves showing disease symptoms of Bipolaris leaf blight, b: Conidiophores and conidia of *Bipolaris maydis* (440 x), c: Conidiophores and conidia of *Bipolaris urochloae* (440 x), d: Conidiophores and conidia of *Bipolaris* sp. (440 x).

blackish brown linear to irregular lesions on both young and mature leaves which spread rapidly to the entire surface of the leaf lamina under high humidity. *Bipolaris* sp. was isolated from *B. bambos* seedlings in nurseries at Nilambur, Peechi, Chandhanathodu, Kulanjithodu, where it occurred intermixed with *B. maydis*. The symptoms produced by this species were similar to those of *B. maydis*.

### *Cultural characters*

1. *B. maydis*: Colony on PDA fast growing, effuse, greyish black, reverse bluish black; conidiophore simple or often in groups from flat, dark brown to black stroma, straight to flexuous, septate, smooth, geniculate, dark brown, paler towards the apex, up to 700 µm long, 5-10 µm thick; conidia solitary, pale brown, smooth 5-9 distoseptate, distinctly curved, 65-73 x 11.5-12.5 µm.

2. *Bipolaris urochloae*: Colony on PDA fast growing, effuse, greyish brown. Conidiophore in single or in small groups, straight or flexuos, pale brown, upto 280 µm long, 7.2-10.2 µm thick, septate, smooth, often with a swollen base. Conidiogenous nodes verrucose; conidia straight, slightly curved or flexuous, broadly fusoid to obclavate, pale to dark olivaceous brown, smooth, 8-16 distoseptate, 86-178 x 14.5-20 µm.

3. *Bipolaris* sp.: Colony on PDA slow growing, effuse, greyish brown, reverse greyish black. Sporulation sparse. Conidiophore straight, pale brown, upto 300 µm long, 8.0-10.4 µm thick, septate, smooth; conidia straight, broadly fusiform, pale brown, 5-6 distoseptate, 39-53 x 16-18 µm with protuberant hilum.

### Pathogenicity test

Pathogenicity of isolates of *Bipolaris* sp. and *B. maydis* was tested on 2-month-old *B. bambos* seedlings raised in polyurethane sheet. *B. urochloae* was tested on 11-month-old *P. pubescens* container seedlings. Foliage infection developed on young and mature leaves as tiny water-soaked specks after two days of incubation. In *B. urochloae* inoculated seedlings, infection developed as minute greyish brown to dark brown lesions on young as well as mature leaves after 36 h of incubation. The infection spread rapidly when the inoculated seedlings removed from the humidity chamber and exposed to direct sunlight. No significant difference was observed in the initial symptoms produced

by different *Bipolaris* spp. However, in *B. urochloae* inoculated *P. pubescens* seedlings, the infection spread very fast and the entire seedling became infected and defoliation occurred within one month of inoculation.

**Discussion**

Information on seedling disease caused by *Bipolaris* spp. in forest nurseries is very meagre, although many species have been well established on graminaceous agricultural crops. Recently, a severe outbreak of foliage disease of *Populus deltoides* Marsh. caused by *B. maydis* has been recorded in nursery and plantation in Punjab (Chauhan and Pandey, 1992). *Bipolaris* spp. causing foliage infection in *Eucalyptus tereticornis* and *Calamus thwaitesii* has also been recorded recently from Kerala (Mohanan and Sharma, 1986; Mohanan, 1990b). *B. urochloae* (= *Helminthosporium urochloae* (Putterill) Subram.) has not been recorded earlier on any forest tree seedlings in India, although, on other graminaceous agricultural hosts it is well established. All the three fungi viz., *B. maydis, B.urochloae* and *Bipolaris* sp. which caused seedling leaf blight are new pathogen record for bamboos. *Bipolaris* sp. (IMI Nos. 326946, 326947) recorded on bamboos differs from the earlier reported *Bipolaris* spp. in cultural and morphological characters (Sivanesan,IMI, pers. commun.). It represents a new species of the genus and hence will be validly published elsewhere. In the pathogenicity trial, the development and spread of infection in inoculated seedlings was rapid when the seedlings were removed from the incubation chamber and kept under direct sunlight. The high incidence of disease in seedbeds under direct sunlight than those under shade also confirms this observation. This clearly shows the requirement of light and high temperature for the disease development. Even though, the disease is widespread in bamboo nurseries in the State, it did not cause any appreciable damage to the seedling stock.

## 7. EXSEROHILUM LEAF SPOT

### Occurrence

Infection was observed in 2- to 8-month-old bareroot as well as container seedlings of *B. bambos*, *D. strictus* and 8-month-old container seedlings of *P. pubescens* in a nursery at Peechi during April-May of years 1989-'90. Disease incidence in 6-month-old *D. strictus* seedlings was found to be low, while in *B. bambos* and *P. pubescens* infection varied from medium to severe and it caused defoliation. Infection spread rapidly during the wet periods, (June-July) affecting the entire foliage of seedlings.

### Symptoms

Leaf spots were observed as minute greyish brown water-soaked lesions on the mature leaves. Under warm-humid condition, the individual lesions coalesced to form large spindle-shaped to irregular lesions with greyish white centre and dark brown to chocolate margin (Plate 3). The diseased areas became necrotic and under high humidity sporulation of the fungus occurred as greyish black spore mass on the adaxial surface of the necrotic lesions. Severe infection led to the spread of lesions to the entire leaf lamina followed by withering of the affected leaves and premature defoliation.

### Causal organisms

1. *Exserohilum rostratum* (Drech.) Leonard & Suggs anamorph of *Setosphaeria rostrata* Leonard (IMI No. 326945).
2. *Exserohilum holmii* (Luttr.) v. Arx. anamorph of *Setosphaeria holmii* (Luttr.) Leonard & Suggs (IMI No. 327737).

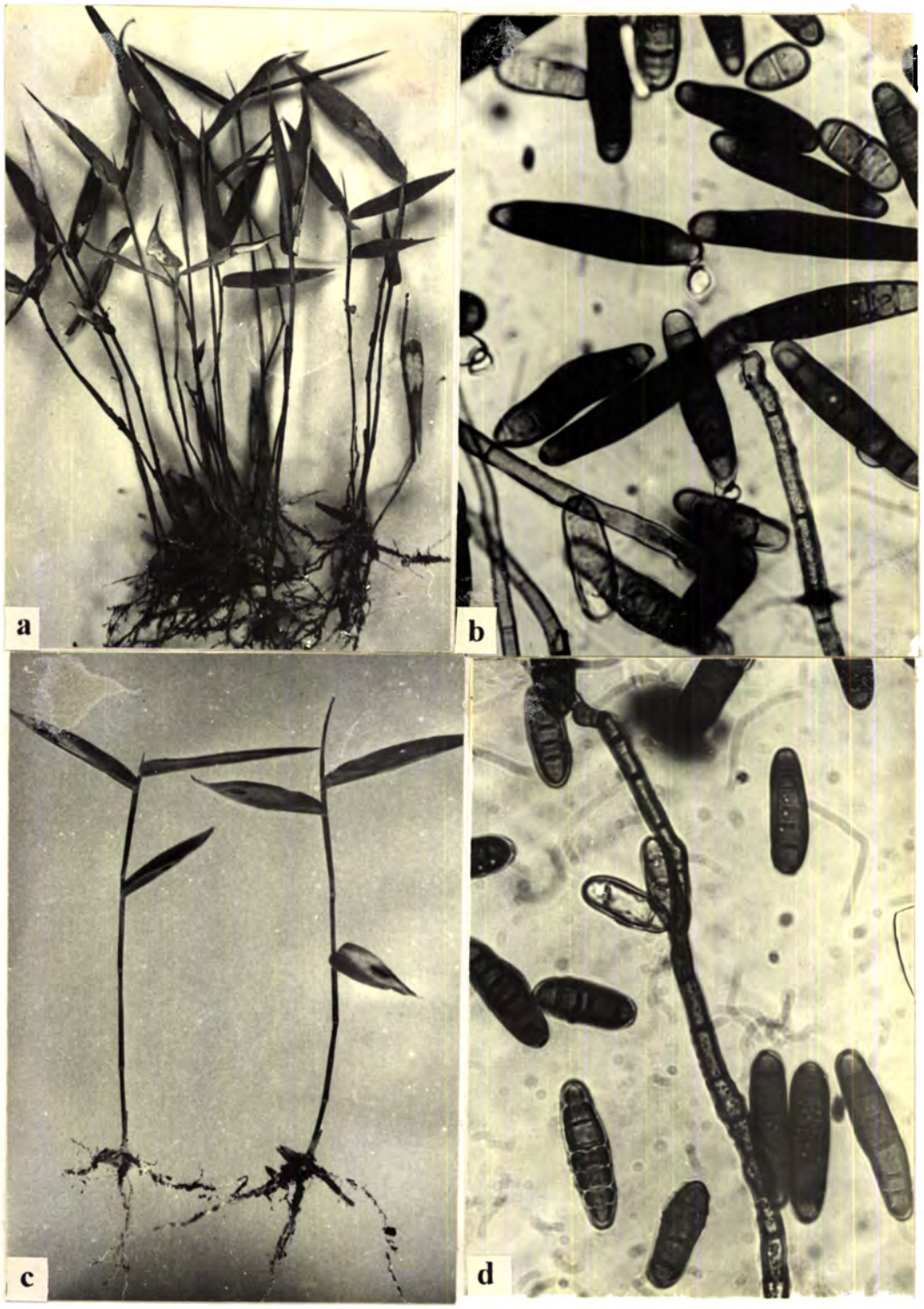



Plate 3. Seedling foliage infection caused by *Exserohilum* spp. a: *Bambusa bambos* seedlings showing Exserohilum leaf spot symptoms, b: Conidiophore and conidia of *Exserohilum rostratum* (440 x), c: *Dendrocalamus strictus* seedlings affected with *Exserohilum holmii*, d: Conidiophores and conidia of *Exserohilum holmii* (440 x).

*E. rostratum* was isolated from *B. bambos* and *D. strictus* seedlings and *E. holmii* from seedlings of *B. bambos* and *P. pubescens*. *E. holmii* produced greyish brown to greyish black water-soaked lesions on *P. pubescens* which coalesced and spread to the entire leaf under warm humid condition. While on *B. bambos* it produced greyish brown irregular lesions with greyish white centres. Heavy sporulation of the fungus occurred on the adaxial surface of the affected leaves of both the bamboo species.

### *Cultural characters*

1. *Exserohilum rostratum*: Colony on PDA fast growing, effuse, blackish brown. Conidiophore upto 200 µm long, 5-8 µm thick, cylindrical, septate, olivaceous brown, pale towards the apex, simple, geniculate; conidia straight to slightly curved, ellipsoidal to narrowly obclavate or rostrate, brown or olivaceous brown, thick-walled, except in a small sub-hyaline region at the apex and a similar region surrounding the hilum which protrudes as a cylinder or a truncate cone from the end of the basal cell; basal septum darker and thicker than the other septa, upto 16-distoseptate, 22-180 x 7-28 µm. Germiation from sub-hyaline region of the end cells and germ tubes growing semiaxially.

2. *Exserohilum holmii*: Colony on PDA fast growing, greyish brown. Conidiophore single or in small groups, simple, cylindrical, straight to flexuous, smooth, septate, pale brown to dark brown, upto 240 µm long, 5.5-9.2 µm thick, sometimes with a basal swelling upto 16 µm wide. Conidia straight, slightly curved, obclavate or rostrate to broadly ellipsoidal, 5-10 distoseptate, end cells often pale and cut off by dark septa, intermediate cells pale to dark golden brown, smooth, 60-128 x 12.5-28.5 µm in the broadest part with a dark protuberant hilum.

### Pathogenicity test

Pathogenicity of isolates of *Exserohilum rostratum* and *E. holmii* tested on 2-month-old *B. bambos* seedlings gave positive results. Infection occurred in *E. rostratum* and *E. holmii* inoculated seedlings within two days of incubation as tiny water-soaked specks. The disease developed rapidly when the inoculated seedlings were removed from the humidity chamber and kept outdoor. *E. rostratum* and *E. holmii* were reisolated from the infected tissues which confirmed pathogenicity of the isolates.

**Discussion**

Exserohilum leaf spot, affecting both bareroot and container seedlings, was recorded only from a nursery at Peechi. This is the first record of *E. holmii* on bamboos as well as first pathogen record from India. Similarly, *E. rostratum* causing leaf spot of *B. bambos* and *Phyllostachys pubescens* is the first pathogen record. Earlier, *E. halodes* (Dresch.) Leonard and Suggs was reported to cause leaf blight of *B. arundinacea* (Retz.) Willd (=*B. bambos*) in forest nursery at Dharward, Karnataka (Bhat *et al.*, 1989). *E. rostratum* has also been recorded to cause seedling foliage infection of *Eucalyptus grandis* and *E. tereticornis* in southern India (Mohanan and Sharma, 1986). The rapid development of Exserohilum infection in inoculated seedlings kept outdoor clearly indicates that for expression of disease symptoms high humidity is not a limiting factor. Since, the pathogens cause withering and premature defoliation only under conducive microclimatic conditions, the disease seems may not pose problems in raising bamboo seedlings. Hence, Exserohilum leaf spot may be rated as economically insignificant.

**8. DACTYLARIA LEAF SPOT**

**Occurrence**

Dactylaria leaf spot was widespread in bamboo nurseries in Kerala and usually occurred in 1- to 10-month-old bareroot and container seedlings of *B. bambos* and *D. strictus* in most of the nurseries surveyed during 1987-'92, and seedlings of *D. brandisii* and *T. siamensis* at Chandhanathodu and *O. wightii* at Palappilly during 1991-'92. Incidence of the disease was generally low in all these nurseries; *B. bambos* and *D. strictus* were the most affected species.

**Symptoms**

The disease manifested as minute water-soaked lesions near the leaf tips. The lesions coalesced and spread to form large circular to irregular greyish brown lesions with greyish white centres and dark brown margins. In seedbeds provided with thick shade and profuse watering which led to severe infection, withering of leaf tips was noticed; leaf sheath and petioles were also got affected with the disease. Under high humidity, heavy sporulation of the fungus was observed on the necrotic leaf spots.

**Causal organism**

*Dactylaria* sp.(IMI Nos. 327745, 327746)

***Cultural characters***

Colony on PDA fast growing, velvety, initially greyish white, later becomes yellowish brown; reverse greyish brown. Hyphae hyaline to pale yellowish brown, septate, branched, thin-walled, 1.5-3.5 µm wide. Conidiophore sub-hyaline to pale yellowish brown, solitary, simple or occasionally branched, erect, straight or flexuous, 2-3 µm wide, base slightly swollen, or bulbous, sympodial, swollen at the apex, often elongating with successive proliferation, producing solitary conidia successively on minute truncate denticels. Conidia sub-hyaline to pale yellowish brown, 0-4 (1-3) septate, cylindrical to slightly clavate, apex obtuse, base obconically truncate, smooth, thin-walled, 5-30 (10-20) x 1.3-2.6 (1.8-2,27) µm.

**Pathogenicity test**

Pathogenicity of *Dactylaria* sp. was tested on 1-month-old *B. bambos* seedlings. infection appeared as water-soaked specks after 48 h of inoculation. The specks developed into characteristic greyish brown circular to irregular lesions with dark brown margins within 15 days of incubation. *Dactylaria* sp. was reisolated from the infected tissues.

**Discussion**

*Dactylaria* Sacc. is an important genus consisting of plant pathogenic, saprophytic as well as nematode trapping species. So far, nearly 35 species of *Dactylaria* have been reported (Das Gupta *et al.*, 1964; Ellis, 1976; Choudhry, 1982). Recently, *D. chrysosperma* (Sacc.) Bhatt & Kendrick and *D. arundica* Choudhry have been recorded on fallen twigs of bamboos viz., *Ochlandra travancorica* and *Arundinaria* spp. respectively from Kerala and Uttar Pradesh (Mani Varghese and Rao, 1979; Choudhry, 1982). Since, the *Dactylaria* isolate from bamboo seedlings vary in cultural and morphological characteristics from the *Dactylaria* species recorded so far, it is possibly a new species. The diseases is economically insignificant.

## 9. COLLETOTRICHUM LEAF SPOT

**Occurrence**

Disease was recorded in 15-day-old to 10-month-old bareroot as well as container seedlings of *B. bambos* in nurseries at Kulanjithodu, Vadasserikkara, Palappilly, Peechi, Niravilpuzha, Begur and Pariyaram during 1988-'92 and *D. strictus* nursery at Dhoni during 1988-'89; disease severity was found low in all the nurseries. Colletotrichum leaf spots were often found intermixed with other leaf spots such as those caused by *Dactylaria* sp., *Bipolaris maydis* and *Bipolaris* sp. However, pure infection was also observed in many nurseries.

**Symptoms**

Disease appeared as minute water-soaked lesions on the abaxial surface of the mature leaves. The lesions spread and formed large

reddish brown areas linear to irregular in shape which often concentrated either at the leaf base or at the margins and tips. The discoloured areas later became necrotic. Merging of lesions with those of other leaf infecting fungi was observed. Infection was also recorded on leaf sheath and petioles of bamboo seedlings.

## Causal organism

*Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. and its teleomorph *Glomerella cingulata* (Stonem.) Spauld. & Schrenk. (IMI Nos. 331635,331798).

## *Cultural characters*

Colony on PDA fast growing, greyish black with pale pink border, reverse pale pink with bluish black areas where the ascocarps developed. Ascocarp developed after seven days of incubation, dark brown to black 140-160 x 145-155 µm; asci clavate, thin-walled, smooth, 8-spored, 55-62 x 12.5-13.5 µm; ascospore 0-1 septate, guttulate, smooth, slightly curved, 18-25 x 4.5-6.5 µm. Setae brown to black, sparse; conidia straight, obtuse at the apex, hyaline, 0-septate, 18-25 x 4.6-6.0 µm

## Pathogenicity test

Pathogenicity was tested employing 25-day-old *B. bambos* seedlings raised over polyurethane sheet. The seedlings inoculated by spraying conidial suspension of the fungus were kept in the humidity chamber. Infection developed only on mature leaves as minute lesions after 48 h of inoculation. The lesions developed into necrotic areas within 12 days of inoculation. *C. gloeosporioides* was reisolated from the infected tissues.

## Discussion

*C. gloeosporioides* is a common leaf infecting fungus in forest nurseries which has been recorded on a large number of forestry

species viz., *Ailantus triphysa, Bombax ceiba, Dalbergia latifolia* Roxb., *Eucalyptus* spp., *Gmelina arborea, Lagerstroemia speciosa* (L.) Pers., etc. (Bakshi *et al.*, 1972; Sharma *et al.*, 1985; Ali, 1993). Earlier the fungus has been recorded on bamboos from U.S.A. (Anon.,1960) and from Malaysia (Azmy and Maziah, 1990). Recently, *C. gloeosporioides* has been recorded on different species of bamboos from Meghalaya (Deka *et al.*, 1990). Though, in bamboos, Colletotrichum leaf spot is not very serious, along with other foliage pathogens viz., *Bipolaris* spp., *Exserohilum* spp. and *Dactylaria* sp. it may cause severe infection and withering of leaves.

## 10. CURVULARIA LEAF SPOT

### Occurrence

Curvularia leaf spot was recorded to infect 1- to 2-month-old bareroot seedlings of *B. bambos* at Nilambur and leaves of 40-day-old vegetatively propagated *D. longispathus, T. oliveri* and *O. scriptoria* in a nursery at KFRI Campus, Peechi during 1988-'89. Disease severity was found low in *B. bambos, T. oliveri* and *O. scriptoria*. Severe infection was recorded only in vegetatively propagated shoots of *D. longispathus*.

### Symptoms

Infection appeared as water-soaked lesions with yellow halo on young and mature leaves. The lesions coalesced and formed circular to irregular greyish black spots with dark yellow halo. The lesions developed near the leaf tips and margins coalesced fast and formed large necrotic areas. The affected leaf tips got rolled in and dried up.

**Causal organism**

*Curvularia pallescens* anamorph of *Cochliobolus pallescens* (Tsuda & Veyama) Sivan. (IMI Nos. 320689,327773).

***Cultural characters***

Colony on PDA olive brown with pale yellow margin, aerial mycelium sparse, colony reverse bluish black; stroma large, erect, black, cylindrical often branched. Conidia pale brown, straight or slightly curved, 3-septate, smooth, 16-27 x 9.0-11.5 µm.

**Pathogenicity test**

Pathogenicity of the isolate was confirmed by spraying conidial suspension of *C. pallescens* on the leaves of 1-month-old *B. bambos* seedlings raised over polyurethane sheets. Infection developed as minute greyish brown to dark brown water-soaked lesions on both young and mature leaves after 72 h of incubation in the humidity chamber which later coalesced and formed irregular greyish black lesions within one week of incubation. *C. pallescens* was reisolated from the infected tissues.

**Discussion**

The leaf spot caused by *C. pallescens* is of minor importance. *C. pallescens* is a weak pathogen and has been recorded as causing foliage infections of minor significance on many forestry crops in Kerala (Sharma *et al.*, 1985). Recently, *C. andropogonis* (Zim.) Boed. has been recorded as causing leaf spot of *O. scriptoria* and *O. travancorica* in Kerala (Balakrishnan *et al.*, 1990). *C. pallescens* is a new record on bamboos.

## 11. ALTERNARIA LEAF TIP BLIGHT

### Occurrence

The disease was recorded in 1- to 3-month-old bareroot seedlings of *D. strictus* at Dhoni, *B. bambos* bareroot as well as container seedlings at Nilambur, Pariyaram, Kalamassery, Vadasserikkara, Begur, Vadavukodu, Thettamala and Kulanjithodu nurseries during the months of April-May. Severe foliage infection led to seedling leaf tip blight.

### Symptoms

Infection manifested as minute greyish brown linear to spindle-shaped lesions near margin, base and tip of both young and mature leaves. The lesions coalesced and caused necrosis of the affected leaf tissues. Infection spread downward under warm-humid conditions. Usually, leaf tips were found severely affected which led to seedling leaf tip blight.

### Causal organism

*Alternaria alternata* (Fr.) Keissler (IMI Nos. 331799,327736).

### *Cultural characters*

Colony on PDA olive grey, reverse greyish brown, aerial mycelium abundant. Conidia pale yellowish brown, 4-6 transverse and 1-3 vertical/oblique septate, 28-55 x 11.5-16.0 µm; beak septate, upto 50 µm long.

### Pathogenicity test

Pathogenicity of *A. alternata* was tested on 1-month-old *D. strictus* and *B. bambos* seedlings. Infection developed as minute

greyish brown lesions mostly at the tips and leaf margins on young and mature leaves of both the species within three days of incubation in humidity chamber. The lesions later turned into dark brown linear to irregular necrotic areas with pale to dark yellow halo around. *A. alternata* was reisolated from the infected tissues.

**Discussion**

*A. alternata* causing leaf tip blight of *B. bambos* and *D. strictus* seedlings during hot season (April-May) occurs in nurseries subjected to water stress. *A. alternata* is a weak pathogen and causes foliage infection on many forestry species. In Kerala, the fungus causes infection on *Eucalyptus grandis* and *E. tereticornis* (Sharma, *et al.*, 1985). *A. alternata* is a new pathogen record on bamboos.

## 12. SEEDLING RHIZOME ROT

**Occurrence**

Seedling rhizome rot was recorded in 11-month-old container seedlings of *B. bambos* in a nursery at Pattikad during 1987-'88 and Peechi during 1988-'89. In both the nurseries the disease observed during May-June, caused four percent seedling mortality at Peechi and five percent at Pattikad.

**Symptoms**

The above ground symptoms of disease were manifested as general wilting of seedlings, rolling up of foliage, yellowing of mature leaves and finally premature defoliation. The affected seedlings when uprooted carefully showed dark yellowish brown discolouration and

decay of growing portion of the rhizome, especially around the rhizome buds. Usually, the fleshy rhizome buds became discoloured and decayed and later the infection spread to the entire rhizome of seedlings. The diseased seedlings were killed outright.

**Causal organism**

*Rhizostilbella hibisci* (Pat.) Seifert state of *Nectria mauritiicola* (Henn.) Seifert & Samuels (IMI No. 326955).

***Cultural characters***

Colony on PDA persian orange in colour with fast growing submerged, branched rhizomorphs; aerial mycelium sparse. Synnamata salmon coloured, paler at apex, globose, conidia ellipsoid to cuneiform, hyaline to pale orange, 11.5-20.7 x 9.0-11.5 µm.

**Pathogenicity test**

Pathogenicity test was conducted employing 12-day-old PDA grown culture of *R. hibisci*. Container grown 10-month-old *B. bambos* seedlings were inoculated by injuring the rhizome buds and young growing tip of the rhizome using sterile scalpel blade. Above ground symptoms developed after 30 days of inoculation. Discolouration and decay of the rhizome led to outright killing of the shoots and also decay of the rhizome. Yellowish brown, branched, large rhizomorphs and slimy spore heads of the fungus developed on the decayed rhizome buds. Seedlings inoculated without injury, developed no above ground as well as underground symptoms even after two months' of incubation.

**Discussion**

Rhizome rot of container seedlings of *B. bambos* caused by *R. hibisci* state of *Nectria mauritiicola* is a new disease record on

bamboos as well as new pathogen record from India. Earlier, two closely related fungi viz., *Sphaerostilbe bambusae* Pat. and *S. hypococcoides* Kalchbr. & Cke. have been recorded to cause root rot of bamboos from India (Mathur, 1936). Recently, *Amylosporus campbelli* (Berk.) Ryv. has been reported as causing root and rhizome rot of *D. strictus* seedlings in nursery at Jabalpur (Tahir *et al.*, 1992).

*R. hibisci* causes browning and rot of the entire rhizome resulting in outright killing of current shoots as well as rhizome buds. The rot of rhizome buds hinders the production of new shoots, and also rhizome growth and its proliferation. In container nurseries, where rhizome rot was recorded, possibly the infection is manifested through mechanical wounds to the rhizome caused during transplanting operation. Pathogenicity trial confirms the role of injury in the manifestation of the disease as the infection developed only in wound inoculated seedlings. Since, the rhizome rot is not common in bamboo nurseries it is of minor importance. The disease can be managed by adopting proper nursery management practices and also proper care during transplanting to avoid any injuries to the seedling rhizome.

## 13. LEAF STRIPPING AND SEEDLING STUNTING

### Occurrence

The disease occurred in 14-month-old container seedlings of *B. bambos* at Pezhad and Kulanjithodu and 4-month-old *B. bambos* bareroot seedlings at Paneli and Periya during 1990-'91; disease incidence was low in all the nurseries. In the Pezhad nursery 5.6 percent of seedlings were found infected due to which a large number of otherwise plantable seedlings had to be discarded.

**Symptoms**

Disease manifested as of pale yellowish white to greenish white stripes on both young and mature leaves. Stripping of leaves was also observed in the new shoots developed from the rhizome. The affected leaves became leathery and often the individual stripes merged together and the leaves became greenish white in colour. Affected seedlings showed stunted growth, stem became thin, fragile, pendulous and it snapped easily. Fifteen 10-month-old diseased container seedlings brought from the nursery to the laboratory and maintained for two years for close observation revealed the systemic nature of infection. All the new shoots developed from the rhizome also showed same symptoms.

**Causal organism**

Unknown etiology. Leaf stripping, mottling, stunting and mosaic diseases of plants were earlier reported to be caused by a virus. The symptomatology of the leaf stripping and stunting disease of bamboo seedlings showed the possibility of viral pathogen.

**Discussion**

Leaf stripping and stunting of *B. bambos* seedlings is a new disease record from India. Symptomatically, the disease appears to be caused by a virus. However, further studies on etiology of the disease need to be undertaken to confirm the causative organism. A similar disease has earlier been reported on cultivated species of bamboos in plantations in Taiwan (Lin *et al.*, 1979). The disease was reported to be caused by Bamboo mosaic virus (BoMV) belonging to the group of potex virus (Lin *et al.*, 1993).

## BAMBOO PLANTATIONS AND NATURAL STANDS

In Kerala, planting of commercially important bamboos viz., *B. bambos* and *D. strictus* in degraded forests, poorly stocked softwood plantations and old teak plantations has been taken up recently. Small-scale trials of *D. longispathus, O. travancorica, T. oliveri,* etc. have also been initiated recently. Usually, 12-to 18-month-old bareroot as well as container seedlings are utilized for planting. For large-scale planting, bareroot seedlings maintained in the transplanting beds at an espacement of 15 x 15 cm are used. Seedlings with intact rhizomes are collected by dismantling the beds carefully. Pruning of shoots about 30-40 cm from the base of the seedlings is often practiced in certain localities. Planting is done in pits taken at an espacement of 8 x 8 m or 10 x 10 m after the onset of south-west monsoon during the month of June-July.

Disease survey conducted in 22 selected representative areas in eight bamboo plantations and 14 natural stands and various trial plots and a Bambusetum in the State during 1987-'91 recorded a total of 27 diseases affecting bamboo culm, rhizome, branch, foliage, culm sheath, etc. (Table 4.4). Among these a few were found economically important which affected the stand productivity considerably, while others were of minor importance. Diseases recorded exclusively in plantations, natural stands and those occurred in both plantations as well as natural stands are treated separately in the following text. Though, a large number of fungi were found associated with various diseases of different bamboo species in plantations, natural stands and trial plots, economically important ones as well as those with confirmed pathogenic connections are dealt with in detail. The fungi causing diseases of minor importance as well as those of unproven pathogenic connections are also given separately.

**Table 4.4: Checklist of diseases in bamboo plantations and natural stands in Kerala recorded during 1987-1991**

| Sl. No. | Disease | Pathogen(s) | Bamboo species affected |
|---|---|---|---|
| 1. | Rhizome bud rot | *Pythium middletonii* | BB |
| 2. | Rot of emerging culm | *F. moniliforme* var. *intermedium* | BB,DS,TO,BBA,DL,BP,BV |
| 3. | Rot of growing culm | *F. equiseti* | BB,BBA,BP,DB,DS,DL,TO |
| 4. | Branch die-back | *F. pallidoroseum* | BB,BV,DS |
| 5. | Necrosis of culm internode | *Curvularia lunata* | TO |
| 6. | Witches' broom | *Balansia linearis* | OE,OS,OT,OTH |
| 7. | Little leaf | MLO | DS |
| 8. | Thread blight | *Botryobasidium salmonicolor* | BB,BBA,BP,BV,DB,DL,DS,OT, OS,OE,TS,BG,BP,BT,BVE |
| 9. | Foliage blight | *Bipolaris maydis* | BB,DB,DL,DS,BP,OM |
| | | *Bipolaris sp.* | BB,DS,DL |
| 10. | Leaf rust | *Dasturella divina* | BBA,BB,BG,BP,BT,BVE,BV, DB,DH,DL,DS,OM,TO,TS |
| 11. | Exserohilum leaf spot | *Exserohilum holmii* | BB,BP,DL |
| | | *E. rostratum* | BB,DS |
| 12. | Zonate spot | *Dactylaria sp.* | BB,DS,DL,BP,OE,OS,OT,TS,Ts |
| 13. | Colletotrichum leaf spot | *C. gloeosporioides* | As,BB,DS,OE,OS,OT |
| 14. | Ascochyta leaf spot | *Ascochyta sp.* | BB,DS,TS |
| 15. | Tar spot | *Phyllachora ischaemi* | BB |
| | | *P. longinaviculata* | BB,DS,OM |
| | | *P. shiraiana* | BB,BV,DS,OT,OS |
| 16. | Petrakomyces leaf spot | *Petrakomyces indicus* | As,BB,DS,OE,OS,Ts |
| 17. | Phoma leaf spot | *Phoma herbarum* | BB,DS |
| | | *P. sorghina*, *Phoma sp.* | BB,DS |
| 18. | Phomopsis leaf spot | *Phomopsis sp.* | BB,DS,Ts |
| 19. | Stagonospora leaf spot | *Stagonospora sp.* | BB,DS |
| 20. | Septoria leaf spot | *Septoria sp.* | Ts |
| 21. | Chaetospermum leaf spot | *Chaetospermum carneum* | BB |
| 22. | Curvularia leaf spot | *Curvularia lunata* | As,OE,OS,OT,Ts |
| 23. | Alternaria leaf tip blight | *Alternaria alternata* | BB,DS |
| 24. | Rosenscheldiella leaf spot | *Rosenscheldiella sp.* | OT |
| 25. | Coccodiella leaf spot | *Coccodiella sp.* | OT |
| 26. | Culm sheath spot | *Pestalozziella sp.* | BB,BP,BV,DB,DS, |
| 27. | Culm staining and die-back | *Apiospora sp.* | BV,DL |

As: *Arundinaria* sp.; BBA: *B.balcooa*; BB: *B.bambos*; BG: *B.glaucescens*; BP: *B. polymorpha*; BV: *B. vulgaris*; BVE: *B.ventricosa*; BT: *B.tulda*; DH: *D.hamiltonii*; DS: *D.strictus*; DB: *D.brandisii*; DL: *D.longispathus*; OE: *O.ebracteata*; OS: *O.scriptoria*; OT: *O.travancorica*; OTH: *O.travancorica* var. *hirsuta*; OW: *O.wightii*; PP: *P. pubescens*; TO: *T.oliveri*; TS: *T.siamensis*; Ts: *Thyrsostachys* sp.

## *DISEASE RECORDED EXCLUSIVELY IN BAMBOO PLANTATIONS*

### 1. RHIZOME BUD ROT

#### Occurrence

The disease was recorded in 1-year-old *B. bambos* plantations at Kaliyar (Kothamangalam Forest Divn.), Ezhattumugam (Vazhachal Forest Divn.) and Irumpupalam (Trichur Forest Divn.) during 1987. Infection was observed during the months of September-October in the low lying and water-logged areas in the plantations. Though, the disease severity in Ezhattumugam and Irumpupalam plantations was low, 35.59 percent and 15.62 percent of the outplanted seedlings respectively were affected. While at Kaliyar, the disease severity was found to be medium and 71.42 percent of the outplanted seedlings were diseased. (Table 4.5).

Table 4.5: Incidence and severity of rhizome bud rot of *B. bambos* caused by *Pythium middletonii* in plantations at different localities in Kerala during 1987

| Sl. No. | Locality | Percent incidence | DSI* | DSR |
|---|---|---|---|---|
| 1. | Kaliyar | 71.42 | 1.71 | M |
| 2. | Ezhattumugam | 35.59 | 0.88 | L |
| 3. | Irumpupalam | 15.62 | 0.40 | L |

*DSI:Disease severity index; DSR: Disease severity rating; L: low; M: medium.

**Symptoms**

Above ground symptoms of the disease manifested as yellowing of the entire foliage of shoots and resulting in complete defoliation. Since pruning of shoots was done at Kaliyar and Ezhattumugam plantations, defoliation of the affected plants was very fast and within 15 to 20 days complete defoliation occurred. The affected plants showed browning and rot of the rhizome buds and tender tissues around the buds (Plate 4); both pointed scaly buds which gave rise to new shoots in the growing season and flat buds which promoted rhizome proliferation, were affected by the disease. As rhizome of even the young, 1-year-old plant was very hard and woody, the discolouration and rot were usually found restricted to the fleshy buds and tender tissues at the growing points. However, the infection spread through the hard and woody rhizome tissues very slowly, and the discolouration often reaching the base of the shoots resulting in the symptom expression of the disease. Since, the scaly buds, flat buds, and the tender portions were also infected, the new shoot production as well as rhizome proliferation were greatly affected resulting in stunted growth and mortality of the plants. Mechanical wounds caused to the seedling rhizome during collection, transportation, planting, etc. and also injury caused by the activities of the rodents, porcupines and pigs in the field were the other entry points for the infection.

**Causal organism**

*Pythium middletonii* Sparrow (IMI No.327739).

***Cultural characters***

Colony on Oat meal agar (OMA) fast growing, white, cottony, floccose, hyphae hyaline, coenocytic except where fructifications formed, 4.0-5.0 µm wide. Sporangia hyaline, cylindrical to clavate, 23.5-36.5 x 4.5-6.0 µm.

Plate 4. A young seedling of *Bambusa bambos* affected with Rhizome bud rot (*Pythium middletonii*) in the field (see arrow).

**Pathogenicity test**

Pathogenicity of *P. middletonii* isolate, grown on OMA, was tested employing 1-year-old seedlings of *B. bambos* grown in large metallic trays (90 x 60 x 20 cm). Infection developed only in seedlings inoculated by injuring the rhizome with sterile scalpel blade. Typical above ground symptoms and rhizome bud rot developed after 30 days of inoculation. *P. middletonii* was reisolated from the decayed rhizome buds. The seedlings inoculated without injury did not develop infection even after three months' of inoculation.

***Field trial***

Observations on disease incidence and survival showed about 96 percent survival of the planted out seedlings with 12 percent disease incidence. Infection was observed only in water-logged seedlings and also in those which had the rhizomes injured.

**Discussion**

In young bamboo plantations, rot of fleshy rhizome buds and subsequent death of outplanted seedling caused by *Pythium middletonii* is a new disease record on bamboos. *P. middletonii* has earlier been recorded from India as the causal agent of damping-off and other seedling diseases of different agricultural as well as forestry crops (Singh and Pavgi, 1974; Rajagopal and Ramakrishnan, 1988; Ali, 1993). Since, the pathogen causes rot of scaly and flat buds of rhizome, it hinders the production of new shoots in the growing season as well as the subterranean proliferation of the rhizome. The pathogen seems to enter through the injury caused during either planting operation or the injury caused by rodents, porcupine, etc. after the planting in

the field. Pathogenicity and field trials also confirm the entry of the pathogen through the wounds as the infection develops only in injured rhizomes. Since the disease could be recorded only from newly raised bamboo plantations, it can be managed by improving the cultural and management practices in the plantations.

## *DISEASES RECORDED EXCLUSIVELY IN NATURAL STANDS*

### 1. WITCHES' BROOM

#### Occurrence

Witches' broom disease was wide-spread in reed bamboo growing areas of the State. It affected all the commercially important reed bamboos viz., *Ochlandra travancorica, O. scriptoria* and *O. ebracteata;* the disease was recorded from all the plots of reed bamboos selected for the study. The incidence of disease varied depending upon the locality; the maximum incidence (24. 65%) was recorded at Periya during 1989-'90 and the minimum (5.98%) at Kottoor during 1988 (Table 4.6). In addition, infection was also recorded in *O. travancorica* and *O. travancorica* var. *hirsuta* in reed catchment areas at Kulathupuzha, Palode (Trivandrum Forest Divn.); Chalakkayam, Nilakkal, Kakki and Muzhiyar (Ranni Forest Divn.); Adimaly, Devikulam, Bhoothathankettu, Pooyamkutty, Edamalayar and Kappayam (Munnar Forest Divn.); Adirappally, Epra and Sholayar (Vazhachal Forest Divn.); Nelliampathy and Pothumala (Nenmara Forest Divn.) and on *O. scriptoria* at Alat (South Wynad Forest Divn.) and Kottiyoor (Cannanore Forest Divn.). The disease was also recorded on a grass, *Pennisetum polystachyon* (L.) Schultes, which might have served as an alternate host, as it was seen

growing in the vicinity of the affected reed bamboos. Usually, brooming symptoms became prominent during the months of December-January with the production of incurved, black shining fructification of the fungus on the affected shoots.

**Table 4.6: Incidence and severity of witches' broom disease in reed bamboo natural stands surveyed during 1988-1991**

| Sl. No. | Locality | Bamboo species | 1988 | | | 1989 | | | 1990 | | | 1991 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | % incidence | DSI[a] | DSR | % incidence | DSI | DSR | % incidence | DSI | DSR | % incidence | DSI | DSR |
| 1. | Periya | OS | 21.91 | 0.23 | L | 24.65 | 0.26 | L | 24.65 | 0.26 | L | | | |
| 2. | Watchumaram | OT | 8.57 | 0.08 | L | 9.28 | 0.11 | L | 10.00 | 0.12 | L | 10.71 | 0.14 | L |
| 3. | Vazhachal | OS | 9.83 | 0.11 | L | 11.47 | 0.13 | L | 11.47 | 0.13 | L | 14.75 | 0.19 | L |
| 4. | Pachakkanam | OT | 7.69 | 0.08 | L | 8.33 | 0.10 | L | 8.97 | 0.12 | L | 9.61 | 0.16 | L |
| 5. | Kottoor | OE | 5.98 | 0.05 | L | 7.69 | 0.08 | L | 8.54 | 0.11 | L | 9.40 | 0.13 | L |

[a]DSI: Disease severity index; DSR: Disease severity rating; OE: *O.ebracteata*; OS: *O.scriptoria*; OT: *O.travancorica*; - Observations not recorded due to flowering.

### Symptoms

Manifestation of the disease was indicated by the development of numerous stunted shoots at the nodes of the mature culms which had normal branches and foliage. These abnormal shoots did not develop into normal branches and produced only highly reduced shoots successively from their nodes. The stunted internodes of these shoots varied from 0.5 to 5.0 cm in length; culm sheaths which covered the internodes also became highly shortened in size and became boat-shaped often with a prominent ligule. Foliage developed from the abnormal

shoots was yellowish green and highly reduced in size. The leaf size varied from 1.5-8.5 x 0.5-1.0 cm as against 35-40 x 8.0-21.5 cm of healthy normal leaf of *O. travancorica*. The internodes showed purplish pink to purple discolouration with highly reduced pale green foliage. Successive development of a large number of highly shortened thin shoots in tuft from the nodes of the infected culms gave rise to the appearance of witches' broom. New shoots emerged from the rhizome during the growing season also showed pronounced brooming symptoms (Plate 5). From an infected rhizome, a large number of abnormal highly shortened shoots, often ranging from 30 to 800 in number, developed. The shoots grew only upto 10-to 50 cm in height showing typical symptoms of the disease. Often one or two normal culms also developed from the infected rhizome which gave rise to apparently healthy branches and foliage. Possibly due to these healthy culms, the diseased clump was not killed outright.

Fungal fructification developed on the affected shoots after five to six months of infection. Initially, shining white fungal mycelial weft appeared on the infected shoot, culm sheath, and foliage. The internodes covered by the boat shaped small culm sheaths became purplish pink to deep magenta in colour with closely adhering white fungal mycelium over them. The distal end of the abnormal shoot as well as the shoot developed immediately from each node of the abnormal shoot became modified into fungal fructification bearing structures. White powdery fungal stroma developed at the base of their nodes and spread to the proximal end which later developed into greyish white to pale yellow, uniformly raised ascomata. The ascomatal stroma extended from the base of the nodes to the distal end except 1 to 2 cm at the terminal portion. As the development of the fructification progressed, the whole structure turned to shining brown to greyish brown in colour with a white basal portion. At this stage, the shoot portion bearing the developing fungal fructification became free from culm

sheath and formed an incurved sickle-shaped structure (Plate 6). The fructification further matured and became shining black in colour. Development of the fructification started during September-October and it usually matured during January-February. After the discharge of the ascospores, the fructification got degenerated during the month of May-June. As new shoots were produced successively from the infected abnormal shoots, the disease also spread to the new shoots. The fungus also produced long, hair-like black rhizomorphs on the affected withered shoots, foliage, and culm sheaths during the dry period.

**Causal organism**

*Balansia linearis* (Rehm.) Diehl (IMI Nos. 322086, 322087, 326955).

***Morphological characters***

Ascocarp shining black, 5.5-10.5 x 0.5-0.8 cm, developed on the infected leaf tissue. Asci cylindrical, hyaline, 77-143 x 3.5-4.2 µm; ascospore hyaline, filiform, fragmented.

**Pathogenicity test**

Mycelial disks of 15-day-old cultures of the fungus, raised from infected tissues as well as the mature ascocarps were inoculated on culm nodes of developing shoots of 2-year-old *O. scriptoria* clump. The infection developed on the branch buds only in three out of twelve inoculated culms after two months of inoculation. Silvery white mycelial strands, which closely stuck over the shoots, were produced from the inoculated node. The nodal shoots showed reduction in their internodal length and foliage size; however, fructification of the fungus did not develop in the infected shoots even after one year of inoculation.

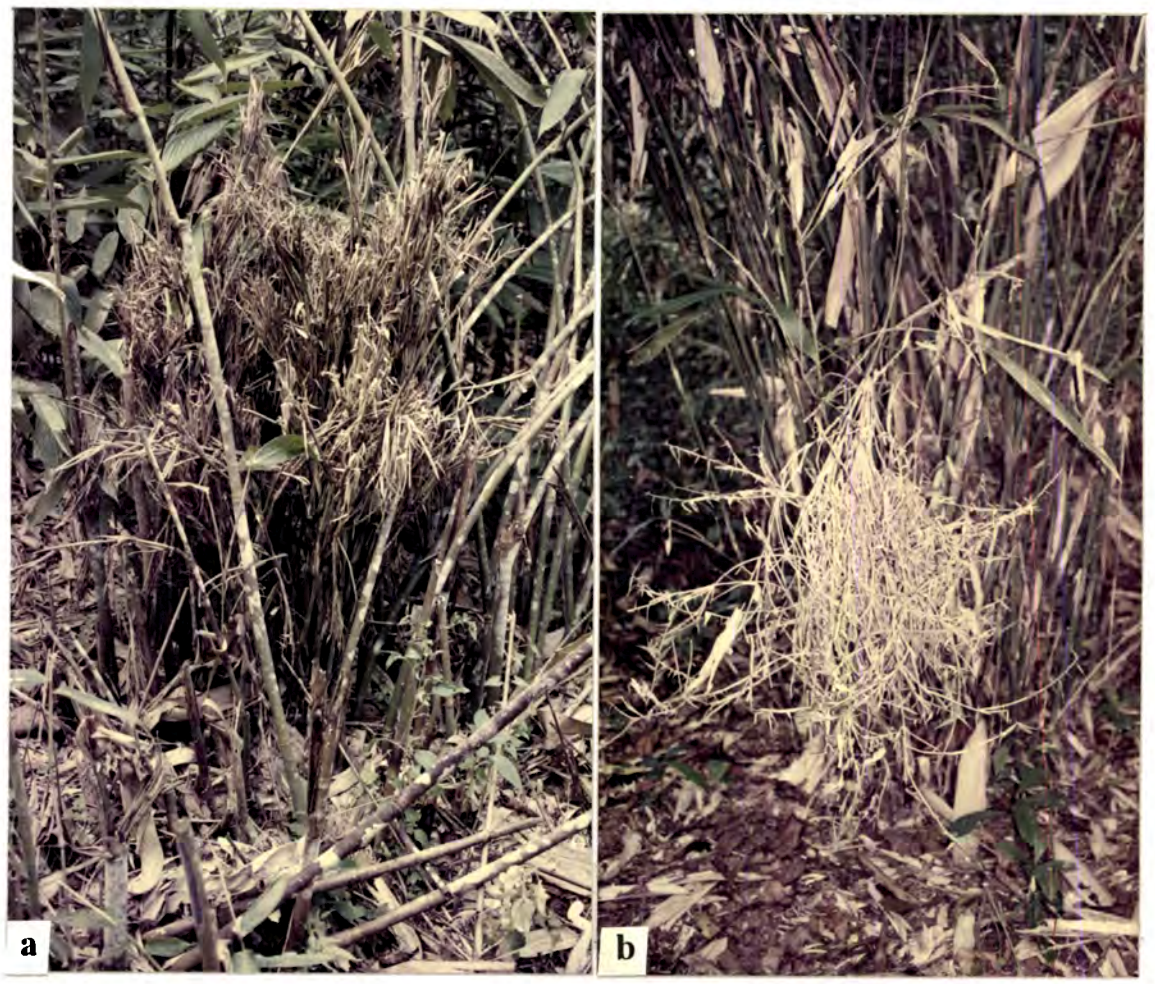



Plate 5. Witches' broom of reed bamboos. a: New culms of *Ochlandra travancorica* showing advanced stage of infection, b: *O. travancorica* clump showing witches' broom infection on culm branches.

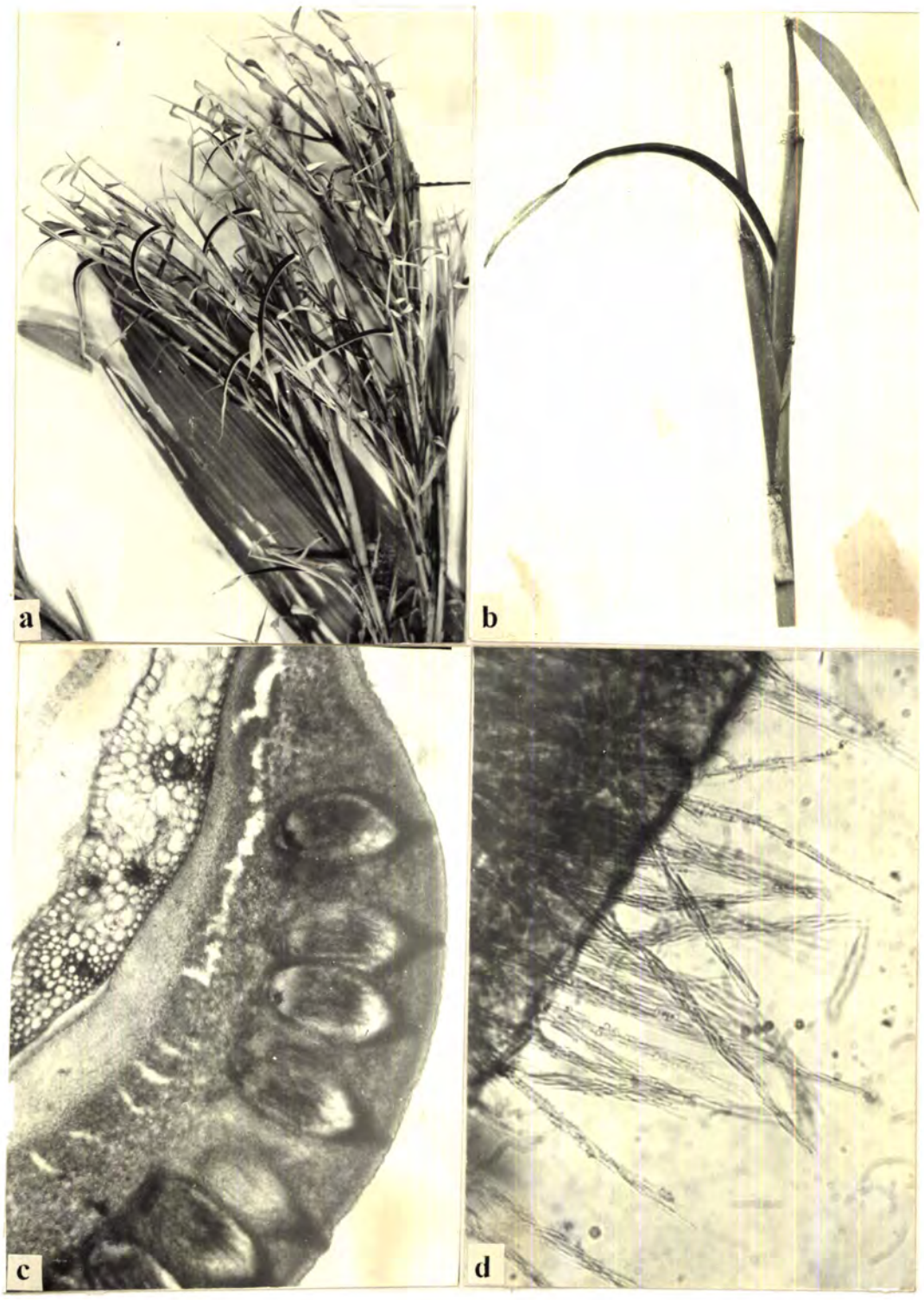



Plate 6. Witches' broom of reed bamboos. a: Witches' broom affected shoot of *Ochlandra travancorica* bearing fructifications of *Balansia linearis*, b: A magnified view of the fructification of *B. linearis*, c: A part of the transverse section of the leaf bearing fructification of *B. linearis* showing ascocarp and asci (160 x), d: A magnified view of asci containing ascospores of *B. linearis* (980 x).

## Discussion

Witches' broom disease caused by *B. linearis*, affecting commercially important reed bamboos, is widespread in the reed catchment areas of the State. Since, the macroconidial *Ephelidia* state of the fungus could not be detected either in naturally / artificially infected host tissues or in culture medium, ascospores produced in large quantity are suspected to be the source of infection in the natural stand, as also reported by Zhu (1989) in the case of *B. take* in China. Witches' broom disease of bamboo has earlier been recorded from China, Indonesia, Japan, Taiwan and Vietnam (Shinohara, 1965; Chen, 1970;Zin *et al.*, 1981; Mao, 1993). *Balansia take* causing witches' broom of *Phyllostachys viridis* and *P. glauca* has been recorded from China. The disease is found widespread in Hunan Province causing 95 to 100 percent infection (Lin and Wu, 1987). The pathogen over-winters in infected bamboo branches and produces conidia in the spring sprouts of infected bamboos, which form the source of infection. Other fungi identified to cause witches' broom of bamboos are *Epichloe bambusae* on *B. vulgaris, D. asper, Gigantochloa* spp. in Indonesia and *Loculistroma bambusae* on *Phyllostachys* and *Aciculosporium take* on *Bambusa* sp. in China (Shinohara, 1965; Chen, 1971; Nozu and Yamamoto, 1972; Kao ad Leu, 1976. Lin *et al.*, 1981). Lin and Wu (1987) reported association of a bacteria-like organism and *B. take* with the witches' broom of *Phyllostachys aurea*.

The underground rhizome was reported as free from infection (Zhu, 1989a,b). However, production of large number of wiry shoots with brooming symptoms from the underground rhizome of the witches' broom diseased bamboo clumps in Kerala, indicates the spread of infection to the rhizome as well as systemic nature of the disease. *B. linearis* is a new pathogen record on bamboos as well as a new record of fungus from India.

## 2. LITTLE LEAF DISEASE

### Occurrence

The disease was recorded in *D. strictus* clumps in natural stands at Agaly, Thakarapady, Goolikadavu (Mannarkade Forest Divn.) and Chinnar (Wild Life Divn. Idukki). Little leaf disease also affected *D. strictus* clumps in sandal reserves at Marayoor (Munnar Forest Divn.), where sandal spike disease also occurred. The disease incidence varied from locality to locality, the highest being at Thakarapady followed by Agaly and Goolikadavu (Table 4.7). In Chinnar, percent incidence of disease was comparatively low than the areas in Mannarkkad Forest Division. Clump to clump spread of infection was found to be slow and an increase of 6 percent was recorded at Agaly, 12.50 percent at Thakarapady, 9.38 percent at Goolikadavu, and 2.32 percent in Chinnar over a period of four years (Table 4.7). The disease severity rating (DSR) at Thakarapady recorded to medium (M) from 1989 onwards and at Goolikadavu during 1991.

**Table 4.7: Incidence and severity of little leaf disease of *D. strictus* in natural stands in Kerala during 1988-1991**

| Sl. No. | Locality | 1988 | | | 1989 | | | 1990 | | | 1991 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % incidence | DSI* | DSR* | % incidence | DSI | DSR | % incidence | DSI | DSR | % incidence | DSI | DSR |
| 1. | Agaly | 64.00 | 0.76 | L | 64.00 | 0.76 | L | 67.16 | 0.85 | L | 70.14 | 1.14 | L |
| 2. | Thakarapady | 77.50 | 1.00 | L | 87.50 | 1.20 | M | 85.50 | 1.28 | M | 90.00 | 1.55 | M |
| 3. | Goolikadavu | 59.37 | 0.62 | L | 59.37 | 0.68 | L | 59.37 | 0.71 | L | 68.75 | 1.16 | M |
| 4. | Chinnar | 9.30 | 0.09 | L | 9.30 | 0.90 | L | 9.30 | 0.11 | L | 11.62 | 0.18 | L |

* DSI: Disease severity index; DSR: Disease severity rating; L: low; M: medium.

**Symptoms**

The disease was characterized by the development of numerous highly reduced abnormal bushy shoots from the nodes of the newly emerged culms and also from culm branches. The internodes of these abnormal shoots were highly reduced in size and the branches developed from their respective nodes also became highly shortened. The foliage developed from these shoots, which showed prominent reduction in size, was needle-like. Profuse development of these abnormal shoots from each node of the developing culm and their successive growth gave rise to a massive bushy structure around each node (Plate 7). The disease also affected the culm elongation; infected culms showed stunted growth and became incurved mainly due to the weight of the abnormal shoots at the nodes. From low to moderately infected clumps, healthy looking, straight growing culms were also produced. In this case development of abnormal shoots occurred from the culm branch nodes. Even though, the growth of the culm was completed within six months of emergence, the abnormal shoots continued to develop from the culm nodes and branch nodes year after year and formed a massive structure of highly reduced and branched nodal shoots. In severely affected clump, all the culms produced from the rhizome in a growing season became infected. The whole clump became bushy with a few diseased and highly deformed culms.

**Histopathology**

Transverse sections of diseased as well as healthy tissues of *D. strictus* prepared by cryomicrotome and observed under Leitz Dialux 20 Microscope showed necrosis in the phloem tissues of the diseased specimens; phloem necrosis or any deformity was not observed in the healthy tissues. Generally, phloem tissues in the diseased nodal and internodal tissues were found more than those of healthy tissues.

*Dienes' stain reaction*

Dienes' stain (0.2%) gave excellent differentiation of the little leaf diseased tissues of *D. strictus*. Dark blue stained distinct areas could be detected in the phloem tissues, while no such distinct blue stained areas were observed in healthy tissues (Plate 7b,c). This indicated the presence of MLOs in the phloem of the diseased tissues.

*Fluorescence microscopy*

Transverse sections taken from diseased and healthy shoots of *D. strictus* when stained with Aniline blue (0.01%) gave excellent differentiation under fluorescence microscope. Bright yellow green fluorescent spots were observed throughout the phloem tissues of diseased specimens (Plate 8a). Transverse sections of a comparable tissues from healthy shoots showed no such fluorescent spots in the phloem (Plate 8b). This indirectly indicated the presence of MLOs in the phloem of the diseased tissues. Cell walls of xylem and their sclerenchymatous tissues, from both diseased as well as healthy shoots, also showed pale yellow fluorescence.

Hoechst 33258, a fluorochrome stain (0.01%) did not give any positive fluorescence in the phloem tissues of the diseased as well as healthy shoots.

*Transmission electron microscopy*

Ultrathin sections of little leaf diseased *D. strictus* shoots revealed pleomorphic bodies inside the sieve elements (Plate 8c,d). These bodies were not observed in comparable sections taken from healthy shoots. The abundance of these bodies varied from cell to cell. However, over all concentration of these bodies in the phloem

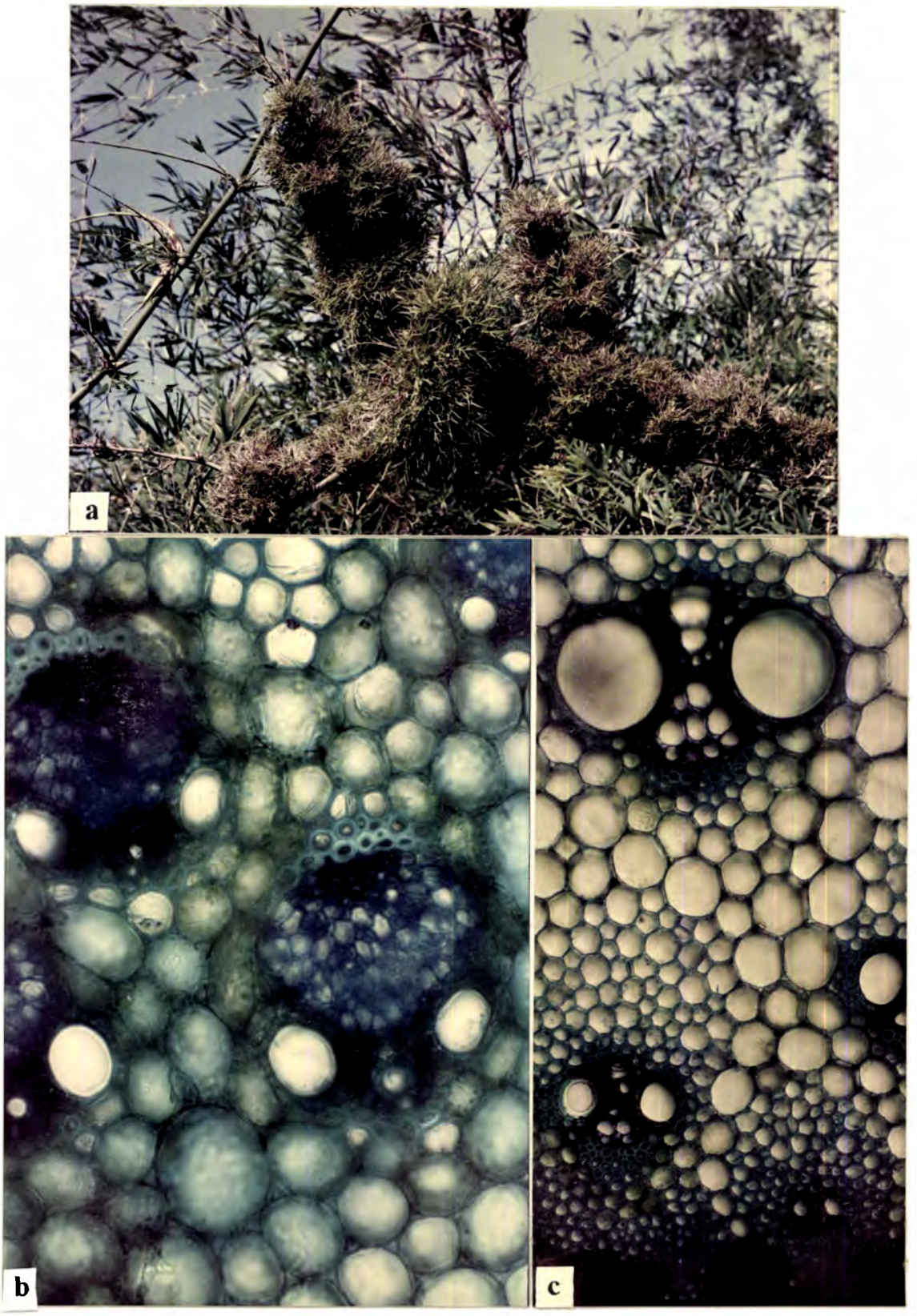



Plate 7. Little leaf disease of *Dendrocalamus strictus*. a: A close up of the diseased culms, b: Diene's staining reaction (note the deep blue staining in phloem tissues) of diseased culm internodal tissues (870 x), c: Diene's staining reaction of healthy tissues (no deep blue staining in phloem tissues)(870 x).

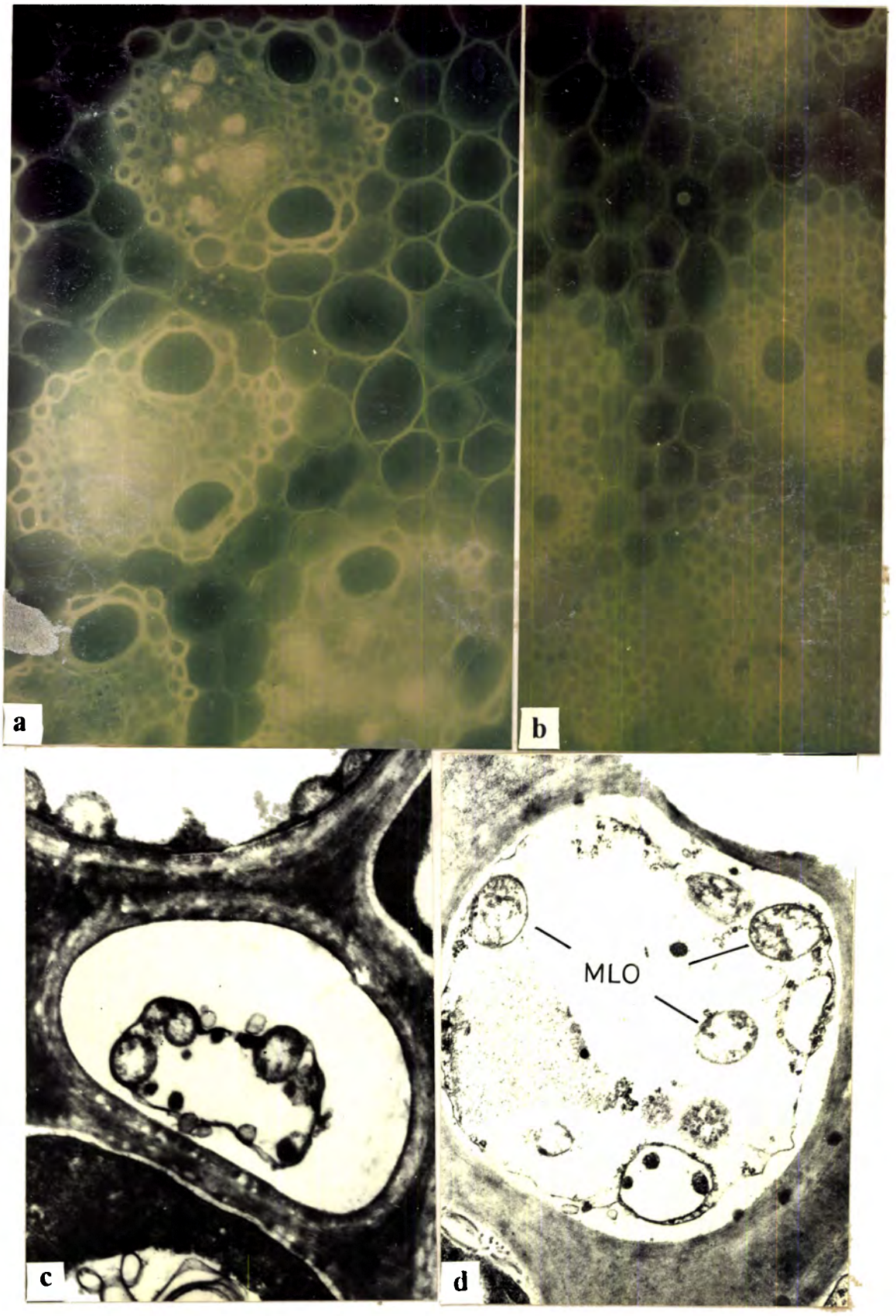



Plate 8. Little leaf disease of *Dendrocalamus strictus*. a: Diseased internodal tissues of *D. strictus* showing Aniline blue staining reaction (870 x). Note the yellow green fluorescent spots in the phloem tissues, b: Aniline blue staining reaction of healthy tissues (870 x), c,d: Transmission electron micrographs of diseased tissues showing MLOs in the phloem sieve cells (18000 x, 19200 x).

cells was low. In size and morphology, these bodies were similar to mycoplasma-like organisms (MLOs) reported to occur in phloem cells of plants affected by yellows type of diseases. Other microorganisms like bacteria, virus-like particles or fungi were not detected from any of the sections examined.

**Isolation and culture of MLOs**

In the inoculated tubes containing the SMC culture medium, no colour change was noticed even after 10 days of incubation which indicated the absence of MLO multiplication. Samples of inoculated medium were periodically examined under dark field microscope for any microbial growth. However, no such growth was observed.

**Screening of tetracycline for disease recovery**

The developing young bamboo culms showing advanced symptoms of little leaf disease, applied with Tetracycline hydrochloride (0.5 g/250 ml) as foliar spray showed disease remission symptoms; seven out of 12 treated culms showed the remission symptoms within one month of treatment. Development of few medium-sized to normal foliage from the abnormal treated shoots was observed; elongation of internodes was also observed in Tetracycline hydrochloride treated shoots. However, in most of the treated bunches of the nodal shoots, after the development of few normal leaves, the disease symptoms reappeared after three months of treatment.

**Discussion**

Little leaf disease caused by MLO was recorded only in *D. strictus* growing in natural stands, situated in the dry tracts of the State.

Disease was also observed in bamboo clumps growing in sandal reserves at Marayoor and Chinnar, where severe sandal spike disease also occurred. Earlier, *D. strictus* has been identified as a collateral host of the sandal spike pathogen (Nayar and Ananthapadmanabha, 1977). However, in Attapady Forest Reserve, where 90 percent disease incidence was recorded, no sandal trees could be found in the vicinity. This probably implies that *D. strictus* is doubtful as a collateral host of sandal spike pathogen.

In Kerala, MLO associated diseases recorded on forest tree species include sandal spike and little leaf of eucalypts (Sharma *et al.*, 1983; Ghosh *et al.*, 1984, 1985a,b). In the present study, Aniline blue (0.01%) gave positive bright yellow green fuorescence indicating the presence of MLO in the phloem sieve cells. Hoechst 33258, a benzimidole derivative DNA binding fluorochrome gave negative result. Negative result with Hoechst 33258 has also been reported in the detection of little leaf of eucalypts by Ghosh *et al.*, (1985b). Dienes' staining reaction gave excellent differentiation of the diseased bamboo tissues. Deep blue staining occurred in the phloem of little leaf diseased tissues whereas such staining was not found in healthy tissues. Electron microscopy proved the presence of MLOs in the sieve cells of the diseased tissues, though,their concentration in the phloem cells is low.

Attempts to culture the MLO associated with bamboo little leaf using SMC medium was unsuccessful. Although, culturing of MLOs has been attempted by various workers using several media (Nayar and Ananthapadmanabha, 1970; Muniappa *et al.*, 1980; Ghosh *et al.*, 1985a), except for the genus *Spiroplasma* all attempts have been unsuccessful. Though, several claims on cultivation of MLO have been reported, none of them have been confirmed.

Antibiotic treatment to control plant diseases associated with MLO has been attempted after the discovery of suppressive effect of tetracycline group of antibiotics on symptom development of mulberry dwarf disease (Ishiie *et al.*, 1967) and tetracycline and chloramphenicol against aster yellows disease (Davis *et al.*, 1968). Since, in bamboos, the process of culm production, elongation and development is completed within six months and after that only a biological consolidation takes place, it is not worth to control the disease of emerged culms by chemicals or antibiotics. Foliar application of tetracycline is tried only to prove the etiology by the production of positive remission symptoms. For practical control measures, the rhizome of the diseased clumps should be treated with the antibiotics much before the production of new shoots.

## *DISEASES RECORDED BOTH IN PLANTATIONS AND NATURAL STANDS*

### 1. ROT OF EMERGING CULM

#### Occurrence

Most of the bamboo plots in plantations and natural stands selected for the survey recorded the disease. The incidence and severity of the disease varied with the locality and the bamboo species. In *B. bambos* plantations at Nilambur, Kollathirumedu, Ezhattumugam, Palappilly, and Irumpupalam, the incidence was low and varied from 5.50 percent to 15.12 percent during 1988-'91 (Table 4.8). In *D. strictus*, the disease incidence was 25.49 percent recorded at Nadukani during 1988; however, during the following years comparatively low percent incidence was observed. Of the bamboo

plantations surveyed, *T. oliveri* at Mundoor, recorded lowest percent disease incidence which ranged from 3.24 to 4.42.

**Table 4.8: Incidence of rot of emerging culms in bamboo plantations in Kerala during 1988-1991**

| Sl. No. | Locality | Bamboo species | No. of clumps observed | Percent incidence | | | |
|---|---|---|---|---|---|---|---|
| | | | | 1988 | 1989 | 1990 | 1991 |
| 1. | Nilambur | BB | 102 | - | 5.50 (109) | 4.03 (124) | 6.04* (149) |
| 2. | Kollathirumedu | BB | 67 | - | 12.59 (127) | 13.46 (156) | 8.57 (140) |
| 3. | Ezhattumugam | BB | 59 | - | 12.60 (119) | 12.32 (146) | 14.86 (148) |
| 4. | Palappilly | BB | 60 | - | 10.40 (125) | 11.11 (144) | 10.18 (167) |
| 5. | Irumpupalam | BB | 64 | 6.80 (132) | 11.92 (151) | 15.11 (172) | 14.00 (200) |
| 6. | Nadukani | DS | 43 | 25.49 (153) | 18.23 (159) | 14.70 (136) | 17.96 (128) |
| 7. | Mundoor | TO | 96 | 3.78 (317) | 3.24 (340) | 4.14 (362) | 4.42 (294) |

* Figures in parenthesis are total number of newly emerged culms.
BB: *B.bambos*; DS: *D. strictus*; TO: *T. oliveri*; - Observations not recorded.

In a Bambusetum at Nilambur, rot of emerging culm was recorded on *B. balcooa, B. bambos, B. polymorpha, B. vulgaris, D. longispathus, D. strictus* and *T. oliveri*. The disease incidence among the seven species of bamboos varied considerably. *B. bambos, D.longispathus* and *D. strictus* recorded comparatively high percent infection during years 1988-'91 (Table 4.9); *B. bambos* recorded highest percent disease incidence (20%) during 1988.

Rot of emerging culm was recorded in natural stands at Thirunelly, Noolpuzha, Muthanga, Anamari, Marayoor, and Chinnar during 1987-'91. Disease incidence varied from 14.5 percent to 24.8 percent during 1987 to 1991 in *B. bambos* plots at Thirunelly. In Noolpuzha, percent disease incidence ranged from 17.1 to 26.8 during 1988-'90 (Table 4.10). Among the *B. bambos* plots in natural stands, highest percent disease incidence was recorded in Anamari (33.7) during 1991. Plots at Muthanga and Marayoor recorded comparatively low incidence throughout the survey period. Percent disease incidence was also low in *D. strictus* stands at Chinnar.

**Table 4.9: Incidence of rot of emerging culms in a Bambusetum at Nilambur during 1988-1991**

| Sl. No. | Bamboo species | No. of clumps observed | Percent incidence | | | |
|---|---|---|---|---|---|---|
| | | | 1988 | 1989 | 1990 | 1991 |
| 1. | *B. balcooa* | 4 | 6.66* (15) | 5.26 (19) | 4.54 (22) | 8.69 (23) |
| 2. | *B. bambos* | 5 | 20.00 (20) | 17.64 (17) | 15.78 (19) | 19.04 (21) |
| 3. | *B. polymorpha* | 4 | 10.00 (20) | 13.04 (23) | 12.00 (25) | 9.52 (21) |
| 4. | *B. vulgaris* | 19 | 5.26 (76) | 2.94 (102) | 2.06 (97) | 2.43 (82) |
| 5. | *D. longispathus* | 12 | 7.29 (96) | 8.08 (99) | 11.60 (112) | 16.66 (74) |
| 6. | *D. strictus* | 18 | 15.78 (38) | 17.50 (40) | 16.21 (37) | 17.77 (45) |
| 7. | *T. oliveri* | 3 | 0 | 0 | 0 | 5.88 (12) |

* Figures in parenthesis are total number of newly emerged culms.

Table 4.10: Incidence of rot of emerging culms in bamboo natural stands in Kerala surveyed during 1987-1991

| Sl. No. | Locality | Bamboo species | No. of clumps observed | Percent incidence | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | 1987 | 1988 | 1989 | 1990 | 1991 |
| 1. | Thirunelly | BB | 114 | 14.51 (317) | 14.65 (423) | 18.39 (397) | 24.75 (412) | 24.68 (316) |
| 2. | Moolpuzha | BB | 98 | 17.12 (368) | 25.00 (268) | 27.58 (116) | 26.76 (116) | |
| 3. | Muthanga | BB | 68 | 8.02 (212) | 5.38 (260) | 16.73 (257) | 19.45 (293) | 19.12 (272) |
| 4. | Anamari | BB | 120 | 22.81 (228) | 13.99 (286) | 18.85 (382) | 22.82 (447) | 33.69 (558) |
| 5. | Marayoor | BB | 55 | 11.11 (117) | 13.33 (135) | 8.07 (161) | 10.30 (165) | |
| 6. | Chinnar | DS | 43 | | 10.62 (113) | 12.40 (121) | 7.95 (88) | 6.12 (98) |

[1] Figures in parenthesis are total number of newly emerged culms.
BB: *B. bambos*; DS: *D. strictus*; - Observations not recorded.

## Symptoms

Rot of emerging culms manifested as greyish brown lesions surrounded by dark brown margin on the outermost culm sheath of emerging bamboo culms, belonging to 'komali' stage (15-to 30 cm in height), near the ground level. Lesions were also formed on tips and margins of culm sheaths. These lesions spread rapidly, became necrotic and covered the entire area of the external culm sheath. Since, at this stage, the culm sheaths of emerging shoots were telescopically arranged tightly one over the other, the infection spread very fast from the outer most culm sheath, which was in contact with the soil, to the inner culm sheaths. As the tissues of the emerging shoots at

this stage were very tender and succulent, the infection spread rapidly, and the tissues became discoloured and decayed with a strong smell of molasses. Since, growth of the emerging culm at this stage was extremely slow lasting for 10- to 15 days after emergence, the disease spread to the entire emerged culm and hindered its further growth and development (Plate 9). Usually, severe infection and mortality were observed at this phase of growth. When the intact culm sheaths of the diseased shoots were removed one by one, the discolouration and spread of rot was observed from outermost sheath to the innermost one and also to the undifferentiated portion of the shoot. Severely infected emerging culms ceased their further growth and became completely decayed. The diseased and later decayed emerging culms came off easily when pulled.

**Histopathology**

Longitudinal median (LMS) and transverse sections (TS) of the diseased shoots showed that infection developed on the outermost culm sheath and spread towards the innermost undifferentiated tissues. Browning and rot were found severe on the outermost four to seven culm sheaths only. The fungal mycelium was detected in the affected vascular tissues and intercellular spaces. In LMS, the spread of discolouration was seen from shoot tip downwards. However, this type of infection did not spread to the inner tissues but caused browning and necrosis on the margins and tips of two to three outer culm sheaths. In many cases apical portions of the sheaths remained free from discolouration. Mining insect larvae were frequently detected in the decayed tissues of the outer culm sheaths.

**Causal organism**

*Fusarium moniliforme* Sheldon var. *intermedium* Neish & Legget (IMI No. 350751)


Plate 9. Rot of emerging culms of bamboos (an arrow shows the affected culms). a: Emerging culms of *Bambusa balcooa* showing typical symptoms, b: Rot of emerging culms of *Dendrocalamus longispathus*, c: A close up of emerging culm of *Bambusa bambos* showing browning and rot of culm sheaths, and unexpanded culm internodes.

*Cultural characters*

Colony on PDA fast growing, violet white, reverse pale yellow; microconidia sparse, 0-1 septate, 9-20 x 2.5-3.5 µm; macroconidia 2-7 septate, 23-36 x 2.5-4.0 µm. Chlamydospore absent.

**Pathogenicity test**

Pathogenicity of *F. moniliforme* var. *intermedium* was tested employing 3-year-old *B. bambos* maintained in large metallic trays ( 90 x 60 x 25 cm). The emerging shoots were inoculated with conidial suspension of the fungus with and without injuries on the culm sheath at the ground level during June 1991 and May 1992. During 1991 a *Sarocladium* like fungus (IMI Nos. 350747, 350748, 350749, 350750) associated with the rot of the emerging culms in many localities was also included in the infection studies. However, the infection developed only in *Fusarium* inoculated shoots in treatment, with injuries; of the ten shoots inoculated, infection developed only in seven shoots. Severe infection and death of the infected shoots was observed during 1992 tests which occurred within 35 days of inoculation. *F. moniliforme* var. *intermedium* was reisolated from the infected tissues.

**Discussion**

Rot of emerging culms, occurring both in plantations and natural stands, is widespread in bamboo growing areas of Kerala affecting most of the species. Comparatively, the disease incidence is more in the natural stands than plantations. In natural stands, where water logging is observed, the disease incidence is usually found high. Among the bamboos surveyed, *B. bambos, D. longispathus* and *D. strictus* are the most affected species. Very high disease incidence and mortality occur in emerging culms of 15 to 30 cm height; this growth stage of the culm is usually referred to as 'Komali' stage (Kondas,

1982). The emerging shoots at this phase showed a period of very slow growth or remained without any elongation for about 10 to 15 days. This gestation period facilitates the incitation and spread of the infection into the innermost tissues. *Fusarium moniliforme* var. *intermedium* associated with the disease is a soil-borne pathogen and the mechanical injuries on the culms sheath caused either during the process of penetration through the soil, or by the mining insect may possibly serve as the avenues for infection. Though, *Sarocladium* sp. was also isolated from the decayed culm sheath, inoculation trials with the same failed to produce any infection. *Sarocladium oryzae* causing sheath rot of paddy has recently been recorded as the casual agent of bamboo blight in Bangladesh (Boa, 1987b). The pathogen has also been recorded from India causing blight of *B. nutans* in coastal belts of Orissa (Jamaluddin *et al.*, 1992). The bamboo blight affects the developed culms and and it spreads from culm tip downwards. However, the culm rot in Kerala affects only the just emerging culms. Five years' data on disease incidence in natural stands, plantations and Bambusetum reveals that large-scale mortality of the emerging culms due to this disease, along with the damage and destruction by the cattle and wild animals may pose serious threat to the stand productivity. Detailed investigation on epidemiology of the disease and control measures are needed. *Fusarium moniliforme* var. *intermedium* is a new pathogen record on bamboos.

## 2. ROT OF GROWING CULM

### Occurrence

Rot of growing bamboo culms was observed both in plantations and natural stands surveyed in the State during 1987-1991. Disease was observed in plantations at Nilambur, Kollathirumedu, Ezhattumugam,

Palappilly, Irumpupalam, Nadukani and Mundoor. In Irumpupalam, 12.1 percent disease incidence was recorded in *B. bambos* clumps during 1988; however, in the following years, disease incidence was comparatively low and it was only 3 percent during 1991 (Table 4.11). During 1989, in *B. bambos* plantations at Ezhattumugam, Palappilly, Nilambur and Kollathirumedu, the percent incidence was 10.4 percent, 11.2 percent, 11 percent and 8.7 percent respectively which decreased subsequently during the following years in all these localities (Table 4.11). Percent incidence was found low in *D. strictus* at Nadukani, and *T. oliveri* at Mundoor during the five years of survey from 1987 to'91.

In natural stands at Noolpuzha, Muthanga and Anamari, comparatively low percent disease incidence was recorded during the survey. Of these, highest percent disease incidence of 14.65 was recorded in Noolpuzha during 1989.

In a Bambusetum at Nilambur, five species of bamboos viz., *B. balcooa, B. bambos, B. polymorpha, D. longispathus* and *D. strictus* were found affected with the disease. Of these, *B. bambos, B. polymorpha* and *D. strictus* were severely affected during 1987 and 1988. In *B. bambos, B. polymorpha* and *D. strictus* which recorded high incidence of the disease during 1987 and 1988, later there was a gradual decline in the disease incidence reaching the minimum during 1991. On the contrary in *D. longispathus*, the incidence steadily increased from 4.2 to 17.6 percent during 1987 to 1991 (Table 4.11).

**Symptoms**

Infection appeared as water-soaked greyish brown spindle-shaped lesions usually at the base of the culm sheaths attached to the nodes. In growing culms of 1 m and above in length, the culm sheaths covered the expanding internodes more or less completely and also protected

Table 4.11: Incidence of rot of growing culms in bamboo plantations, natural stands and Bambusetum surveyed during 1987-1991

| Sl. No. | Locality | Bamboo species | Percent incidence | | | | |
|---|---|---|---|---|---|---|---|
| | | | 1987 | 1988 | 1989 | 1990 | 1991 |
| 1. | Nilambur | BB | - | - | 11.00 (109) | 6.45 (124) | 3.35* (149) |
| 2. | Kollathirumedu | BB | - | - | 8.66 (127) | 7.69 (156) | 6.42 (140) |
| 3. | Ezhattumugam | BB | - | - | 10.43 (119) | 7.27 (146) | 5.93 (148) |
| 4. | Palappilly | BB | - | - | 11.20 (125) | 11.80 (144) | 7.18 (167) |
| 5. | Irumpupalam | BB | - | 12.12 (132) | 7.28 (151) | 5.23 (172) | 3.00 (200) |
| 6. | Nadukani | DS | 8.53 (164) | 5.88 (153) | 4.40 (159) | 4.41 (136) | 6.25 (128) |
| 7. | Mundoor | TO | 3.82 (366) | 3.78 (317) | 2.35 (340) | 2.49 (362) | 2.39 (294) |
| 8. | Noolpuzha** | BB | 11.41 (368) | 8.21 (268) | 14.65 (116) | 10.34 (116) | - |
| 9. | Muthanga** | BB | 9.91 (212) | 5.76 (260) | 4.28 (257) | 2.38 (293) | 0.73 (272) |
| 10. | Anamari** | BB | 5.26 (228) | 2.79 (286) | 1.57 (382) | 1.56 (447) | 1.61 (558) |
| 11. | Nilambur (Bambusetum) | BB | 16.66 (18) | 25.00 (20) | 17.64 (17) | 10.52 (19) | 4.76 (21) |
| | | BBA | 0 (18) | 0 (15) | 4.54 (19) | 0 (22) | 8.69 (23) |
| | | BP | 18.18 (22) | 25.00 (20) | 13.04 (17) | 8.00 (19) | 4.76 (21) |
| | | DL | 4.22 (71) | 5.20 (96) | 6.25 (99) | 15.17 (112) | 17.56 (74) |
| | | DS | 14.70 (34) | 18.42 (38) | 20.00 (40) | 18.91 (37) | 8.88 (45) |

*Figures in parenthesis are total number of newly emerged culms. **Natural stands; BB: *B. bambos*; BBA: *B. balcooa*; BP: *B. polymorpha*; DS: *D. strictus*; DL: *D. longispathus*; TO: *T. oliveri*; - Observations not recorded.

the buds at the nodes from mechanical injuries. Infection was predisposed by the injuries made by a sap sucking insect, *Purohitha cervina* Distant (Fulgoridae) on culm sheath at the nodal region. Oozing of sap from the pin-prick like injuries made by the insect occurred and the infection developed in and around the wounds (Plate 10). The lesions coalesced and spread to form dark greyish brown irregular necrotic areas with dark brown margins; the infection often spread to the entire culm sheath covering the internode. Subsequently, the infection also spread to the tissues beneath the sheath i.e., branch buds, culm node and internodal tissues. Since, the culms at this stage were tender and succulent in nature and grew rapidly, the rot of the affected tissues progressed from one internode to another at a faster pace. Severely infected culm ceased its growth, became shriveled, decayed and fell off. In many instances, diseased culms fell off before they complete their elongation phase. Medium to severe infection caused various deformities to the culm including shriveling and necrosis of culm internodes, twisting and bending of culms due to severe necrosis on one side of the culm, partial development of branches, breaking of culm at the point of infection, etc. The infected culm sheaths became closely attached to the internodes and did not fall off even at the time of development of branches. Infection on branch buds hindered the development of normal branches from the nodes.

The causal fungus sporulated profusely on the necrotic tissues of the culm internode and culm sheath. Build up of the insect (*P. cervina*) population at the culm elongation phase was found responsible for the spread of the disease within the individual culm or among the culms and clumps by way of dispersal of fungal spores mechanically.

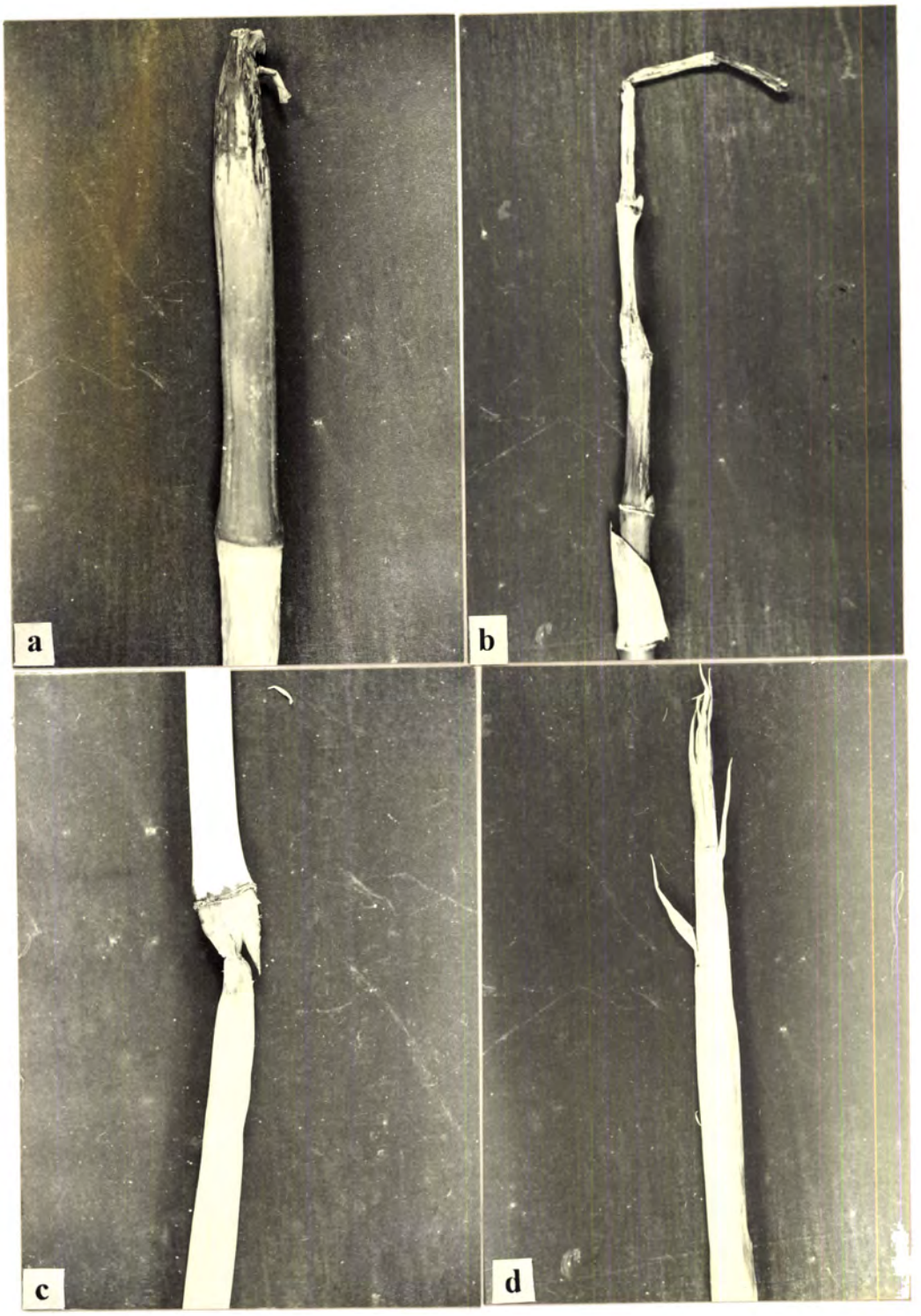



Plate 10. Rot of growing culms of bamboos. a-d: different stages of culm infection of *Bambusa polymorpha* caused by *Fusarium equiseti*.

**Causal organism**

*Fusarium eguiseti* (Corda) Sacc. (IMI No.322572)

*Cultural characters*

Colony on PDA pinkish white, powdery, aerial mycelium sparse; reverse pink. Macroconidia produced from single or grouped phialides, variable in size, 3-6 septate, 23-57 x 3.5-8.5 µm. Chlamydospores globose, 7.0-8.5 µm dia., intercalary, solitary in chains or clumps.

**Pathogenicity test**

Pathogenicity of *Fusarium eguiseti* was tested during July 1992 by employing young growing culms from 3-year-old clumps of *B. bambos*. Infection developed only in the injured and inoculated culms; uninjured inoculated culms did not develop any infection. Infection occurred as discrete necrotic lesions around the wounds after three days of inoculation which coalesced and spread to the base of the culm sheath. When the infected culm sheath was removed, discolouration and necrosis could be seen on the nodes and expanding internodes. Since, the inoculation was done at the base of the unexpanded internode of the growing culm, the infection reached upto three to five internodes above the inoculated node. *F. eguiseti* was reisolated from the infected tissues.

**Discussion**

Rot of growing culms, caused by *Fusarium eguiseti* occurs in most of the bamboo species surveyed both in plantations and natural stands. Young 2- to 4-year-old clumps of *B. bambos, D. longispathus,* and *D. strictus* in plantations and Bambusetum were found to be severely affected and succumbed to infection. After the initial period of slow growth, the culm elongation takes place in spurts of increasing rates

and the whole process of culm elongation is completed within 70 to 90 days of culm emergence as in the case of *B. bambos*. Since, the bamboo culms lack terminal growth and all the culm internodes are arranged telescopically one above the other, injuries made by the sap sucking insect, *Purohitha cervina* on the outermost culm sheath, also affect a few inner culm sheaths and the unexpanded culm internodes. Later, the infection also spreads to the tissues of culm internodes. The wounds made by the sap sucking insect serve as the avenue for the infection by *F. eguiseti*. The pathogenicity test also confirms that the infection occurs only through the injuries made on the culm sheaths or culm internodes. *F. eguiseti* has earlier been recorded as the causal agent of various diseases in forestry as well as agricultural crops in India (Shukla and Bhargava, 1975; Singh and Joshi, 1972). Symptomatically, the disease is different from culm blight of village bamboos caused by *Sarocladium oryzae*, reported from Bangladesh (Boa and Rahman, 1987), and those reported from coastal belts of Orissa (Jamaluddin, 1992). Though, often a *Sarocladium* like fungus could be isolated from the diseased culms, in pathogenicity trials it failed to produce any disease symptoms. Five years' data on the disease from selected plots in plantations, natural stands and Bambusetum reveal that, high incidence of disease which occurred during 1987-1988 can be well correlated with the heavy build up of the insect population which was observed during these years. In the following years, as the insect population, which usually builds up during the months of June-July, was found diminishing in the bamboo plots (Bambusetum), the disease incidence was also showed a decreasing trend. Since, the disease may pose practical problems in bamboo stands, especially those in establishing phase, close monitoring of the disease and sap sucking insect is required.

## 3. BRANCH DIE-BACK

### Occurrence

Branch die-back was found widespread in *B. bambos* and *D. strictus* plantations and natural stands surveyed. The disease was common in new culms. Branch die-back was recorded in *B. bambos* plantations at Nilambur, Kollathirumedu, Ezhattumugam, Palappilly, Irumpupalam and *D. strictus* plantation at Nadukani and natural stands at Thirunelly, Noolpuzha, Muthanga, Anamari, Marayoor and Chinnar during 1989-'91. The disease was also recorded in clumps of *B. vulgaris* and *D. strictus* in a Bambusetum at Nilambur during 1989-'91. Though, the disease severity was low in all the plots surveyed, percent disease incidence was found comparatively high in plantations than natural stands (Table 4.12). Culms in young developing clumps in plantations were found severely affected by the disease. The disease occurred during the months of September-October and became severe during December-January causing die-back of branches at the top and culm tips.

### Symptoms

Infection was recorded on the branches and top three to five internodes of young culm in the form of small greyish magenta coloured linear lesions which later developed into necrotic streaks. Infection was observed on the foliage as pale yellowish linear lesions which later spread to the entire leaf lamina, resulting in leaf necrosis, withering and subsequent premature defoliation (Plate 11a). The necrotic streaks on the branches and culm internodes coalesced to form large streaks; often the entire length of apical three to five culm internodes as well as the affected branches became discoloured. As the leaves of the infected branches defoliated prematurely, discolouration and necrosis on the branches and culm tip became very

prominent (Plate 11b). Infection spread from branches to the culm node and from there to the internode downwards. Under high humidity, causal fungus sporulated on the infected necrotic areas of the culm internodes and branches. Infection caused premature defoliation and die-back of branches and culm tip.

**Table 4.12: Severity of branch die-back caused by *Fusarium pallidoroseum* in bamboo plantations, natural stands and Bambusetum in Kerala surveyed during 1989-1991**

| Sl. No. | Locality | Bamboo species | 1989 | | | 1990 | | | 1991 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | % incidence | DSI | DSR | % incidence | DSI | DSR | % incidence | DSI | DSR[*] |
| | **Plantation** | | | | | | | | | | |
| 1. | Nilambur | BB | 44.11 | 0.80 | L | 33.33 | 0.65 | L | 33.33 | 0.55 | L |
| 2. | Kollathirumedu | BB | 47.76 | 0.67 | L | 46.26 | 0.59 | L | 47.76 | 0.59 | L |
| 3. | Ezhattumugam | BB | 0 | 0 | 0 | 34.38 | 0.44 | L | 39.06 | 0.50 | L |
| 4. | Palappilly | BB | 0 | 0 | 0 | 37.66 | 0.46 | L | 51.66 | 0.52 | L |
| 5. | Irumpupalam | BB | 34.37 | 0.34 | L | 14.06 | 0.15 | L | 20.31 | 0.21 | L |
| 6. | Nadukani | DS | 30.23 | 0.32 | L | 25.58 | 0.25 | L | 30.23 | 0.34 | L |
| | **Natural stands** | | | | | | | | | | |
| 1. | Thirunelly | BB | 10.52 | 0.11 | L | 6.14 | 0.07 | L | 3.51 | 0.03 | L |
| 2. | Moolpuzha | BB | 4.08 | 0.04 | L | 6.12 | 0.07 | L | 3.06 | 0.03 | L |
| 3. | Muthanga | BB | 10.59 | 0.12 | L | 8.82 | 0.08 | L | 7.35 | 0.07 | L |
| 4. | Anamari | BB | 5.83 | 0.05 | L | 2.50 | 0.03 | L | 1.66 | 0.02 | L |
| 5. | Marayoor | BB | 9.09 | 0.09 | L | 3.64 | 0.04 | L | 10.10 | 0.13 | L |
| 6. | Chinnar | DS | 13.95 | 0.13 | L | 9.30 | 0.12 | L | 6.98 | 0.07 | L |
| 7. | Nilambur | BV | 21.00 | 0.26 | L | 31.57 | 0.42 | L | 36.84 | 0.42 | L |
| | (Bambusetum) | DS | 50.00 | 0.57 | L | 55.55 | 0.83 | L | 66.66 | 0.94 | L |

[*] DSI: Disease severity index; DSR: Disease severity rating; L: low; M: medium; BB: *B. bambos*; BV: *B. vulgaris*; DS: *D. strictus*.


Plate 11. Branch die-back of *Bambusa bambos* caused by *Fusarium pallidoroseum*. a: Infected culm and branches showing browning, necrosis and withering of foliage, b: Advanced stage of infection showing defoliated culm due to severe necrosis of culm internodes and branches.

## Causal organism

*Fusarium pallidoroseum* (Cooke) Sacc. (IMI No. 320686)

### *Cultural characters*

Colony on PDA fast growing, pale yellow, reverse yellowish brown. Primary conidia with wedge-shaped foot cell, 0-1 septate, 11.5-23.0 x 2.5-4.0 µm; secondary conidia with typical heeled foot cell, 3-5 septate, 20.0-40.5 x 3.5-5.0 µm. Chlamydospores sparse, globose, 9.0-10.5 µm dia, yellowish brown, intercalary or in chains.

## Pathogenicity test

Pathogenicity of *F. pallidoroseum* was tested on fully developed new shoots of 3-year-old *B. bambos* clump. Infection developed within four days of inoculation both on injured and uninjured culm tips and branches as well as the foliage which were sprayed with a conidial suspension of the fungus. Characteristic linear greyish magenta coloured lesions developed on the culm internodes and branches, which later spread and became necrotic. Infection also developed on petiole, leaf sheath and leaves as pale yellow lesions which later spread and became necrotic. Foliage blight, withering and premature defoliation were observed within 40 days of inoculation. *F. pallidoroseum* was reisolated from the diseased tissues.

## Discussion

Recently, foliage infections caused by *F. pallidoroseum* on bamboos in North Eastern states (Deka *et al.*, 1990) and by *F. semitectum* in Kerala (Balakrishnan *et al.*, 1990) have been recorded. A similar disease affecting the foliage of basket bamboo (*Phyllostachys* sp.), caused by *Fusarium* sp., has been recorded from Yontai County, Fujian Province, China (Kuai, 1987). The disease caused more than 30 percent

infection; the leaf tips and outer margin of the leaves begin to wither which are finally defoliated. *F. semitectum* causing wilt of *D. latiflorus* has also been reported from the same area (Xie *et al.*, 1987). The cold injury was found to be the predisposing factor for the infection. In Kerala, *F. pallidoroseum* has been recorded on *Acacia auriculiformus*, *A. melanoxylon* causing foliage and twig blight (Mohanan and Sharma, 1988), and on *Calamus thwaitesii* and *C. hookerinus* causing foliage infection (Mohanan, 1990b).

## 4. NECROSIS OF CULM INTERNODE

### Occurrence

The disease was recorded only in a *Thyrsostachys oliveri* plantation at Mundoor (Palakkade Forest Divn.) during 1988-1990. The infection occurred in new culms which were produced late in the growing season i.e., in the months of August-September. Severity of the disease was low and the percent incidence of the disease during 1988, '89, '90 was 2.8, 1.5 and 1.1 respectively. Possibly, mechanical injury on the new developing culms caused by the cattle predisposed the infection.

### Symptoms

The disease manifested as small dark brown to black lesions, invariably associated with a small longitudinal split or crack, at the culm node. The internodal lesions spread rapidly in the upward and downward direction, causing infection to both the internodes forming a large necrotic area with pale yellow halo. Under high humidity the pathogen produced spores on the necrotic tissues. The infection resulted in formation of numerous abnormal shoots from the affected

nodes. The internal tissues of the node and internodes showed pronounced discolouration. Such affected culms got snapped easily by wind or animals at the point of infection.

**Causal organism**

*Curvularia lunata* (Wakker) Boedijn anamorph of *Cochliobolus lunatus* Nelson & Haasis (IMI No. 326949)

***Cultural characters***

Colony on PDA fast growing, greyish black, aerial mycelium sparse, stroma large, black, cylindrical, branched. Conidia cylindrical, slightly curved, 2- to 3-septate, pale to dark brown, 16.5-24.5 x 9.0-15.5 µm.

**Pathogenicity test**

Pathogenicity of *Curvularia lunata* was tested on new culms of *T. oliveri* during June 1991. The shoots were inoculated with conidial suspension of the fungus after making small injuries at the node by sterile scalpel blade. Infection developed as water-soaked greyish brown to dark brown lesion around the injury within seven days of inoculation. Later, the infection spread and the entire internode became necrotic within one month of inoculation. The inoculated uninjured shoots did not develop any infection. *C. lunata* was reisolated from the necrotic tissues of the infected shoots.

**Discussion**

Among the bamboo species surveyed, only very few diseases have been recorded on *Thyrsostachys oliveri*. *C. lunata* causes necrosis of culm internodes, usually on the late emerged culms of *T. oliveri*.

Since, the disease affects only the late emerged and otherwise slow growing culms, which are usually very few in number, it is not considered to be economically important. *C. lunata* is a weak pathogen and usually causes infection on fleshy tissues; the infection of supple bamboo culm is predisposed by the mechanical injury caused on the culm; pathogenicity trial also confirms the mode of infection.

## 5. THREAD BLIGHT

### Occurrence

Disease was recorded in *B. bambos* plantations at Nilambur, Kollathirumedu, Ezhattumugam, Palappilly and Irumpupalam, in *D. strictus* plantation at Nadukani, and in *T. oliveri* plantation at Mundoor during 1989-1991; in natural stands, the disease was recorded in *O. scriptoria* at Periya and Vazhachal, in *O. travancorica* at Watchumaram and Pachakkanam, in *O. ebracteata* in Kottoor, in *B. bambos* at Thirunelly, Noolpuzha, Muthanga and Anamari. Disease severity was low in all the localities surveyed (Table 4.13). In a Bambusetum at Nilambur, a total of eleven species of bamboos were found affected with the disease (Table 4.14). Disease severity was low in all the bamboo species in the Bambusetum except in *B. vulgaris* which showed medium severity with 94.73 and 94. 93 percent disease incidence during 1990 and 1991 (Table 4.14). The disease was also observed in all the reed bamboo catchment areas of the State, surveyed. Since, free water on the host surface and high atmospheric humidity were the favouring factors for the development and spread of the infection, disease appeared during the monsoons, subsided and almost disappeared during the dry period. Usually, infection occurred after the onset of South-West monsoon during June

Table 4.13: Incidence and severity of thread blight in bamboo plantations and natural stands at different localities in Kerala surveyed during 1989-1991

| Sl. No. | Locality | Bamboo species | 1989 | | | 1990 | | | 1991 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | % incidence | DSI | DSR | % incidence | DSI | DSR | % incidence | DSI | DSR* |
| | **Plantation** | | | | | | | | | | |
| 1. | Nilambur | BB | 35.29 | 0.38 | L | 25.49 | 0.25 | L | 29.41 | 0.32 | L |
| 2. | Kollathirumedu | BB | 35.82 | 0.40 | L | 46.26 | 0.49 | L | 11.94 | 0.16 | L |
| 3. | Ezhattumugam | BB | 38.77 | 0.35 | L | 33.89 | 0.40 | L | 18.64 | 0.20 | L |
| 4. | Palappilly | BB | 41.66 | 0.41 | L | 19.40 | 0.25 | L | 35.82 | 0.45 | L |
| 5. | Irumpupalam | BB | 34.37 | 0.37 | L | 32.81 | 0.32 | L | 14.06 | 0.14 | L |
| 6. | Nadukani | DS | 6.79 | 0.06 | L | 16.27 | 0.16 | L | 13.95 | 0.14 | L |
| 7. | Mundoor | TO | 0 | 0 | | 3.13 | 0.31 | L | 2.08 | 0.02 | L |
| | **Natural stand** | | | | | | | | | | |
| 1. | Thirunelly | BB | 14.03 | 0.14 | L | 9.65 | 0.09 | L | 6.14 | 0.06 | L |
| 2. | Noolpuzha | BB | 5.10 | 0.05 | L | 14.28 | 0.14 | L | 14.28 | 0.14 | L |
| 3. | Muthanga | BB | 14.70 | 0.15 | L | 14.70 | 0.15 | L | 19.12 | 0.19 | L |
| 4. | Anamari | BB | 6.66 | 0.67 | L | 9.16 | 0.09 | L | 5.00 | 0.05 | L |
| 5. | Periya | OS | 15.03 | 0.15 | L | 30.13 | 0.32 | L | 19.17 | 0.21 | L |
| 6. | Watchumaram | OT | 17.85 | 0.22 | L | 12.14 | 0.17 | L | 12.85 | 0.19 | L |
| 7. | Vazhachal | OS | 14.75 | 0.15 | L | 16.39 | 0.20 | L | 26.22 | 0.39 | L |
| 8. | Pachakkanam | OT | 18.58 | 0.23 | L | 8.97 | 0.10 | L | 14.10 | 0.04 | L |
| 9. | Kottoor | OE | 9.40 | 0.10 | L | 12.82 | 0.14 | L | 14.52 | 0.18 | L |

*DSI Disease severity index;DSR Disease severity rating; L: low; M: medium; BB: *B. bambos*; DS: *D. strictus*; TO: *T. oliveri*; OE: *O. ebracteata*; OS: *O. scriptoria*; OT: *O. travancorica*.

and continued till the end of North-East monsoon i.e., during September-October. Infection on the new foliage developed either from the mycelial threads which perennated on the culms and branches or from the air-borne asexual or sexual spores of the fungus. In high

elevated areas, the disease affected reed bamboos during the months of June-July and it continued till December-January, often affecting the entire shoots of the clump depending on the prevailing climatic conditions.

**Symptoms**

Infection on the foliage manifested as large water-soaked irregular lesions with greyish green centre and greyish white margin. Usually, the lesions appeared at the base of the leaf and advanced towards the leaf tip or at any place on the foliage and subsequently spread throughout the lamina. Fine silvery white fungal mycelial strands appeared on the lower surface of the corresponding lesions on the foliage (Plate 12).

Spread of the disease was mainly through the physical contact of the advancing fungal hyphae on the diseased foliage with the healthy neighbouring foliage. Free water on the foliage surface and high ambient humidity favoured the mycelial growth of the fungus on the host and also the spread of the disease. Rapid spread of the disease could be judged from a linear hyphal growth of 80 mm recorded on infected intact leaf of *B. vulgaris* within 48 hours. Diseased foliage stuck together closely due to the mycelial weft of the fungus at the leaf margins, leaf tips and leaf bases where they came into contact with each other. The whole foliage of the affected shoot became greyish white, and often appeared as affected with chemical toxicity. Infection caused browning and necrosis leading to blight of the culm and branches, especially of foliage. White to pale orange pustules developed on the affected plant parts. During the dry period the blighted foliage dried up, withered and defoliated; but many leaves remained stuck together on the dried up twigs because of the mycelial strands. The mycelial threads on the dried up and partly killed

branches perennated during the dry period and formed the source of infection during the wet period.

Table 4.14: Incidence and severity of thread blight in Bambusetum at Nilambur during 1989-1991

| Sl. No. | Bamboo species | No. of clumps observed | 1989 | | | 1990 | | | 1991 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | % incidence | DSI | DSR | % incidence | DSI | DSR | % incidence | DSI | DSR* |
| 1. | *B. balcooa* | 4 | 50.00 | 0.50 | L | 50.00 | 0.50 | L | 25.00 | 0.25 | L |
| 2. | *B. bambos* | 5 | 40.00 | 0.40 | L | 40.00 | 0.40 | L | 20.00 | 0.20 | L |
| 3. | *B. glaucescens* | 1 | 0 | 0 | | 0 | 0 | | 100.00 | 1.00 | L |
| 4. | *B. polymorpha* | 3 | 33.33 | 0.33 | L | 66.66 | 0.66 | L | 33.33 | 0.33 | L |
| 5. | *B. tulda* | 1 | 0 | 0 | | 100.00 | 1.00 | L | 0 | 0 | |
| 6. | *B. ventricosa* | 2 | 0 | 0 | | 50.00 | 0.50 | L | 50.00 | 0.50 | L |
| 7. | *B. vulgaris* | 19 | 63.15 | 1.05 | L | 94.73 | 1.37 | M | 94.93 | 1.32 | M |
| 8. | *D. brandisii* | 1 | 0 | 0 | | 0 | 0 | | 100.00 | 1.00 | L |
| 9. | *D. longispathus* | 12 | 50.00 | 0.58 | L | 41.66 | 0.42 | L | 33.33 | 0.42 | L |
| 10. | *D. strictus* | 18 | 38.88 | 0.50 | L | 50.00 | 0.66 | L | 44.44 | 0.72 | L |
| 11. | *T. siamensis* | 1 | 0 | 0 | | 0 | 0 | | 100.00 | 1.00 | L |

*DSI Disease severity index; DSR Disease severity rating; L: low; M: medium; Nil.

## Causal organism

*Botryobasidium salmonicolor* (Berk. & Br.) Venkatanarayanan (IMI NO.327740).

## *Cultural characters*

Colony on PDA fast growing, covering the 90 mm Petri dish within 48 h of incubation, pale pink; aserual spores hyaline, thin-walled, globose, 7.5-11.5 x 6-10 µm.


Plate 12. Thread blight of bamboos caused by *Botryobasidium salmonicolor*. a: Mycelial weft of *B. salmonicolor* on culm surface of *Ochlandra travancorica*, b: Leaves of *Bambusa polymorpha* showing blight symptoms and advancing mycelial weft.

## Discussion

Thread blight of bamboos caused by *B. salmonicolor* was recorded in plantations and natural stands; severe infection is observed on *B. bambos, B. vulgaris* and *D. strictus* in plantations and *Ochlandra* species in natural stands. Thread blight is a common disease in natural forest and it has been recorded on many plantation crops as well as other species growing in natural forests (Butler and Bisby, 1931; Anon., 1951). Thread blight was recorded in bamboos as early as in 1953 by Rogers from Karnataka and recently by Balakrishnan *et el.* (1990) from Kerala. Among the bamboo species surveyed, *B. vulgaris* is the severely affected species which showed 94.7 percent infection during 1990 and 1991. Even though, the disease is widespread, especially in tracts of high rainfall areas, and caused large-scale defoliation, it seems to be economically unimportant.

## 6. FOLIAGE BLIGHT

### Occurrence

Most of the bamboo species were found affected with the foliage blight; *B. bambos* and *D. longispathus* were the most affected ones. The disease was recorded in plantations and natural stands of *B. bambos* and *D. strictus* during 1988-1991 (Table 4.15). Disease severity was low in all the areas except in a plantation at Nilambur where severity was found to be medium in 1990 and 1991, the disease incidence being 97.05 percent and 80.39 percent respectively. Foliage blight was also recorded in *B. brandisii, D.longispathus* and *D. strictus* in a Bambusetum at Nilambur. In addition to the selected plots, the disease was also recorded in natural stands of *B.bambos* and *D.strictus* at Thudukky, Kadukuman and Anavay during 1988-1990.

Table 4.15: Incidence and severity of foliage blight in plantations and natural stands of bamboos in different localities in Kerala surveyed during 1988-1991

| Sl. No. | Locality | Bamboo species | 1988 | | | 1989 | | | 1990 | | | 1991 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | % incidence | DSI* | DSR | % incidence | DSI | DSR | % incidence | DSI | DSR | % incidence | DSI | DSR |
| | **Plantation** | | | | | | | | | | | | | |
| 1. | Nilambur | BB | 61.76 | 0.75 | L | 71.56 | 0.87 | L | 97.05 | 1.13 | M | 80.39 | 1.18 | M |
| 2. | Kollathirumedu | BB | 79.10 | 0.86 | L | 53.73 | 0.56 | L | 59.70 | 0.72 | L | 82.08 | 0.98 | L |
| 3. | Ezhattumugam | BB | 40.67 | 0.47 | L | 44.06 | 0.47 | L | 35.59 | 0.42 | L | 47.45 | 0.61 | L |
| 4. | Palappilly | BB | 91.66 | 0.98 | L | 95.00 | 0.98 | L | 100.00 | 1.08 | L | 95.00 | 10.33 | L |
| 5. | Irumpupalam | BB | 42.19 | 0.45 | L | 46.88 | 0.44 | L | 25.00 | 0.25 | L | 45.31 | 0.53 | L |
| 6. | Nadukani | DS | 30.23 | 0.33 | L | 27.90 | 0.30 | L | | | | 34.88 | 0.37 | L |
| | **Natural stand** | | | | | | | | | | | | | |
| 1. | Thirunelly | BB | 14.91 | 0.15 | L | 18.42 | 0.18 | L | 21.92 | 0.24 | L | 21.05 | 0.24 | L |
| 2. | Noolpuzha | BB | 23.47 | 0.23 | L | 21.42 | 0.23 | L | 21.43 | 0.24 | L | 27.55 | 0.32 | L |
| 3. | Muthanga | BB | 35.29 | 0.43 | L | 45.58 | 0.50 | L | 55.88 | 0.62 | L | 27.94 | 0.32 | L |
| 4. | Anamari | BB | 18.33 | 0.23 | L | 30.83 | 0.34 | L | 35.83 | 0.48 | L | 22.50 | 0.28 | L |
| 5. | Marayoor | BB | 23.66 | 0.25 | L | 32.72 | 0.36 | L | 29.09 | 0.35 | L | 21.81 | 0.25 | L |
| 6. | Chinnar | DS | 18.60 | 0.23 | L | 34.88 | 0.39 | L | 37.20 | 0.44 | L | 16.28 | 0.19 | L |
| 7. | Agaly | DS | | | | 8.95 | 0.08 | L | 17.91 | 0.18 | L | 13.42 | 0.13 | L |
| 8. | Goolikadavu | DS | | | | 34.37 | 0.37 | L | 28.12 | 0.28 | L | 56.25 | 0.69 | L |
| 9. | Thakarapady | DS | | | | 47.50 | 0.43 | L | 22.50 | 0.25 | L | 45.00 | 0.53 | L |

*DSI Disease severity index; DSR Disease severity rating; - Observations not recorded; L: low; M: medium; BB: *B.bambos*; DS: *D.strictus*.

**Symptoms**

Infection appeared as small water-soaked greyish brown spindle-shaped lesions on both young and mature leaves during August-

September. Around the small lesions, pale yellow to yellowish orange halo developed. These lesions coalesced and formed large spreading greyish brown to yellowish brown irregular lesions with dark brown border, often covering the entire leaf lamina. Such leaves became necrotic and blighted. The colour of the lesion, its size and nature of spread varied slightly depending on the bamboo species, leaf maturity, fungal species associated and microclimatic conditions. Generally, in *D. longispathus*, water-soaked, spindle-shaped lesions became circular to irregular, fast spreading necrotic spots with dark brown concentric areas alternate with pale brown areas. The necrotic spots spread to the entire foliage and caused foliage blight. In *B. bambos* and *D. strictus*, infection appeared mainly at the foliage tips and spread towards the base of the foliage. Severe infection caused yellowing of the foliage followed by leaf blight and later withering. Often greyish black to black fungal spore mass developed on the abaxial surface of the necrotic areas on the blighted foliage.

**Causal organisms**

1. *Bipolaris maydis* (Nisikado & Miyake) Shoem., anamorph of *Cochliobolus heterostrophus* (Dresch.) Dresch.(IMI NO.326944).
2. *Bipolaris* sp. (IMI No. 326947).

Usually, *B. maydis* produced dark brown lesions with greyish brown centre. In *O. monostigma*, the disease symptoms were the production of greyish yellow water-soaked irregular lesions, usually near the leaf tip, while in *D. longispathus* the lesions were water-soaked and spindle-shaped which later spread fast and became irregular necrotic spots with dark brown margin. The fungus sporulated heavily on the adaxial surface of the necrotic lesions. The cultural and

morphological characters of the two pathogens were identical to those of *B. maydis* and *Bipolaris* sp.(IMI No.326946) causing leaf spot in bamboo seedlings.

**Pathogenicity test**

Result on the pathogenicity test of *Bipolaris* sp. and *B. maydis* is provided under the Nursery diseases.

**Discussion**

*Bipolaris* spp., the common foliage pathogens of crops belonging to Gramineae have also been recorded on forestry crops viz., *Populus deltoides*, *Eucalyptus tereticornis*, *Acacia auriculiformis* A. Cunn., *A. melanoxylon* R. Br., etc., causing foliage blight (Mohanan and Sharma, 1986, 1988; Chauhan and Pandey, 1992). Earlier, *Drechslera rostrata* and *Exserohilum halodes*, two closely related fungi were recorded as causing foliage blight in bamboo nurseries and plantations from Madhya Pradesh (Harsh *et al.*, 1989) and Karnataka (Bhat *et al.*, 1989). In the present study, young (2- to 4-year-old) bamboo plantations of *B. bambos* and *D. longispathus* are found to be severely infected in successive years which in turn affect the clump vigour. Since, the new culms produced from such infected clumps are become stunted in height and show low vigour, appropriate control measures for the disease have to be worked out. Harsh *et al.* (1989) suggested application of Difolatan (0.2% a.i.) or Fytolan (0.4% a.i.) for controlling the foliage infection caused by *D. rostrata*. *B. maydis*, *B. urochloae* and hitherto undescribed *Bipolaris* sp. are also recorded from bamboo nurseries during this study. Foliage blight of bamboos caused by *Bipolaris* spp. is a new disease record.

## 7. LEAF RUST

### Occurrence

Foliage rust of bamboos was widespread in Kerala. The disease was recorded in *B. bambos* and *D. strictus* in plantations and natural stands. In plantations at Nilambur, cent percent disease incidence was recorded during 1988-'91 with medium disease severity (Table 4.16). In natural stands at Marayoor cent percent disease incidence was observed only during 1988 and 1991 and the disease severity was rated as medium. In *D. strictus*, disease incidence as well as disease severity were low in plantations as well as natural stands. In a Bambusetum at Nilambur, among the 14 species of bamboos recorded to be affected by rust, the maximum disease severity was found to be only moderate in *B. bambos, B. vulgaris, B. ventricosa, D. strictus* and *O. monostigma*; in other species the severity was low (Table 4.17). Rust infection was also recorded in *B. ventricosa* in Botanical Garden, Calicut University and in *O. travancorica* at Kakki and Pamba.

### Symptoms

Initially, infection appeared as minute pin-head, water-soaked flecks on the adaxial surface of the foliage where yellowish orange to rust brown linearly arranged urediniosori developed. On the corresponding abaxial surface of the flecks greyish brown to dark brown lesions with yellowish orange halo formed. Often numerous such lesions developed on a single leaf lamina which later coalesced and spread to the entire leaf (Plate 13,14). Severe infection caused yellowing and necrosis of the leaf tissues between the spots. Uredinia developed during August-September and continued to produce bright yellowish orange coloured urediniospores till April-May. Development of uredinia on the abaxial surface of the leaves was

rarely observed. Teliosori developed linearly on the adaxial surface of the foliage either in the degenerating urediniosori or separately during December-January. Severe uredinial infection caused abnormal defoliation even before the development of teliosori.

**Table 4.16: Incidence and severity of leaf rust caused by *Dasturella divina* in bamboo plantations and natural stands in different localities in Kerala surveyed during 1988-1991**

| Sl. No. | Locality | Bamboo species | 1988 | | | 1989 | | | 1990 | | | 1991 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | % incidence | DSI* | DSR | % incidence | DSI | DSR | % incidence | DSI | DSR | %incidence | DSI | DSR |
| | **Plantation** | | | | | | | | | | | | | |
| 1. | Nilambur | BB | 100.00 | 1.15 | M | 100.00 | 1.30 | M | 100.00 | 1.19 | M | 100.00 | 1.28 | M |
| 2. | Kollathirumedu | BB | 95.52 | 1.00 | M | 98.50 | 1.18 | M | 97.01 | 1.13 | L | 97.01 | 1.18 | M |
| 3. | Ezhattumugam | BB | 84.75 | 1.20 | M | 86.44 | 1.00 | L | 89.83 | 1.01 | L | 96.61 | 1.03 | L |
| 4. | Palappilly | BB | 83.33 | 0.87 | L | 75.00 | 0.77 | L | 100.00 | 1.07 | L | 100.00 | 1.22 | M |
| 5. | Irumpupalam | BB | 87.50 | 0.92 | L | 92.19 | 1.00 | L | 96.88 | 0.98 | L | 93.75 | 0.97 | L |
| 6. | Nadukani | DS | | | | 55.81 | 0.60 | L | 55.81 | 0.60 | L | 55.81 | 0.58 | L |
| | **Natural stand** | | | | | | | | | | | | | |
| 1. | Thirunelly | BB | 36.84 | 0.40 | L | 33.33 | 0.36 | L | 28.07 | 0.30 | L | 52.63 | 0.54 | L |
| 2. | Noolpuzha | BB | 69.39 | 0.74 | L | 62.24 | 0.67 | L | 73.47 | 0.91 | L | 45.92 | 0.49 | L |
| 3. | Muthanga | BB | 38.23 | 0.41 | L | 72.05 | 0.81 | L | 54.41 | 0.63 | L | 51.47 | 0.69 | L |
| 4. | Anamari | BB | 90.83 | 0.93 | L | 59.17 | 0.66 | L | 50.00 | 0.57 | L | 56.67 | 0.59 | L |
| 5. | Marayoor | BB | 100.00 | 1.55 | M | 96.36 | 1.25 | M | 94.55 | 1.33 | M | 100.00 | 1.35 | M |
| 6. | Chinnar | DS | 44.19 | 0.47 | L | 65.12 | 0.72 | L | 76.74 | 0.90 | L | 62.79 | 0.67 | L |
| 7. | Agaly | DS | | | | 64.18 | 0.69 | L | 52.23 | 0.58 | L | 40.30 | 0.45 | L |
| 8. | Goolikadavu | DS | | | | 53.13 | 0.53 | L | 59.38 | 0.59 | L | 59.38 | 0.63 | L |
| 9. | Thakarapady | DS | | | | 42.50 | 0.43 | L | 45.00 | 0.48 | L | 47.50 | 0.50 | L |

* DSI: Disease severity index; DSR Disease severity rating; BB: *B.bambos*; DS: *D.strictus*. Observations not recorded; L: low; M: medium.

Table 4.17: Incidence and severity of leaf rust caused by *Dasturella divina* in Bambusetum at Nilambur during 1989-1991

| Sl. No. | Bamboo species | No. of clumps observed | 1989 | | | 1990 | | | 1991 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | %incidence | DSI | DSR | %incidence | DSI | DSR | %incidence | DSI | DSR* |
| 1. | *B. balcooa* | 4 | 50.00 | 0.50 | L | 50.00 | 0.50 | L | 75.00 | 0.75 | L |
| 2. | *B. bambos* | 5 | 100.00 | 1.20 | M | 100.00 | 1.40 | M | 100.00 | 1.20 | M |
| 3. | *B. glaucescens* | 1 | | | | 0 | 0 | | 100.00 | 1.00 | L |
| 4. | *B. polymorpha* | 3 | 100.00 | 1.00 | L | 100.00 | 1.00 | L | 100.00 | 1.00 | L |
| 5. | *B. tulda* | 1 | | | | 0 | 0 | | 100.00 | 1.00 | L |
| 6. | *B. ventricosa* | 2 | | | | 100.00 | 2.00 | M | 100.00 | 2.00 | M |
| 7. | *B. vulgaris* | 19 | 100.00 | 1.11 | M | 100.00 | 1.21 | M | 100.00 | 1.32 | M |
| 8. | *D. brandisii* | 1 | 100.00 | 1.00 | L | 100.00 | 1.00 | L | 100.00 | 1.00 | L |
| 9. | *D. hamiltonii* | 1 | | | | 0 | 0 | | 100.00 | 1.00 | L |
| 10. | *D. longispathus* | 12 | 41.66 | 0.42 | L | 33.36 | 0.33 | L | 58.33 | 0.58 | L |
| 11. | *D. strictus* | 18 | 100.00 | 1.17 | M | 100.00 | 1.33 | M | 100.00 | 1.44 | M |
| 12. | *O. monostigma* | 1 | 100.00 | 1.00 | L | 100.00 | 2.00 | M | 100.00 | 2.00 | M |
| 13. | *T. oliveri* | 3 | 0 | 0 | | 0 | 0 | | 100.00 | 1.00 | L |
| 14. | *T. siamensis* | 1 | | | | 0 | 0 | | 33.33 | 0.33 | L |

*DSI Disease severity index; DSR Disease severity rating; - Observations not recorded; L: low; M: medium.

## Causal organism

*Dasturella divina* (Syd.) Mundk. & Khes. (IMI Nos. 322081,322078).

## Discussion

Leaf rust caused by *D. divina* is found to be widespread affecting most of the bamboo species in Kerala; *B. bambos, B. vulgaris, B. ventricosa, D. strictus* and *O. monostigma* are observed to be the most


Plate 13. Leaf rust of bamboos caused by *Dasturella divina*. a: Severe uredinial infection on the adaxial surface of the leaf of *Bambusa vulgaris*, b: Severe uredinial infection of *Oxytenanthera monostigma* leaves resulting in necrosis.

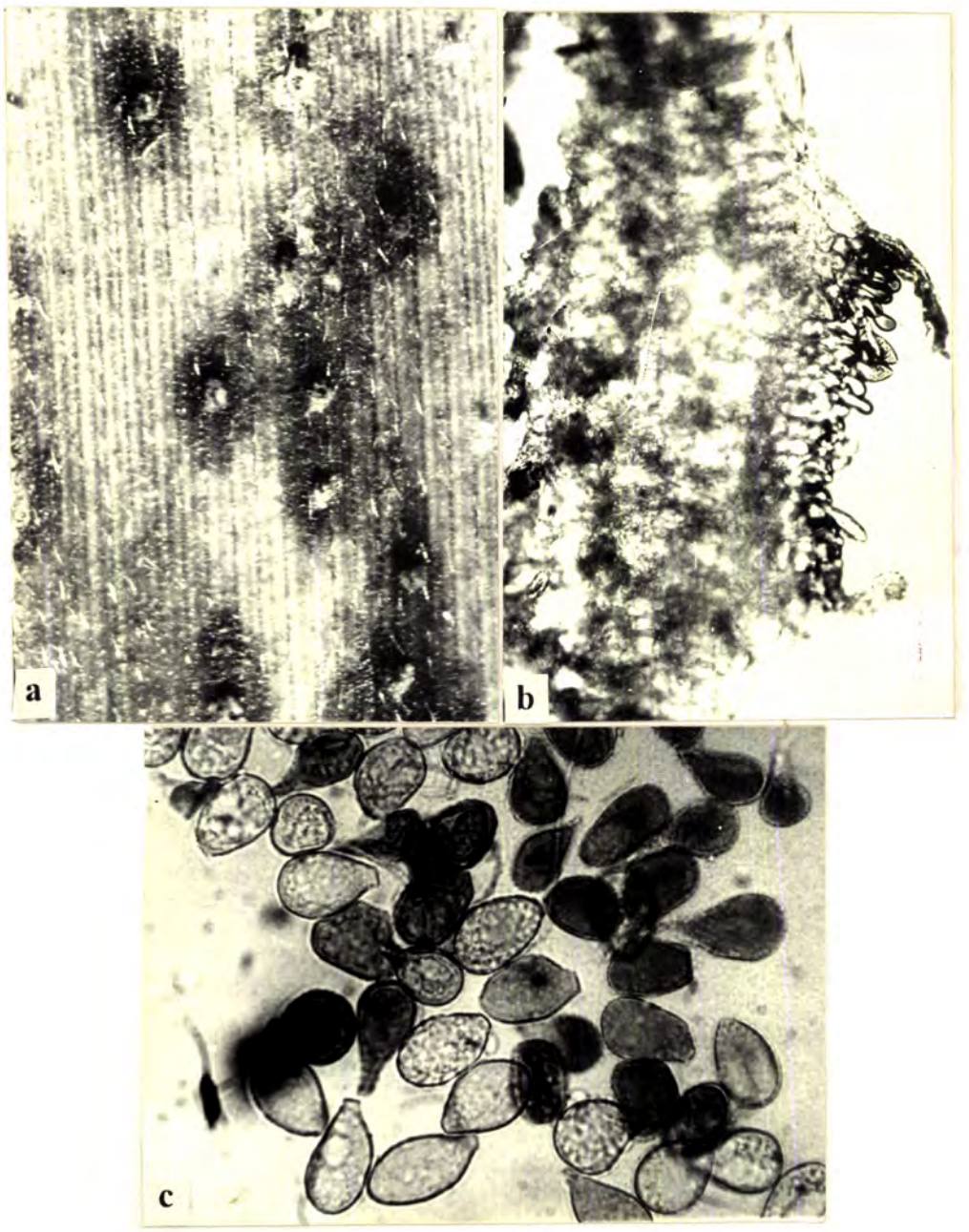



Plate 14. Leaf rust of bamboos caused by *Dasturella divina*. a: A magnified view of uredinial sori on leaf of *Bambusa bambos* (320 x), b: A vertical section of leaf of *B. bambos* through uredinium (430 x), c: Urediniospores(680 x).

affected species, whereas *T. oliveri* is the least affected. *D. divina* has earlier been recorded as having 0 to IV stages and of these 0 to I stages occur on *Randia* spp. (= *Catunaregum* spp.) and other two stages on bamboos (Bakshi *et al.*, 1972). In the present study, no alternate host is observed either in plantations or natural stands. Though, *Randia* spp. occur in bamboo natural stands in Kerala, rust infection was seldom observed. However, undergrowth belonging to Gramineae is found affected with the same leaf rust. Among the rust fungi viz., *D. divina, D. bambusina, Puccinia* spp., and *Tunicospora bagchi,* recorded on bamboos from India, *D. divina* is the most widespread in the country (Sujan singh and Bakshi, 1964; Nema and Mishra, 1965; Singh and Pandey, 1971; Bakshi *et al.*, 1972). *D. divina* is a new pathogen record on *B. balcooa, B. polymorpha, B. tulda, B. ventricosa, B. vulgaris, D. brandisii, D. hamiltonii, D. longispathus, Oxytenanthera monostigma, T. oliveri* and *T. siamensis.*

## DISEASES OF MINOR IMPORTANCE

As the disease survey in bamboo growing areas in the State was conducted extensively for a period of five years, quite a large number of diseases of minor significance could also be recorded. Most of these diseases were of common occurrence in bamboo plantations, natural stands and trial plots affecting different species of bamboos. A total of 17 such diseases were recorded on different species of bamboos with which twenty two species of fungi belonging to 17 genera were associated; majority of the diseases were leaf spot.

## 1. EXSEROHILUM LEAF SPOT

### Occurrence

Leaf spot was recorded in *B. bambos* plantations at Nilambur, Irumpupalam and Ezhattumugam during 1990 and 1991 and also in natural stands at Marayoor during 1989. In *D. strictus* the leaf spot was observed in natural stands at Agaly, Thakarapady and Chinnar. Disease was also recorded in *D. longispathus* and *B. polymorpha* in a Bambusetum at Nilambur and also few clumps in natural stands at Anavay and Kadukuman during 1988. The disease occurred on mature leaves during August-September and was sporadic in distribution in the plots surveyed.

### Symptoms

Infection manifested as small water-soaked greyish black linear to irregular lesions on mature leaves, which later coalesced and spread to the entire leaf lamina. The infection appeared in August-September; leaf necrosis, withering and premature defoliation recorded in October. The fungus sporulated profusely on the lower surface of the affected leaf.

### Causasl organism

1. *Exserohilum rostratum* (Dresch.) Leonard & Suggs anamorph of *Setosphaeria rostrata* Leonard (IMI No. 326945).
2. *Exserohilum holmii* (Luttr.) v. Arx. anamorph of *Setosphaeria holmii* (Luttr.) Leonard & Suggs (IMI No. 327737).

*E. rostratum* produced greyish black linear to irregular lesions on the foliage which later spread to the entire leaf lamina. The fungus

sporulated heavily under high humid conditions on the lower surface of the necrotic lesions on the affected foliage. *E. holmii* produced dark greyish brown to greyish black water-soaked lesions which often spread to the entire leaf lamina. Generally, no marked difference in symptoms was observed in different bamboo species, except in juvenile leaves of *D. longispathus*, where the lesions were olive yellow, spindle-shaped and water-soaked, which later spread to the entire leaf lamina and became necrotic.

### Discussion

*E. holmii* and *E. rostratum* are new pathogen record on bamboos. Recently, *E. halodes* and *Drechslera rostrata* have been recorded from Karnataka and Madhya Pradesh respectively as causing foliage blight on *Bambusa* sp. (Bhat *et al.*, 1989; Harsh *et al.*,1989). During this study, *E. holmii* and *E. rostratum* have also been recorded in bamboo nurseries in Kerala. Earlier, *Exserohilum* spp. causing foliage infection have been recorded in *Euacalyptus tereticonis*, *Acacia auriculiformis*, *A. melanoxylon*, *Calamus thwaitesii* Becc. and *C. psuedotenuis* Becc. ex Becc. & Hkf. in Kerala (Mohanan and Sharma, 1989; Mohanan, 1990b).

## 2. ZONATE LEAF SPOT

### Occurrence

The disease was recorded in all the plots of *B. bambos*, *D. strictus*, *O. travancorica*, *O. scriptoria* and *O. ebracteata* surveyed during 1987-1991. However, the disease incidence as well as severity were very low in all the areas surveyed. Zonate leaf spot was also recorded in *B. polymorpha* and *D. longispathus*, *Oxytenanthera monostigma* and *T. siamensis* in a Bambusetum at Nilambur, and in

*Thyrsostachys* sp. in Kulathupuzha during 1988-1991. Infection occurred usually on foliage in the lower branches. The development and spread of infection depended on the bamboo species as well as the local microclimatic conditions.

**Symptoms**

Infection appeared as minute greyish brown spots of 2- to 3 mm across, late in July. The spots enlarged to 5- to 8 mm in dia and became yellowish brown with dark brown margins. The spots further spread and formed reniform semicircular to circular greyish brown areas of 5- to 10 mm in width with dark brown wavy margin around the light coloured central spot; later these developed into a large zonate leaf spots of 3- to 12 cm in dia depending on the host species and climatic conditions (Plate 15). In *O. travancorica* and *O. ebracteata*, a single spot often spread and developed into a large zonate spot of 10- to 12 cm dia extending the whole width of the foliage. In *B. bambos* and *D. strictus*, only two to three concentric rings developed around the central spot. In *Oxytenanthera monostigma* and *T. siamensis* after the development of one to two rings around the central spot, under high humidity the outer rings, deep magenta to dark brown in colour, spread to the entire leaf lamina.

**Causal organism**

*Dactylaria* sp. (IMI No 322576).

This fungus showed similar cultural and morphological characters of *Dactylaria* sp. (IMI Nos. 327745, 327746) causing leaf spot of bamboo seedlings.

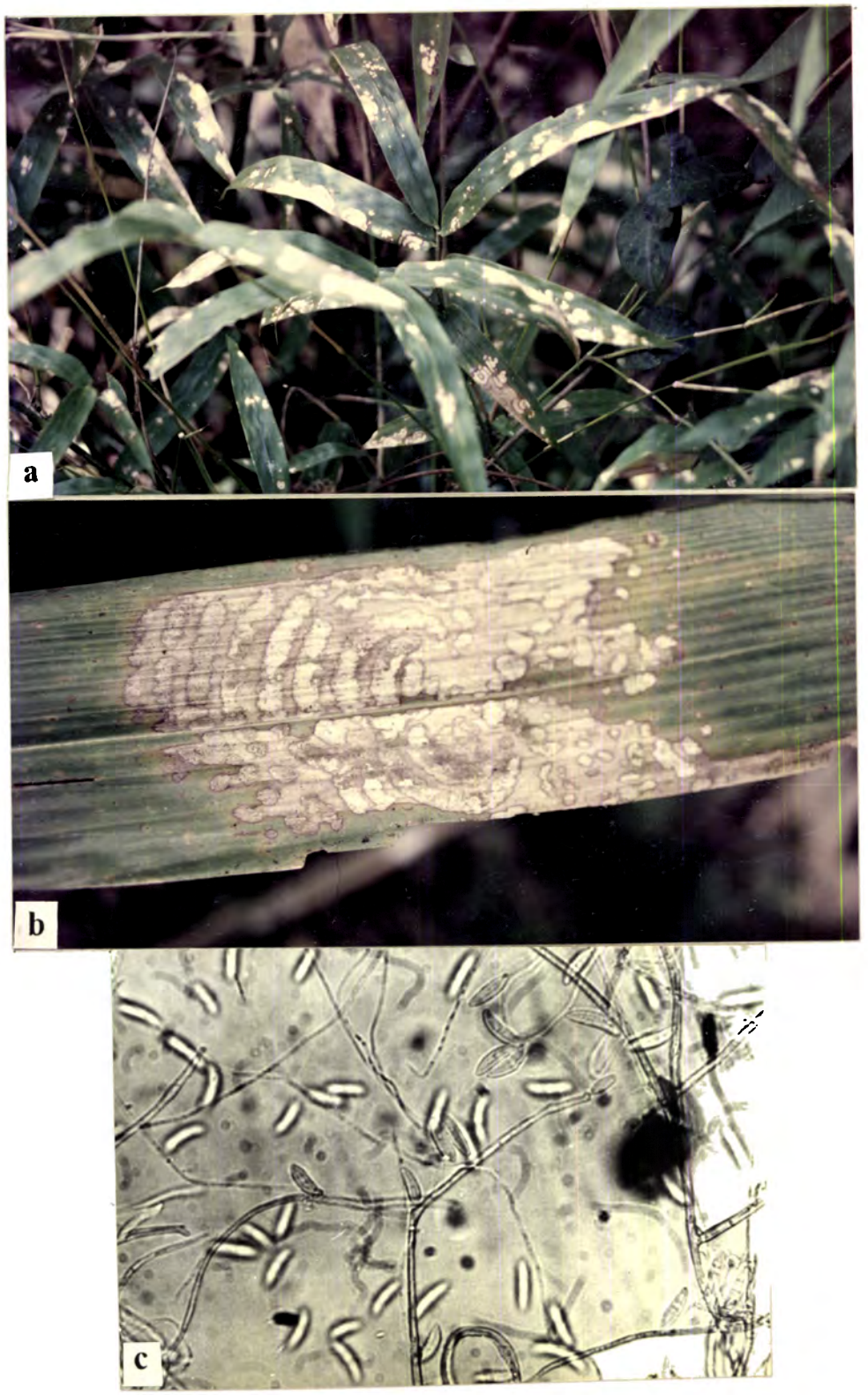



Plate 15. Leaf spot diseases of bamboos. a: Leaves of *Bambusa bambos* showing typical symptoms of zonate leaf spot caused by *Dactylaria* sp., b: Leaf of *Ochlandra travancorica* showing charasteristic large zonate spot, c: Conidiophores and conidia of *Dactylaria* sp. 670 x).

### Discussion

Zonate leaf spot caused by *Dactylaria* sp., which affects nine species of bamboos is a new pathogen record on bamboos. The disease is also observed on bamboo seedlings in nurseries in Kerala. The zonate leaf spot becomes very prominent on the foliage of reed bamboos, because of their large sized leaves.

## 3. COLLETOTRICHUM LEAF SPOT

### Occurrence

In *B. bambos* plantations, the disease was recorded from Kollathirumedu, Irumpupalam, and Palappilly; in natural stands, it occurred at Thirunelly, Anamari and Marayoor. In *D. strictus* plantations, the leaf spot was observed at Nadukani and at Agaly and Chinnar in natural stands. The disease was also recorded in all the selected plots of reed bamboos. Besides, it was also recorded in *D. strictus* clumps at Thudukky and Anavay (Mannarkkad Forest Divn.) and in *Arundinaria* sp. at Munnar. Infection occurred on the foliage, especially those on the lower branches of the new culms, during the months of September-November.

### Symptoms

The disease manifested as water-soaked small greyish brown spots on juvenile as well as mature leaves. These spots spread and coalesced to form large dark purple, linear to irregular areas which often covered the entire leaf lamina, as in *O. travancorica* and *O. ebracteata*. Infected foliage became pale yellowish green and leathery. Infection also spread to branches and caused discolouration and

necrosis of the branches. Infection often led to leaf necrosis and premature defoliation. Usually, Colletotrichum leaf spot was found intermixed with Zonate leaf spot caused by *Dactylaria* sp.

**Causal organism**

*Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. anamorph of *Glomerella cingulata* (Stonem.) Spauld & Schrenk. (IMI Nos. 331798, 331801, 331802, 331803, 331804).

**Discussion**

*Colletotrichum gloeosporioides*, a common foliage pathogen, has been recorded on a large number of forestry species causing various disease symptoms such as leaf spot, shot-hole, leaf blight, leaf withering, etc. (Bakshi, 1976; Sharma *et al.*, 1985; Sankaran and Balasundaran, 1986; Mohanan, 1988, 1990a,b). In the present study, the fungus is also recorded as causing seedling foliage infection. In India, the pathogen has earlier been recorded on bamboos in Meghalaya (Deka *et al.*, 1990). Colletotrichum foliage infection has also been recorded on bamboos from Malaysia (Azmy and Maziah, 1990) and U.S.A. (Anon., 1960).

**4. ASCOCHYTA LEAF SPOT**

**Occurrence**

The disease was recorded in plantations as well as natural stands during November-December; *B. bambos*, *D. strictus* and *Thyrsostachys* sp. were the affected bamboos. In *D. strictus*, the disease was recorded at Agaly, Thudukky, Kadukuman, Marayoor and Chinnar; in *B.bambos* at

Anavay, Kodanad and Kollathirumedu and in *Thyrsostachys* sp. at Kulathupuzha.

**Symptoms**

Infection appeared as minute spindle-shaped yellowish brown to brown water-soaked spots on the upper surface of the leaf. Both juvenile and mature leaves were found affected by the disease. The spot spread to form 3- to 5 mm in dia with greyish white centre. During December-January, dark brown to black pycnidia developed over the necrotic spots from which pinkish white spore mass oozed out under high humidity (Plate 16a,b). In severe infection, necrosis of the affected leaf tissues and foliage blight occurred.

**Causal organism**

*Ascochyta* sp. (IMI No. 331647).

***Cultural characters***

Colony on PDA greyish white, reverse bluish black; pycnidia black, 115-125 x 110-130 µm, ostiolate; conidial ooze pinkish white. Conidia hyaline, 1-septate, cylindrical, 8.5-13.0 x 3.0-3.5 µm.

**Discussion**

Leaf spot caused by a hitherto undescribed species of *Ascochyta* is a new pathogen record on bamboos. Earlier, *A. bambusina* Rao has been recorded on *B. nana* from Maharashtra (Tilak and Rao, 1967) and *A. phaseolarum* Sacc. on *Bambusa* sp. from Kerala (Balakrishnan *et al.*, 1990). The present isolate was quite near to *Ascochyta caryoticola* Punith. in taxonomic details, but differed in having conidia of

variable shapes (B.C.Sutton,IMI, pers. commun.). This *Ascochyta* sp. appears to be an undescribed species which will be validly published elsewhere.

## 5. TAR SPOT

### Occurrence

Usually, the tar spot was observed on the foliage of the lower branches of the culms, affecting both the juvenile and mature leaves and also the leaf sheaths. *B. bambos, B. vulgaris, D. strictus, Oxytenanthera monostigma, Thyrsostachys* sp., *Ochlandra scriptoria, O. travancorica* were the species found affected.

### Symptoms

Infection appeared as pin-head pale to dark yellowish brown lesions on the abaxial surface of the leaf. The lesions spread and developed into oval to circular spots with dark brown centre and pale yellow margin. Usually, four to six small spots (3-6 mm dia), appeared on the leaf lamina, as well as on the leaf sheath. Ascocarps developed as dark brown to black raised structures in the necrotic spots. Though, three species of *Phyllachora* were recorded on bamboos, no difference was observed in their symptoms produced.

### Causal organisms

1. *Phyllachora longinaviculata* Parbery (IMI No. 322077).
2. *P. shiraiana* Sydow. (IMI No. 322079).
3. *P. ischaemi* Sydow. (IMI No. 322807).

*P. longinaviculata* was recorded on *B. bambos* in plantations at Nilambur, Kollathirumedu, and Palappilly and also in natural stands at Muthanga, Noolpuzha and Marayoor. On *D. strictus* it was recorded from Agaly, Goolikkadavu and Chinnar. *P. shiraiana* was recorded on *B. bambos* in plantations at Irumpupalam and Ezhattumugam; on *D. strictus* in natural stands at Thudukky and Anavay (Mannarkkad Forest Divn.); on *O. travancorica* and *O. scriptoria* at Vazhachal; on *B. vulgaris* in Nilambur; and on *Thyrsostachys* sp. at Kulathupuzha. *P. ischaemi* was recorded in a plantation of *B. bambos* at Nilambur.

### *Morphological characters*

1. *P. longinaviculata*: Ascocarp black, erumpent, globose; asci thin-walled, 140-170 x 21-28 µm; ascospore biserially arranged, 8-spored. Ascospore hyaline to pale yellow, 0-septate, guttulate, 32-42 x 11.5-13.8 µm.

2. *P. shiraiana*: Ascocarp yellowish brown to dark brown, globose. Asci thin-walled, club shaped, hyaline to pale yellow, 72-115 x 14.0-18.5 µm, 8-spored, biserially arranged. Ascospore 1-celled, guttulate, 18.0-20.8 x 7-8 µm.

3. *P. ischaemi*: Ascocarp brown to black, globose; asci thin-walled, cylindrical, hyaline to pale yellow, 8-spored, 122-143 x 11.0-11.5 µm. Ascospore 0-septate, hyaline, guttulate, 18.5-21.0 x 6.4-7.6 µm.

### Discussion

Of the three species of *Phyllachora* causing tar spot on different species of bamboos, *P. longinaviculata* and *P. ischaemi* are new pathogen record on bamboos as well as new record of fungi from India. From Kerala, *P. bambusae* and *P. malabarensis* causing tar spot have earlier been recorded. *P. shiraiana* already recorded on bamboos from Maharashtra (Sydow and Butler, 1911), is a new record on *Ochlandra travancorica, O. scriptoria* and *D. strictus*.

## 6. PETRAKOMYCES LEAF SPOT

### Occurrence

This leaf spot disease was recorded during July-September both in plantations and natural stands. The disease was observed in *B. bambos* plantations at Nilambur, Irumpupalam, Ezhattumugam and Kollathirumedu, and in natural stands at Muthanga, Thirunelly and Noolpuzha; *B. bambos* was also found affected in trial plots at Mallana and Kalady (Malayattoor Forest Divn.). In *D. strictus*, the leaf spots were observed in natural stands at Agaly and Chinnar and also isolated clumps at Thudukky and Kadukuman. The disease was also recorded on *Arundinaria* sp. (Munnar), *Thyrsostachys* sp. (Kulathupuzha), *O. scriptoria* (Periya) and *O. ebracteata* (Kottiyoor).

### Symptoms

The disease manifested as pin-head sized brown water-soaked lesions on the foliage, especially the lower ones on the new culms. These lesions enlarged to form 3-5 mm dia oval to elliptical dark violet spots with pale yellow halo. Later, the spots appeared as raised black structures bearing pycnidia of the fungus (Plate 17b,c,d).

### Causal organism

*Petrakomyces indicus* Subram. & Ramakr.(IMI No. 322075, 322084).

### *Morphological characters*

Pycnidia black, stroma enclosing pycnidial cavity; ostiole absent, opening by an elongate cleft. Conidia 1-celled, hyaline to pale brown, 32-40 x 10.5-11.5 µm, with a simple, hyaline apical filamentous appendage, 32-50 µm long.

**Discussion**

*Petrakomyces indicus* causing leaf spot of *Arundinaria* sp., *B. bambos*, *D. strictus*, *Ochlandra ebracteata*, *O. scriptoria* and *Thyrsostachys* is a new pathogen and host record. Earlier, *P. indicus* has been recorded on *Bambusa* sp. from Tamil Nadu and Karnataka (Subramanian and Ramakrishnan, 1953; Rangaswami *et al.*, 1970).

## 7. PHOMA LEAF SPOT

**Occurrence**

In *D. strictus*, Phoma leaf spot was observed in natural stands at Agaly, Thakarapady, Goolikadavu (Mannarkkad Forest Divn.), Chinnar and in plantations at Nadukani. In *B. bambos*, the infection was observed in plantations at Nilambur, Palappilly and Kollathirumedu and also in clumps at Kumily (Kottayam Forest Divn.), and Kannavam (Cannanore Forest Divn.).

**Symptoms**

Infection occurred as small pin-head sized brown lesions on the adaxial surface of the leaves. Both juvenile and mature leaves were found affected. The spot turned spindle-shaped and later coalesced to form large irregular spot with greyish white centre and dark brown margin. The spot developed during August-September and pycnidia were formed in the necrotic lesions during November-December as erumpent structures. Under high humidity, cream to pink coloured gelatinous spore mass was produced in cirii from the pycnidia (Plate 16c,d). Though, three species of a *Phoma* were associated with the infection, no difference in symptoms produced on the host was observed.

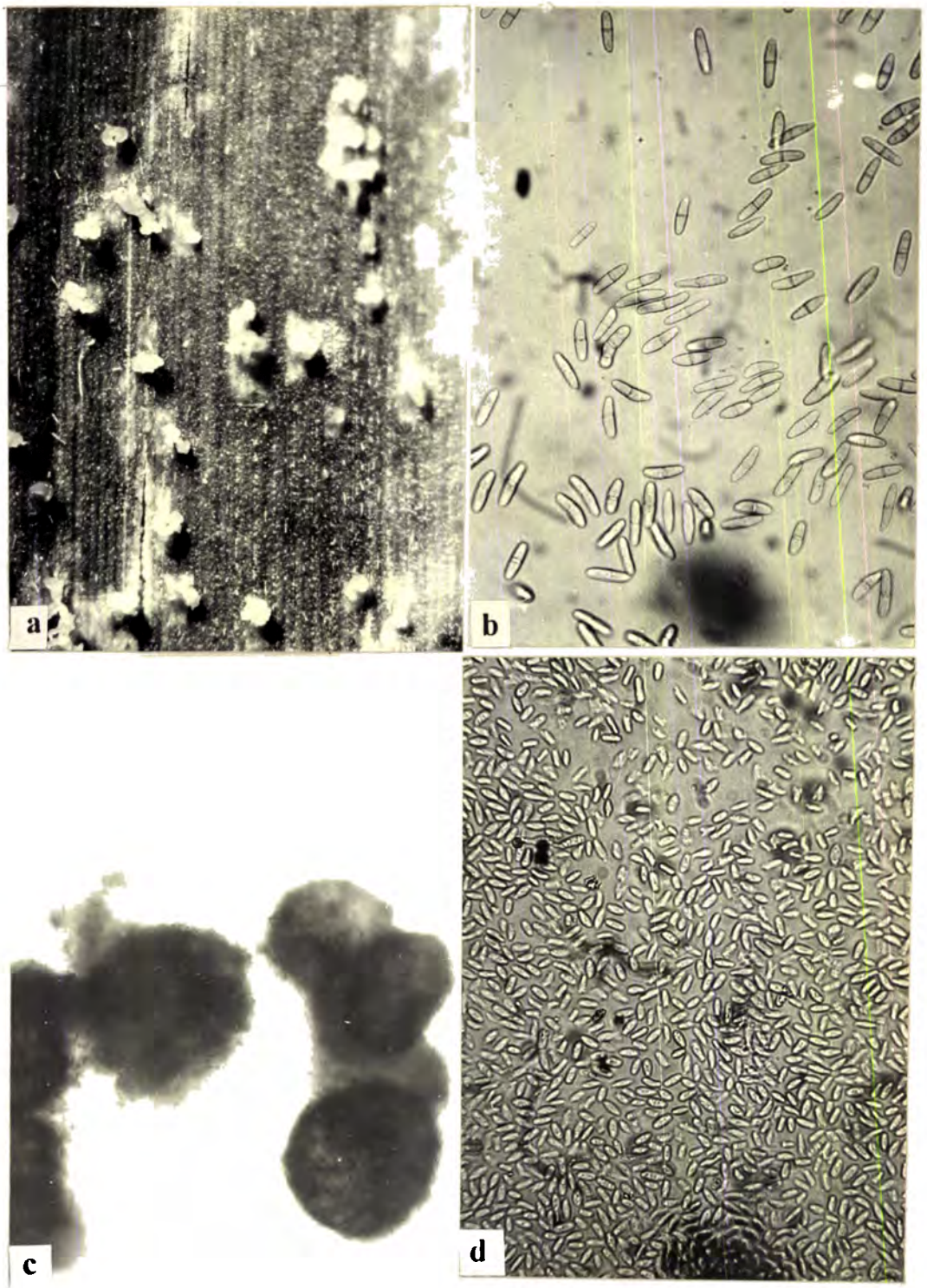



Plate 16. Leaf spot diseases of bamboos. a: A magnified view of pycnidia of *Ascochyta* sp. on *Dendrocalamus strictus* leaf (note the pycnidial ooze)(160 x), b: Conidia of *Ascochyta* sp.(640 x), c: A close up of pycnidia of *Phoma* sp. on *D. strictus* leaf (320 x), d: Conidia of *Phoma* sp. (675 x).

## Causal organisms

1. *Phoma sorghina* (Sacc.) Boerma, Dorenbosch & Van Kesteran (IMI NO. 331797).
2. *Phoma herbarum* Westend. (IMI NO. 331645).
3. *Phoma* sp. (IMI No. 331646).

## *Cultural characters*

1. *Phoma sorghina*: Colony on PDA olive brown to greyish brown with fluffy to dense aerial mycelium with characteristic pink tinged areas, reverse reddish. Pycnidia dark brown to black, ostiolate, 220-320 x 180-300 µm. Conidial ooze pinkish white; conidia hyaline, 0-septate, guttulate, 4.5-8.0 x 2.2-3.0 µm. Chlamydospores single celled.

2. *P. herbarum*: Colony on PDA pale yellow to greyish white with sparse aerial mycelium; reverse reddish. Pycnidia abundant, brown to black, globose to ellipsoid, separate or aggregated, unilocular, thin-walled, ostiolate, 30-80 x 28-78 µm. Conidia hyaline, cylindrical to ellipsoid, straight, guttulate, 0-septate, 2.8-4.0 x 1.5-2.0 µm.

3. *Phoma* sp.: Colony on PDA greyish white, slow growing, aerial mycelium felty or wooly with grey or olivaceous areas; reverse reddish. Pycnidia dark brown to black, ostiolate, 210-350 x 200-290 µm. Conidial ooze purplish pink; conidia hyaline, 0-septate, occasionally becoming 1-septate, cylindrical, ellipsoid, or pyriform, guttulate, 4.5-8.5 x 2.5-3.0 µm

## Discussion

Three species of *Phoma* viz., *P. herbarum, P. sorghina* and a hitherto undescribed *Phoma* sp. were found causing leaf spot on bamboos. So far, no *Phoma* species have been recorded on bamboos; all the three *Phoma* species recorded in the present study are new pathogen record. The isolates of *Phoma* sp. was found to be near to *P. macrostoma*, but differed in conidial characters (Punithalingam, IMI, pers. commun.). Since, it appears to be an undescribed species, it will be validly published elsewhere.

## 8. PHOMOPSIS LEAF SPOT

### Occurrence

In *B. bambos*, spot caused by *Phomopsis* sp. was recorded in plantation at Palappilly, natural stand at Kadukuman and in isolated clumps at Arippa (Trivandrum Forest Divn.). The disease was also recorded in natural stands of *D. strictus* at Anavay and Thudukky; in *Thyrsostachys* sp. the disease was observed at Kulathupuzha.

### Symptoms

The infection occurred as minute greyish brown water-soaked lesions on the mature leaves which later spread to form circular to irregular spots with dark brown wavy margin. In *D. strictus*, the spots enlarged to form larger spots 5- to 8 mm in dia with dark brown 2- to 3 concentric rings (Plate 17a). Pycnidia developed in the necrotic tissues during November-December and the conidia oozed out in yellowish cirii.

### Causal organism

*Phomopsis* sp. (IMI Nos. 331633, 331641).

### *Cultural characters*

Colony on PDA greyish white with sparse aerial mycelium; reverse pale brown. Pycnidia scattered, or aggregated, dark brown to black, 960-1020 x 950-980 µm. Only β conidia were produced, hyaline, sigmoid, 16-22 µm in length.

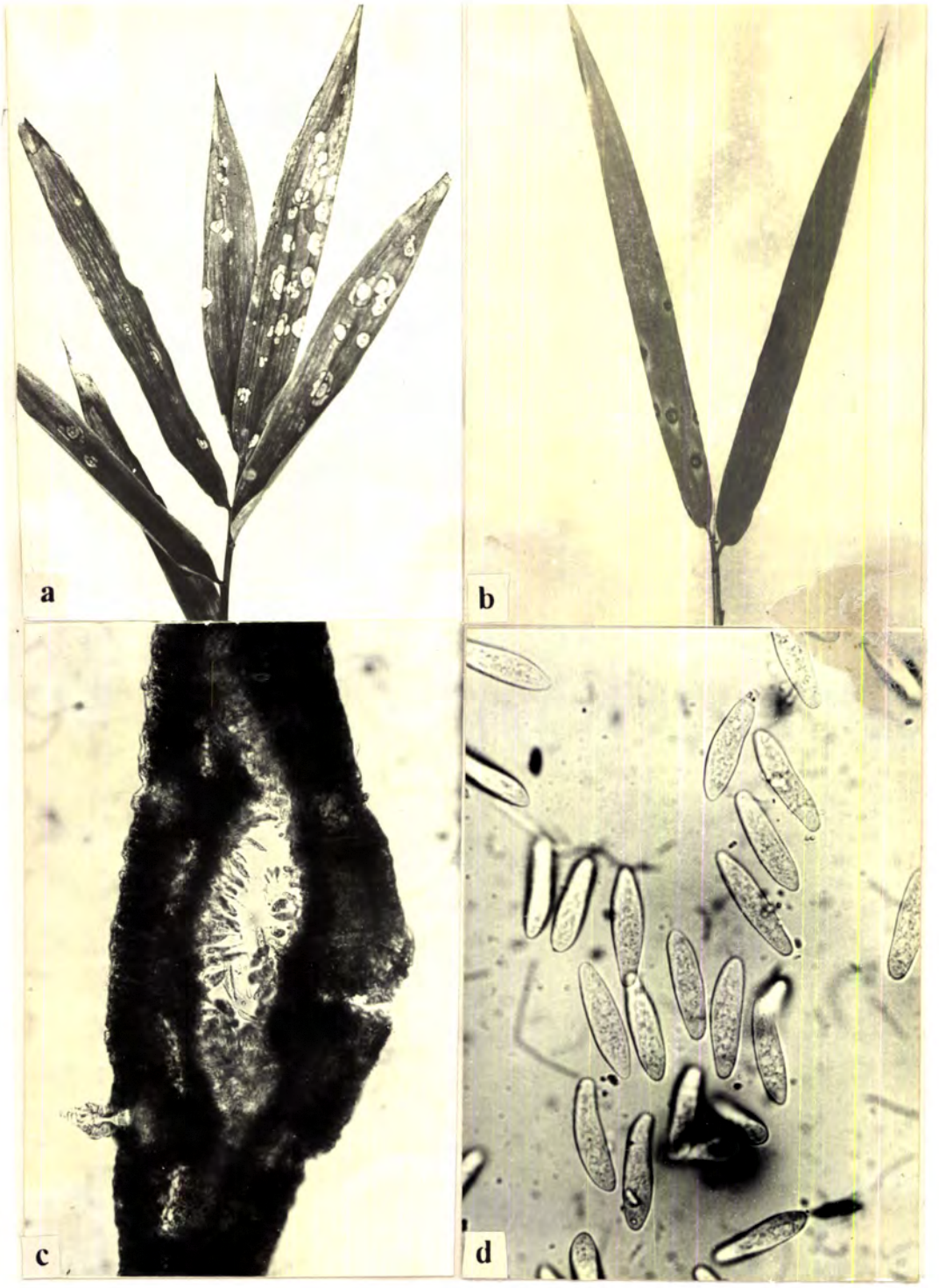



Plate 17. Leaf spot diseases of bamboos. a: *Dendrocalamus strictus* leaves showing spots caused by *Phomopsis* sp., b: Symptoms of leaf spot caused by *Petrakomyces indicus* on *Thyrsostachys* sp., c: A vertical section of leaf through pycnidium of *P. indicus* (430 x), d: Conidia of *P. indicus* (680 x)

**Discussion**

The genera, *Phomopsis* consisting of a large number of species has been reported causing foliage disease of various forestry tree species in the country (Bakshi *et al.*, 1972; Bakshi, 1976; Sharma *et al.*, 1985; Mohanan and Sharma, 1987a,b; Sankaran *et al.*, 1987,1988). So far, a *Phomopsis* sp. has not been recorded on bamboos. This is the first record of *Phomopsis* sp. on bamboos (*B. bambos, D. strictus* and *Thyrsostachys* sp.). Since, this *Phomopsis* sp. appears to be an undescribed species, it will be validly published elsewhere.

**9. STAGONOSPORA LEAF SPOT**

**Occurrence**

The leaf spot was recorded in natural stands of *B. bambos* at Thirunelly, and Thudukky and in natural stands of *D. strictus* at Agaly and Chinnar. The disease affected mature leaves during the months of December-January.

**Symptoms**

The infection appeared as dark brown irregular lesions of 3-to 5 mm dia on mature leaves, which later enlarge and became brownish black necrotic spots. The spots usually developed along the leaf margins.

**Causal organism**

*Stagonospora* sp. (IMI No. 322076).

*Morphological characters*

Pycnidia black, erumpent, globose, ostiolate, 120-210 µm dia. Conidial ooze yellowish orange; conidia hyaline, 2-septate, cylindrical to ellipsoid, minutely guttulate, 23-30 x 4.2-4.8 µm.

**Discussion**

A large number of *Stagonospora* spp. have been recorded on forestry tree species in India (Sydow and Butler, 1916; Sydow and Mitter, 1933; Thirumalachar, 1950; Singh and Khanna, 1970). So far, no *Stagonospora* has been recorded on bamboos. The present isolate of *Stagonospora* sp. is a new pathogen record on *B. bambos* and *D. strictus*. As the fungus appears to be an undescribed species, it will be validly published elsewhere.

## 10. SEPTORIA LEAF SPOT

**Occurrence**

The leaf spot was recorded on mature leaves of *Thyrsostachys* sp. in a trial plot at Kulathupuzha in the months of December-January, during 1987 to 1991.

**Symptoms**

Infection appeared as greyish brown to dark brown lesions of 2- to 4 mm dia on the upper surface of the mature leaves. Pale to dark brown pycnidia developed in the centre of the lesion. Usually, leaf spots caused by *Phomopsis* sp., *Petrakomyces* sp., and *Septoria* sp. were found intermixed on the same leaf.

**Causal organism**

*Septoria* sp. (IMI No.322084).

***Morphological characters***

Pycnidia immersed in the leaf tissue, opening through the epidermis by rounded ostiole, dark brown, sub-globose, 55-100 µm dia. Conidial ooze pale yellow to orange; conidia hyaline, cylindrical, straight to slightly curved, 1-3 septate, 11.5-23.5 x 2.5-3.5 µm.

**Discussion**

*Septoria* species causing foliage infection on forestry tree species have been recorded from India (Patel *et al.*, 1949; Tilak and Viswanathan, 1960; Sahni, 1966). This is the first record of *Septoria* on bamboos. Since, the present fungus appears to be an undescribed species, it will be validly published elsewhere.

## 11. CHAETOSPERMUM LEAF SPOT

**Occurrence**

The leaf spot was recorded in plantations of *B. bambos* at Ezhattumugam during 1987-1988, at Kollathirumedu and trial plot at Mallana (Malayattoor Forest Divn.) during 1989. The disease was observed during the months of August-September, usually on the mature leaves of the lower branches of culms.

**Symptoms**

The disease manifested as numerous minute pale yellow lesions arranged linearly on the upper surface of the mature leaves. Free

water on the leaf surface possibly helped in rapid spread of the lesions. Usually, development of a large number such lesions on the leaf imparted yellowish colour to the affected foliage. Yellowish brown minute pycnidia developed in the necrotic areas during October.

**Causal organism**

*Chaetospermum carneum* Tassi (IMI No. 331638).

***Cultural characters***

Colony on PDA greyish white, aerial mycelium sparse; pycnidia developed after four days of incubation, yellowish brown, globose to sub-globose, 180-200 µm dia; conidia hyaline, smooth, cylindrical, thin-walled, apex obtuse, 23.0-27.6 x 4.5-5.0 µm, with 2-to 3 sub-apical and supra basal appendages.

**Discussion**

So far, four species of *Chaetospermum* have been recorded to cause plant diseases in India (Mukerji and Bhasin, 1986). *C. carneum* causing leaf spot is a new pathogen record on bamboos as well as a new fungus record from India.

**12. CURVULARIA LEAF SPOT**

**Occurrence**

The leaf spot was recorded in *Arundinaria* sp. at Munnar and *Thyrsostachys* sp. at Kulathupuzha during 1988 and in reed bamboos viz., *O. travancorica, O. scriptoria* and *O. ebracteata* at Pachakkanam (Ranni Forest Divn.), Peruvannamuzhy (Calicut Forest Divn.) and Kottoor respectively during the months of June-July in 1989 and 1990.

The disease affected only the juvenlie foliage of new culms and the disease was found restricted only to a few clumps in each locality.

**Symptoms**

The leaf spots appeared as greyish black irregular lesions on the juvenile expanding foliage, especially those in the lower branches of new culms. Later, the lesions enlarged and covered the entire leaf lamina and became necrotic. The causal fungus sporulated profusely on the affected tissues.

**Causal organism**

*Curvularia lunata* (Wakker) Boedijn anamorph of *Cochliobolus lunatus* Nelson & Haasis (IMI Nos. 326949, 326950, 326951).

***Cultural characters***

Colony on PDA fast growing, greyish black, aerial mycelium sparse; stroma large, black, cylindrical, branched. Conidia solitary, cylindrical, slightly curved, 2-3 septate, pale to dark brown, 16.5-25.5 x 9.5-16.0 µm.

**Discussion**

*C. lunata*, causing leaf spot, is a new pathogen record on bamboos. *C. lunata* is a weak pathogen and has also been recorded as causing foliage infection on many agricultural, horticultural and forestry species in India (Mukerji and Bhasin, 1986; Bilgrami *et al.*, 1991). In the present study. *C. lunata* has also been recorded as causing necrosis of culm internodes of *T. oliveri*. Earlier, *C. andropogonis* has been recorded as causing foliage infection of *Bambusa* sp. from Kerala (Balakrishnan *et al.*, 1990).

## 13. ALTERNARIA LEAF TIP BLIGHT

### Occurrence

The leaf tip blight was recorded in *B. bambos* plantations at Ezhattumugam, Kollathirumedu and Palappilly during 1990 and 1991. The leaf spot was also recorded in natural stands of *D. strictus* at Goolikadavu and Chinnar during 1989. Usually, the infection was also observed in mature leaves, especially those of the lower branches.

### Symptoms

The disease manifested as small yellowish brown irregular lesions usually near the leaf tip, which later spread to form necrotic spots. The infection caused blight of the leaf tip.

### Causal organism

*Alternaria alternata* (Fr.) Keissler (IMI No. 327736).

### *Cultural characters*

Colony on PDA olive grey, reverse greyish brown, aerial mycelium abundant. Conidia yellowish brown, 4-8 transverse and 1-4 longitudinal or oblique septate, 28-55 x 9.0-16.5 µm in the middle; beak pale, 2.0-4.5 µm thick, 50 µm long.

### Discussion

*A. alternata* is a common leaf spot fungus and has been recorded on a large number of agricultural as well as forestry species in India (Bakshi, 1976; Bilgrami *et al.*, 1991). In *Eucalyptus* spp. it causes

leaf tip blight (Sharma *et al.*, 1985); in *Albizia lebbeck* and *Melia azadirach* it causes leaf spots. In the present study, *A. alternata* is also found to be causing leaf tip blight of *B. bambos* and *D. strictus* nursery seedlings.

## 14. ROSENSCHELDIELLA LEAF SPOT

### Occurrence

This leaf spot was recorded in *O. travancorica* in natural stands at Watchumaram and Pachakkanam, and in trial plot at Peruvannamuzhy and also in natural stands at Adirappally (Vazhachal Forest Divn.) during the months of September-October.

### Symptoms

The infection appeared as minute yellowish brown linear lesions on the mature leaves during September-October. The lesions enlarged and formed 3-5 mm dia necrotic spots with yellow halo. The fungal fructifications developed in linear rows in the necrotic spots on the upper surface of the leaf(Plate 18a).

### Causal organism

*Rosenscheldiella* sp. (IMI No. 349072).

### *Morphological characters*

Ascocarp black, in groups on upper surface of the leaf, spherical to ovoid, thick-walled, ostiolate, 70-105 x 73.5-112.0 µm. Asci hyaline, clavate, 4-spored, 18.5-23.5 x 9.5-11.5 µm; ascospore hyaline, one septate, 9.0-11.5 x 2.5-2.8 µm.

**Discussion**

*Rosenscheldiella* sp., recorded on leaves of *O. travancorica*, is a new pathogen record on bamboos. Earlier, *R. cinnamomi* Muthappa (Muthappa, 1967), *R. eugeniae* Petch (Ananthanarayanan, 1962) and *R. indica* Anahosur (Anahosur, 1970) have been recorded on forestry tree species in India. Since, this isolate appears to be an undescribed species, it will be validly published elsewhere.

## 15. COCCODIELLA LEAF SPOT

**Occurrence**

The leaf spot was recorded in natural stands (Watchumaram and Pachakkanam) and in trial plot (Peruvannamuzhy) of *O. travancorica*. The disease was observed on mature leaves during the months of September-October.

**Symptoms**

The infection appeared as yellowish brown minute lesions which enlarged to form dark brown linear necrotic spot. Fructifications of the causal fungus developed in the necrotic spot on the lower surface of the leaf (Plate 18b).

**Causal organism**

*Coccodiella* sp. (IMI No. 349068).

*Morphological characters*

Ascocarp black, solitary, spherical to ovoid, thin-walled, 565-775 x 495-565 µm. Asci hyaline to pale yellow, cylindrical to club-shaped, 8-spored, 213-220 x 14.5-16.5 µm; ascospore hyaline, ellipsoid, 0-septate, 34.5-41.5 x 11.0-11.5 µm.

**Discussion**

So far, only *C. quericifolia* Bose and Mueller has been recorded on leaves of *Quercus glauca* Thumb. from India (Bose and Mueller, 1964). *Coccodiella* sp. is a new pathogen record on bamboos. The present isolate appears to be an undescribed species as all the currently known species of *Coccodiella* from monocots have smaller ascospores (B.C.Sutton,IMI, pers. commun.). The fungus will be validly published elsewhere.

**16. CULM SHEATH SPOT**

**Occurrence**

Culm sheath spot was recorded in *B. bambos* plantations at Irumpupalam, Ezhattumugam, Palappilly, and Kollathirumedu and in *D. strictus* plantation at Nadukani during 1987-1991. Infection was also recorded in *B. vulgaris* in trial plot at KFRI Campus, Peechi, and in *D. brandisii* and *B. polymorpha* in a Bambusetum at Nilambur. The spots were observed in culm sheaths of expanding culm internodes during the months of June-July. The infection on the culm sheaths did not spread to the culm nodes or internodes.

**Symptoms**

The infection appeared as small brown spindle-shaped to irregular lesions, usually at the margin and tip of the culm sheath. The lesion spread to form large 5-12 mm dia irregular necrotic spots with dark brown to purple margin. The infection caused browning and necrosis of margin and tip of the sheath. Sheath spot and necrosis were more pronounced in sheaths covering the lower 4-7 culm internodes.

**Causal organism**

*Pestalozziella* sp. (IMI No. 331637).

***Cultural characters***

Colony on PDA white, aerial mycelium sparse, sporodochia developed after three days of incubation. Conidial ooze pale yellow; conidia hyaline, 0-septate, clavate to cylindrical, thin-walled, smooth, 20.5-25.0 x 6.5-7.2 µm, with 2-3 subapical cellular appendages of 20-35 µm long (Plate 18c).

**Discussion**

The disease affected the culm sheaths protecting the developing culm internodes as well as nodal buds. Since, the culm sheath fall off after the development of the branches from the nodes, and the infection does not spread to the culm, such a spot disease is unlikely to become important. So far, only three species of *Pestalozziella* have been recorded from India, of which *P. artocarpi* Nag Raj & Kendrick caused leaf spot of trees (Nag Raj and Kendrick, 1972). *Pestalozziella* sp., a hitherto undescribed species causing spot disease of culm sheath of bamboos is a new pathogen record.

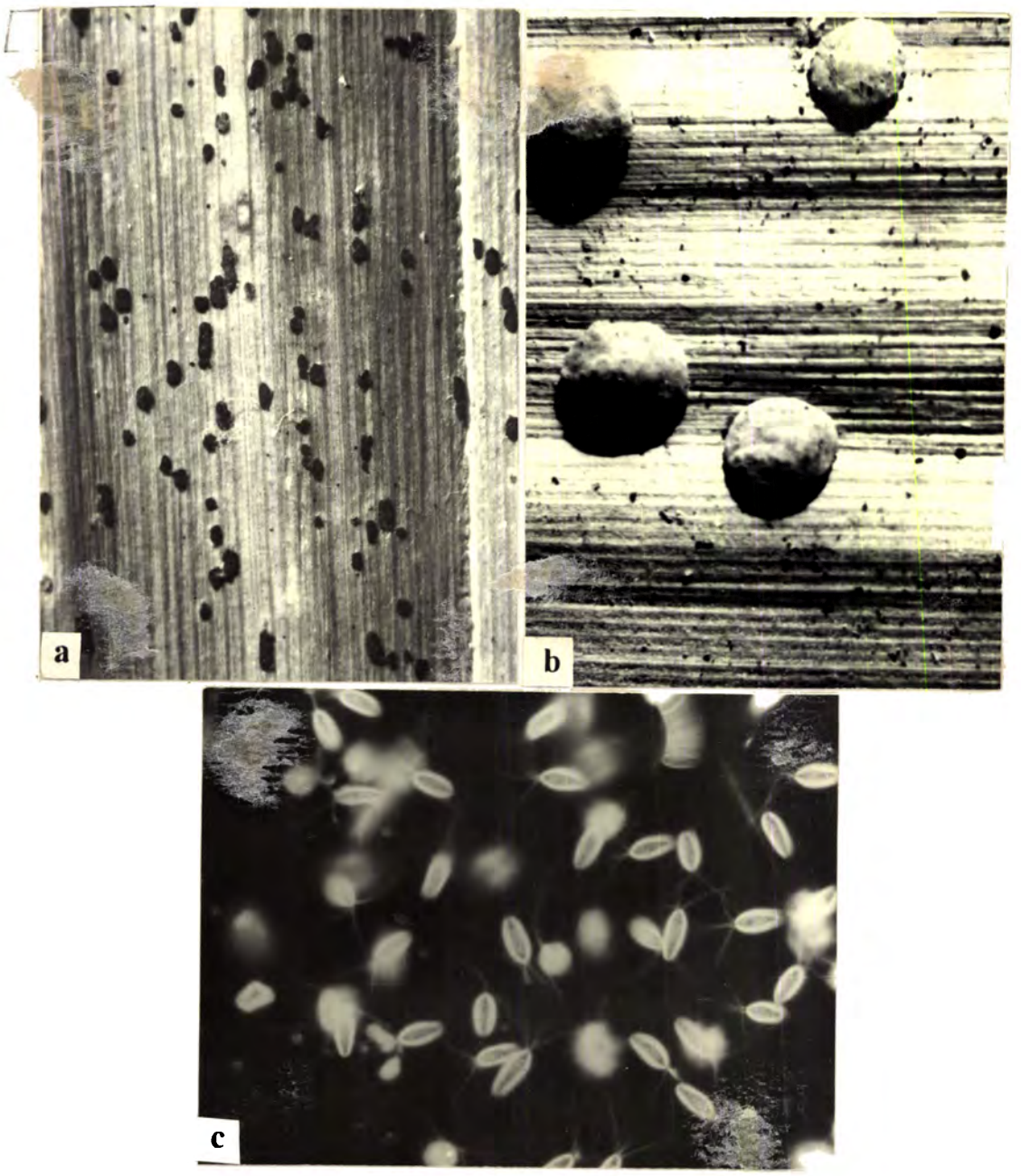



Plate 18. Leaf spot diseases of bamboos. a: *Ochlandra travancorica* leaf showing fructifications of *Rosenscheldiella* sp. (160 x), b: A magnified view of ascocarps of *Coccodiella* sp. on *O. travancorica* leaf (540 x), c: Conidia of *Pestalozziella* sp. (in dark field) causing culm sheath spot (640 x).

## 17. CULM STAINING AND DIE-BACK

### Occurrence

The disease was recorded in 7-year-old clumps of *B. vulgaris* and *D. longispathus* in a Bambusetum at Nilambur. Disease occurred only in new culms during the months of July-August. Of the 19 clumps of *B. vulgaris* observed, infection was observed in two clumps during 1990, seven during 1991 which increased to 16 clumps during 1992. In *B. vulgaris* percent culm infection was 10, 46 and 98 respectively during these years. Disease incidence in *D. longispathus* was low and of the 12 clumps in the plot, only two were infected during 1992; about seven percent of the new culms were affected.

### Symptoms

Infection was found to be predisposed by injury made by the bamboo hispine beetle, *Estigmena chinensis* Hope on the new culms (Plate 19a,b). The culm borer attacked the juvenile culms and made bore holes of 1- to 2 mm dia usually at each node. The severity of the infestation depended on the insect population and their activities. Usually, bore holes were found made on almost all the nodes of the culm as well as branches. Pale purple to dark brown linear lesions developed around each bore hole which later spread to the entire culm internode and became necrotic (Plate 19c). Raised black fructifications of the causal fungus developed on the affected internodes during September-October. Infection also spread to the branches. Usually, the discolouration of the culm internodes and later necrosis and die-back started from the distal end towards the base of the culm. Infection caused die-back of the branches and culm, which later became completely covered with the black fructifications of the fungus (Plate 19d).


Plate 19. Culm staining and die-back of bamboos. a: A clump of *Bambusa vulgaris* showing advanced stage of infection, b: A bore hole made by insect (*Estigmenia chinensis*) on the young growing culm, c: Early staining symptoms on the culms, d: Fructifications of *Apiospora* sp. on the affected culm.

**Causal organism**

*Apiospora* sp. (IMI No.349066).

***Morphological characters***

Ascocarp black, single or in groups, arranged linearly; asci cylindrical, hyaline, 8-spored, 80-119 x 24.0-25.2 µm; ascospore hyaline, one septate, 38.5-42.0 x 10.8-14.0 µm.

**Discussion**

Earlier, *A. indica* Theiss & Syd. has been recorded on twig and culms of *Bambusa* sp. from Kerala and elsewhere (Berkeley, 1856; Butler and Bisby, 1931). *A. montagnei* Sacc. and *Arthrinum* state of *A. camptospora* Penz. et Sacc.have also been recorded on dead bamboo culms (C. Mohanan, unpublished observation), however, they are not associated with the die-back. Since, the culm staining and die-back of *D. longispathus* and *B. vulgaris* caused by *Apiospora* sp. is predisposed by the infestation of the borer, the build up of the borer population has to be checked in order to avoid the infection by the *Apiospora*, especially in preservation plots and Bambusetum. This disease does not appear to become important as it was recorded only in a Bambusetum at Nilambur.

# MANAGEMENT OF RHIZOCTONIA WEB BLIGHT

## LABORATORY TRIALS

*Rhizoctonia solani*, mycelial state of *Thanatephorus cucumeris* (Frank) Donk has emerged as the most important pathogen in bamboo nurseries in the State. The fungus caused various diseases in bamboo nurseries viz., damping-off, seedling spear rot, web blight and seedling wilt. Of these, web blight was the widespread and economically important disease which affected the planting stock considerably. In nature, *R. solani* occurs as a collective species or a species complex, which is made up of divergent populations (Parmeter and Whitney, 1970). The species is so diverse that many attempts have been made to organize isolates of *R. solani* into groups based on similar morphological, physiological, pathological, and on anastomosis and intraspecific characters. Since, isolates of *R. solani* collected from different bamboo nurseries in the State, showed considerable variation in cultural and morphological characters (Plate 20), it was suspected that these isolates may belong to different anastomosis groups. Therefore, studies pertaining to characterization of *R. solani* bamboo isolates, their relative virulence, utilization and growth in different carbon and nitrogen sources, their responses to different antagonistic organisms, and efficacy of different fungicides against *R. solani* isolates were carried out in the laboratory.

### CHARACTERIZATION OF BAMBOO ISOLATES OF RHIZOCTONIA SOLANI

#### Anastomosis grouping

Fifty six isolates of *R. solani* recovered from diseased bamboo seedlings collected from 15 nurseries in the State during 1987 to 1992

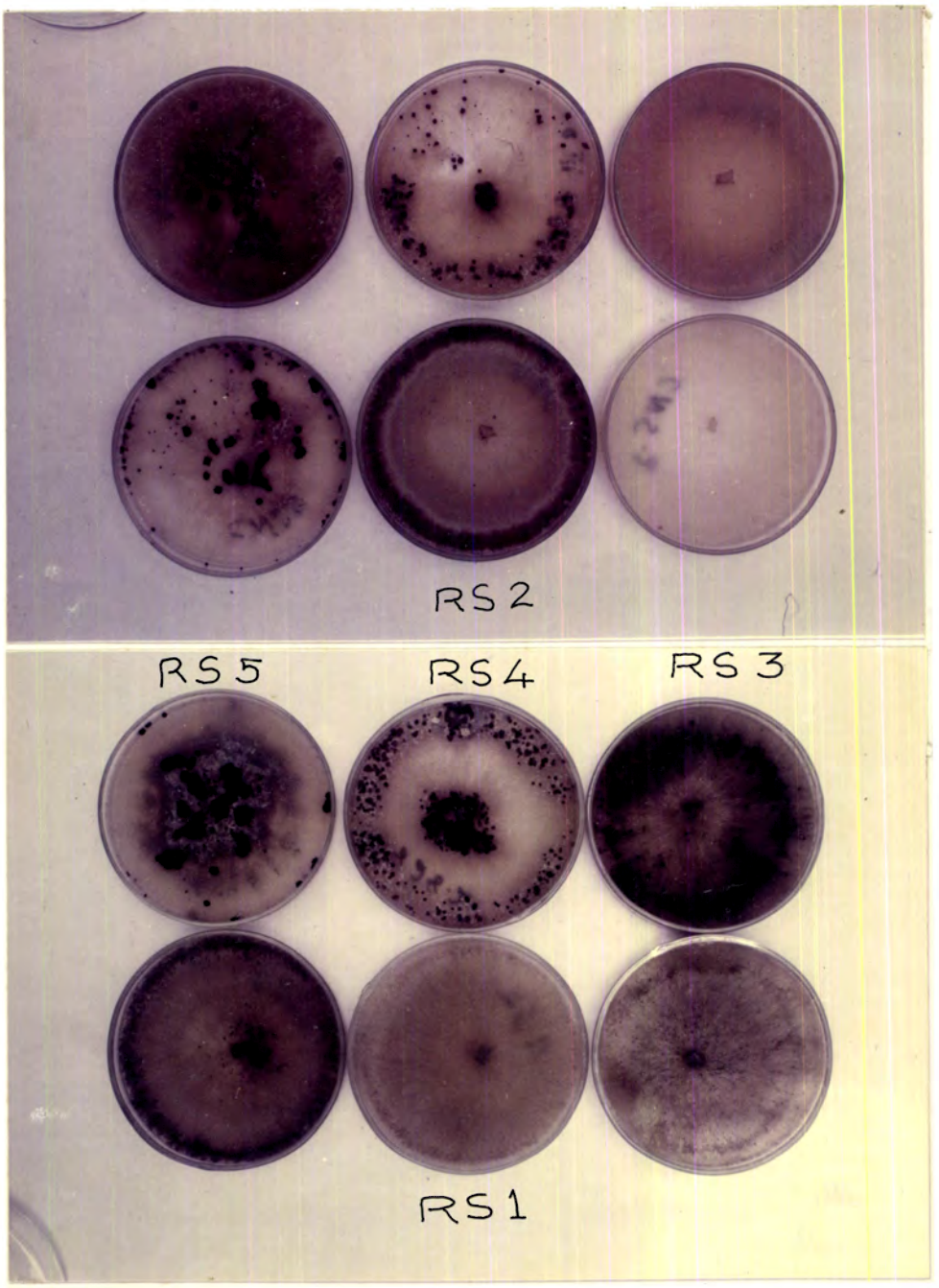



Plate 20. Potato dextrose agar culture of bamboo isolates of *Rhizoctonia solani* showing a range of cultural characteristics. RS1-RS5: Isolates selected for the study.

were screened against authentic *R. solani* tester isolates (courtsey: Dr. Akira Ogoshi, Hokkaido University, Japan). Anastomosis occurred between hyphal tips, hyphal tip and side branches or between side branches (Plate 21a,b). Anastomosis appeared to follow random cell contact but sometimes this was the result of attraction between hyphae which eventually anastomosed. Usually, three types of hyphal fusions were observed; perfect fusion, imperfect fusion and contact fusion. Perfect fusion was observed among hyphae originating from the same isolate (self fusion), where complete fusion of cell walls and cytoplasms occurred with continuous living cytoplasm at the fusion site. Fusion between different isolates (non-self fusion) usually resulted in plasmolysis of fused cells and it was treated as imperfect fusion (Plate 21b,c). Anastomosis group was assigned to an isolate, when the paired isolate showed imperfect fusion with the authentic AG tester isolate. The imperfect fusion between the hyphae resulted in granulation in the cytoplasm of the fused cell, vacuolation and collapse of the cytoplasm, resulting in killing of the fused cells and adjacent cells of the paired isolates (Plate 21c). Contact fusion between hyphae without lysis of cell walls at the site of contact was also observed but not considered as anastomosis. Of the fifty six isolates of *R. solani* tested, 28 belonged to AG1-IA, 17 isolates AG1-IC, 9 isolates AG2-2IV and two isolates did not anastomose with any of the tester isolates (Table 4.18). AG1-IA and AG1-IC were the predominant groups in the bamboo nurseries and found distributed widely in the State. Both AG1-IA and AG1-IC were associated with the damping-off and web blight. Isolates AG2-2IV, which were mainly associated with seedling root, stem and foliage infections, were restricted in their distribution in the bamboo nurseries.

Multinucleate condition was found to be common in the hyphae. This was confirmed by Aniline blue staining which showed deep blue coloured nuclei in contrast to the light blue cytoplasm (Plate 21d,e). The

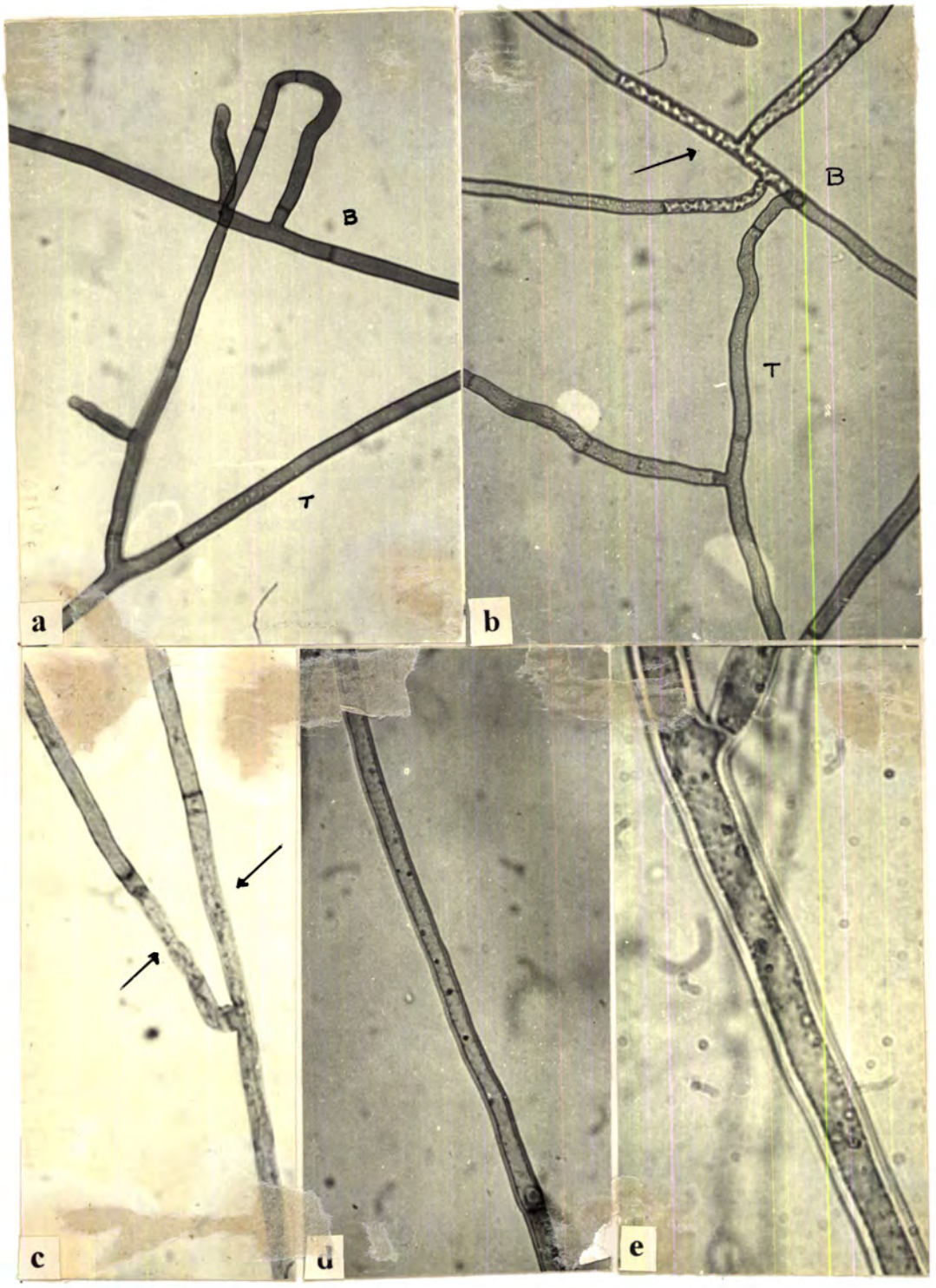



Plate 21. Hyphal anastomosis of *Rhizoctonia solani*. a: Anastomosis between hyphae of tester isolate (T) and *R. solani* bamboo isolate (B) (440 x), b,c: Plasmolysis of the fused cells (440 x) (see arrows). d, e: multinucleate cells of *R. solani* (440 x, 1080 x).

dolipore septum remained unstained, especially in young actively growing multinucleate cells.

**Table 4.18: Origin and anastomosis group (AG) of 56 isolates of *R.solani***

| Sl. No. | Locality | Bamboo species | Source | No. of isolate tested | Anastomosis group |
|---|---|---|---|---|---|
| 1. | Vadavukode | BB[a] | leaf, stem | 2 | AG1-IA |
| 2. | Kalamassery | BB | leaf | 1 | AG1-IA |
| 3. | Dhoni | DS | leaf, stem | 4 | AG1-IA (3), AG1-IC (1) |
| 4. | Peechi | BB | leaf, stem | 6 | AG1-IA (4), AG1-IC (2) |
| 5. | Nilambur | BB,DS | leaf, stem | 4 | AG1-IA (2), AG1-IC (2) |
| 6. | Pattikad | BB | leaf | 1 | AG1-IA |
| 7. | Palappilly | BB | leaf | 2 | AG1-IA (1), AG |
| 8. | Pariyaram | BB | stem | 1 | AG1-IC |
| 9. | Kulanjithodu | BB | leaf, stem | 4 | AG1-IA (2), AG1-IC (2) |
| 10. | Niravilpuzha | BB | leaf, stem | 6 | AG1-IA (3), AG1-IC (3) |
| 11. | Periya | BB | leaf, stem | 4 | AG1-IA (3), AG1-IC (1) |
| 12. | Begur | BB | leaf | 2 | AG1-IA (1), AG |
| 13. | Paneli | BB | leaf, stem | 6 | AG1-IC (1), AG2-2IV (5) |
| 14. | Pezhad | BB | leaf, stem | 4 | AG1-IA (1), AG2-2IV (3) |
| 15. | Chandhanathodu | BB,DS,TS | leaf, stem root | 9 | AG1-IA (4), AG1-IC (4), AG2-2IV (1)[‡] |

[a]BB: *B. bambos*; DS: *D. strictus*; TS: *T. siamensis*; [‡] isolate causing wilt; not anastomose with tester isolates.

## Cultural characters, growth and relative virulence of *R. solani* isolates

### *Cultural characters*

Five isolates (RS1, RS2, RS3, RS4, RS5) of *R. solani* showed considerable variation in one or the other cultural characters such as

mycelial growth, colony colour, hyphal dia, sclerotial production, size, etc. on PDA (Table 4.19). Colony growth varied from submerged growth to cottony growth and colony colour ranged from pale yellow brown to dark brown. Hyphal diameter of the isolates ranged from 6.5- to 11 um (Table 4.19).

**Table 4.19: Morphological characters of five different isolates of *R. solani* on PDA**

| *R. solani* isolate | Mycelial growth | Colony colour after 10 days of incubation | Days taken for sclerotial production | Relative* abundance and colour of sclerotia | Sclerotial dia (mm) | Hyphal dia (µm) |
|---|---|---|---|---|---|---|
| RS1 (AG1-IC) | Submerged growth | Pale yellow brown | 12 | 1 (yellowish brown) | 0.28-0.80 | 8.0-11.0 |
| RS2 (AG1-IC) | Mostly submerged, scanty aerial growth | Yellowish brown | 15 | 1 (light brown) | 0.25-0.75 | 7.0- 8.8 |
| RS3 (AG1-IA) | Mostly submerged, scanty aerial growth | Dark brown | 18 | 1 (dark brown) | 0.40-0.70 | 6.5- 8.6 |
| RS4 (AG1-IA) | Spongy aerial growth | Light Yellow brown | 8 | 4 (dark brown) | 1.00-4.00 | 8.0-11.0 |
| RS5 (AG2-2IV) | Cottony growth | Light brown | 10 | 3 (blackish brown) | 1.00-3.50 | 6.5- 8.0 |

* 1 poor (widely scattered); 3 abundant; 4 excellent (closely aggregated)

Production of sclerotia and their relative abundance also varied among the five isolates. Isolates RS1 and RS2 produced scanty, small sclerotia (0.25-0.8 mm dia); while RS4 produced abundant, large (1-4 mm dia), dark brown sclerotia. Isolate RS3 produced dark brown sclerotia mostly at the periphery of the colony. Whereas, isolate RS5

produced abundant blackish-brown, large sclerotia (1-3.5 mm), usually aggregated at the centre of the colony. The time taken for sclerotial formation also varied among isolates. Isolate RS4 was able to produce abundant sclerotia within eight days of inoculation, while isolate RS3 took almost 18 days to produce sclerotial bodies in the culture.

*Growth*

All the five isolates showed some differences in their rate of growth on PDA. Isolate RS4 grew very fast and attained a diameter growth of 90 mm within 46 h, showing a highest growth rate of 2.16 mm $h^{-1}$. In contrast, isolate RS3 was comparatively slow growing than the other four isolates which attained a mean diameter growth of 66.2 mm at 46 h with a mean growth rate of 1.45 mm $h^{-1}$. ANOVA of growth rate data of different isolates showed significant F value at P=0.05 (Table 4.20). Growth rates of different *R. solani* isolates in each replication and the corresponding coefficient of determination ($R^2$) values are given in Table 4.21. Growth curves fitted for the mean diameter growth at 4 h interval, of different isolates upto 46 h incubation showed linear pattern (Fig.3).

*Relative virulence of R. solani isolates*

The symptoms produced and disease severity and spread on bamboo seedlings varied depending upon the RS isolates. Isolates RS1 and RS2 caused infection mainly on the seedling foliage and less frequently on the stem. Whereas isolate RS3 caused severe web blight of seedlings, affecting stem and foliage; disease spread was very rapid and seedlings died within 7 to 10 days of infection due to multiple infection. Isolates RS4 and RS5 also caused infection of seedling stem and foliage, however, disease severity was comparatively less than those infected with RS3 isolate.

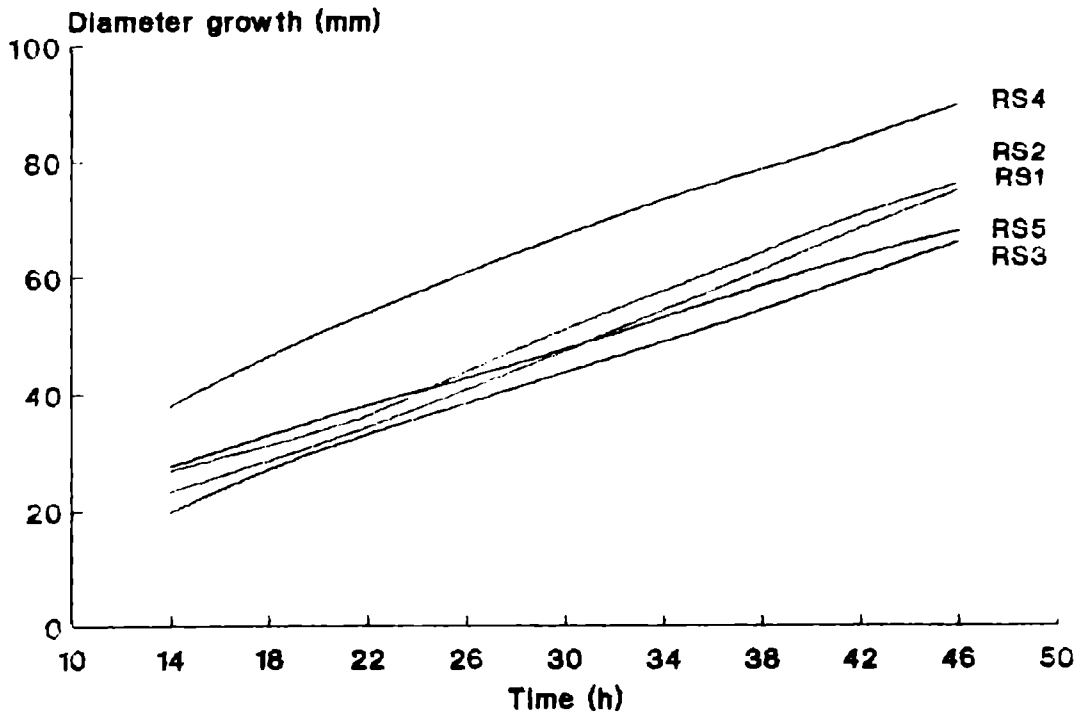



Fig.3: Growth of *R. solani* isolates (RS1,RS2,RS3,RS4,RS5) on PDA

Table 4.20: Analysis of variance of data on growth rate of RS isolates

| Source | df | Sum of squares | Mean squares | F |
|---|---|---|---|---|
| RS isolates | 4 | 0.898 | 0.225 | 147.759* |
| Residual | 10 | 0.015 | 0.002 | |

*Significant at P=0.05

Table 4.21: Growth rate of five different *R. solani* isolates on PDA

| *R. solani* isolate | Replication | Growth rate* (y=bt) | $R^2$ | *R. solani* isolate | Replication | Growth rate (y=bt) | $R^2$ |
|---|---|---|---|---|---|---|---|
| RS1 | 1 | 1.6153 | 0.9983 | RS4 | 1 | 2.1878 | 0.9876 |
| | 2 | 1.5960 | 0.9995 | | 2 | 2.1418 | 0.9919 |
| | 3 | 1.5714 | 0.9964 | | 3 | 2.1576 | 0.9876 |
| RS2 | 1 | 1.7435 | 0.9983 | RS5 | 1 | 1.5127 | 0.9935 |
| | 2 | 1.6935 | 0.9990 | | 2 | 1.6344 | 0.9958 |
| | 3 | 1.6406 | 0.9996 | | 3 | 1.5714 | 0.9964 |
| RS3 | 1 | 1.4288 | 0.9996 | | | | |
| | 2 | 1.4862 | 0.9987 | | | | |
| | 3 | 1.4450 | 0.9996 | | | | |

*Mean growth rate (mm $h^{-1}$) upto 46 h.

High inoculum level ($I_1$) had higher percent infection of web blight than in low level ($I_2$). Highest percent seedling infection (42.94) was observed in isolate RS3 with high inoculum level, followed by 28.50 percent infection in the low inoculum level of the same isolate. In the ANOVA, the interaction between *R. solani* isolates and inoculum levels was found highly significant (Table 4.22). DMRT showed significantly different groups (Table 4.23). Of the five *R. solani* isolates, isolate RS3 was found highly virulent which gave highest percent infection in both the levels of inoculum; isolate RS5 was moderately virulent attaining 26.58 percent infection at high inoculum level, while isolate RS4 gave 18.73 percent infection also at high inoculum level. Isolate RS1 had comparatively low virulence as compared to other isolates which caused only foliage infection and seldom affected the stem. For this isolate only low infection (4.53%) was recorded even at high inoculum level.

Table 4.22: Analysis of variance of data on virulence of *R. solani* isolates

| Source | df | Sum of squares | Mean squares | F |
|---|---|---|---|---|
| RS isolate | 4 | 22.022 | 5.505 | 137.224* |
| Inoculum conc. | 1 | 3.574 | 3.574 | 89.090* |
| RS isolate x Inoculum conc. | 4 | 1.121 | 0.280 | 6.986* |
| Residual | 20 | 0.802 | 0.040 | |

*Significant at P=0.05.

Table 4.23: Relative virulence of five different *R. solani* isolates

| Inoculum level | Percent infection** RS1 | RS2 | RS3 | RS4 | RS5 |
|---|---|---|---|---|---|
| $I_1$ | $4.53^{bc}$ | $5.31^{c}$ | $42.94^{cd}$ | $18.73^{c}$ | $26.58^{f}$ |
| $I_2$ | $3.29^{ab}$ | $3.03^{a}$ | $28.50^{f}$ | $4.57^{bc}$ | $12.42^{d}$ |

**Values with the same superscript(s) do not differ significantly at P 0.05.
$I_1$: High inoculum level (2:100); $I_2$ Low inoculum level (2:1000);

Utilization of carbon and nitrogen sources by *R. solani* isolates

All the ten carbon sources (C) screened supported better growth of the five *R. solani* isolates than the control without C source. Among the monosaccharides, hexose sugars were utilized better by all the RS isolates as mycelial growth varied from good to excellent depending

upon the RS isolates than the pentose sugars. Pentose sugars gave only poor to fair growth of all the RS isolates. Among disaccharides, D-sucrose supported excellent growth for all the isolates, except RS5. D-maltose gave excellent growth for RS1, RS2 and RS4 while D-cellobiose supported excellent growth of RS1, RS2 and RS3. Trisaccharide, D-raffinose supported excellent growth of isolates RS2 and RS4.

In the ANOVA, interactions of RS isolates and carbon sources were found highly significant (Tables 4.24). DMRT performed separately for each RS isolate with carbon sources showed significantly different groups.

**Table 4.24: Analysis of variance of data on utilization of different carbon sources by *R. solani* isolates**

| Source | df | Sum of squares | Mean square | F |
|---|---|---|---|---|
| RS Isolate | 4 | 28632.24 | 7158.06 | 32.572* |
| Carbon source | 10 | 140334.77 | 14033.48 | 63.857* |
| RS Isolate x Carbon source | 40 | 29431.96 | 735.80 | 3.348* |
| Residual | 55 | 12087.00 | 219.76 | |

*Significant at P=0.05.

Isolate RS1 gave excellent growth in seven out of ten carbon sources. Of these D-sucrose gave highest value (172.00 mg) followed by D-cellobiose. D-raffinose supported very good growth while two pentoses, D-arabinose and D-ribose supported only fair growth. However, they were significantly different from control (Table 4.25). Isolate RS2 had excellent growth in eight out of ten carbon sources

and poor to fair growth in two pentoses, D-ribose and D-arabinose. Highest growth of 176.00 mg was recorded in D-mannose which significantly differed from all the carbon sources except D-raffinose, D-glucose and D-galactose. D-cellobiose, D-glucose, D-sucrose and D-fructose supported excellent and almost similar growth and were not significantly different from each other.

Isolate RS3 did not show excellent growth in any of the carbon sources tested, but recorded very good growth in D-maltose; D-sucrose supported only fair growth. Growth in D-maltose significantly differed from D-cellobiose, D-ribose and D-arabinose. Excellent growth of RS4 was obtained in all the carbon sources tested except in D-ribose and D-arabinose. Highest growth of 163.50 mg was recorded in D-maltose which differed significantly from D-ribose, D-arabinose and control. D-ribose and D-arabinose supported only poor to fair growth of RS4. RS5 gave excellent growth in D-sucrose and D-mannose. Highest growth was recorded in D-sucrose (133.50), very good growth in D-galactose, D-fructose and good growth in D-raffinose, D-cellobiose, D-maltose and D-glucose. As in the case of other RS isolates, D-ribose and D-arabinose supported only poor to fair growth for RS5.

All the organic nitrogen sources supported comparatively better growth for RS isolates screened than control without N source. L-asparagine gave excellent growth for two RS isolates, (RS1, RS5), whereas L-arginine, L-glutamic acid, L-leucine and D L-phenylalanine supported excellent growth for one RS isolate. In general, L-tyrosine recorded good to very good growth for all the five RS isolates. L-alanine supported poor to fair growth for all the RS isolates, except good growth of RS5. L-methionine showed only poor to fair growth of all the isolates except RS1 which had good growth. In the ANOVA, interactions of RS isolates and organic nitrogen sources were found highly significant. DMRT showed significantly different groups (Table 4.26,27).

Table 4.25: Effect of ten different carbon sources with $KNO_3$ as nitrogen source on mycelial growth (mg) of five different *R. solani* isolates

| Sl. No. | Carbon source | Mycelial growth of *R. solani* isolates | | | | |
|---|---|---|---|---|---|---|
| | | RS1 (SE) | RS2 (SE) | RS3 (SE) | RS4 (SE) | RS5 (SE) |
| 1. | D-galactose | 144.00$^{de*}$ (15.00) | 167.50$^{cd}$ (6.50) | 90.50$^{bcd}$ (14.50) | 146.50$^{b}$ (4.50) | 100.50$^{cde}$ (18.50) |
| 2. | D-arabinose | 74.50$^{bc}$ (2.50) | 53.50$^{a}$ (11.50 | 64.50$^{b}$ (12.50 | 57.00$^{a}$ (12.50 | 74.00$^{bc}$ (9.00) |
| 3. | D-ribose | 60.00$^{ab}$ (6.00) | 47.50$^{a}$ (14.50) | 73.00$^{bc}$ (4.00) | 48.00$^{a}$ (18.00) | 51.00$^{ab}$ (14.00) |
| 4. | D-raffinose | 101.00$^{c}$ (3.00) | 148.00$^{bcd}$ (10.00) | 91.00$^{bcd}$ (11.00) | 161.50$^{b}$ (5.50) | 99.50$^{cde}$ (19.50) |
| 5. | D-cellobiose | 154.00$^{de}$ (9.00) | 137.00$^{bc}$ (2.00) | 71.00$^{bc}$ (1.00) | 149.00$^{b}$ (13.00) | 98.00$^{cde}$ (4.00) |
| 6. | D-maltose | 142.50$^{de}$ (15.50) | 126.50$^{b}$ (1.50) | 105.00$^{d}$ (12.000 | 163.50$^{b}$ (15.50) | 120.50$^{de}$ (18.50) |
| 7. | D-mannose | 145.50$^{de}$ (4.50) | 176.00$^{d}$ (18.00) | 96.00$^{cd}$ (6.00) | 137.00$^{b}$ (1.00) | 125.00$^{de}$ (3.00) |
| 8. | D-glucose | 133.00$^{d}$ (8.50) | 141.00$^{bc}$ (14.00) | 98.50$^{cd}$ (8.50) | 159.00$^{b}$ (14.00) | 85.50$^{bcd}$ (3.50) |
| 9. | D-sucrose | 172.00$^{e}$ (13.50) | 134.50$^{bc}$ (3.50) | 101.00$^{cd}$ (7.00) | 151.00$^{b}$ (21.00) | 133.50$^{e}$ (4.50) |
| 10. | D-fructose | 135.00$^{d}$ (3.50) | 143.50$^{bc}$ (0.50) | 87.50$^{bcd}$ (4.50) | 153.50$^{b}$ (0.50) | 117.00$^{cde}$ (18.50) |
| 11. | Control | 37.00$^{a}$ (0.50) | 30.00$^{a}$ (2.00) | 28.50$^{a}$ (5.00) | 33.00$^{a}$ (2.50) | 31.50$^{a}$ (2.50) |

*Values in a column sharing the same superscript (s) do not differ significantly at P=0.05.

Table 4.26: Analysis of variance of data on utilization of organic nitrogen sources by *R. solani* isolates

| Source | df | Sum of squares | Mean square | F |
|---|---|---|---|---|
| RS Isolate | 4 | 25409.38 | 6352.34 | 51.027* |
| Org.nitrogen source | 8 | 75100.62 | 9387.58 | 75.409* |
| RS Isolate x Org.nitrogen source | 32 | 68419.82 | 2138.12 | 17.175* |
| Explained | 44 | 168929.82 | 3839.31 | 30.841* |
| Residual | 45 | 5602.00 | 124.49 | |

*Significant at P=0.05.

Isolate RS1 showed excellent growth in L-asparagine, L-arginine, L-glutamic acid and D-L-phenylalanine; very good growth in L-tyrosine and good growth in L-leucine. L-alanine and L-methionine supported only poor to fair growth. Highest growth was recorded in L-asparagine (162.00 mg) whereas lowest in L-alanine (32.50 mg). Growth in L-asparagine and L-arginine significantly differed from that of L-tyrosine, L-leucine, L-methionine, L-alanine and control.

Isolate RS2 recorded excellent growth only in L-leucine and L-tyrosine. All the N sources supported poor to fair growth only. Highest growth was recorded in L-leucine (180.00 mg) which was significantly different from all other N sources. L-alanine and D-L-phenylalanine supported fair growth, whereas growth in L-arginine, L-asparagine, L-glutamic acid and L-methionine was poor. The lowest growth was in L-asparagine (25.50 mg) which was significantly different from that of control. Isolate RS3 had comparatively poor growth in all N sources. Only L-tyrosine supported good growth (100.00 mg). Isolate RS4 did not give excellent growth in any of the N sources.

Table 4.27: Effect of organic nitrogen sources on mycelial growth (mg) of five different *R. solani* isolates

| Sl. No. | Nitrogen source | Mycelial growth of *R. solani* isolates | | | | |
|---|---|---|---|---|---|---|
| | | RS1 (SE) | RS2 (SE) | RS3 (SE) | RS4 (SE) | RS5 (SE) |
| 1. | L-alanine | 32.50$^{a*}$ (3.50) | 72.00$^{e}$ (2.00) | 24.00$^{ab}$ (2.00) | 30.00$^{a}$ (6.00) | 83.50$^{cd}$ (11.00) |
| 2. | L-arginine | 135.50$^{de}$ (2.50) | 39.50$^{cd}$ (11.50 | 30.50$^{abc}$ (12.50 | 90.00$^{d}$ (12.50 | 60.00$^{bc}$ (9.00) |
| 3. | L-asparagine | 162.00$^{e}$ (5.00) | 25.50$^{b}$ (5.50) | 65.00$^{de}$ (4.00) | 116.00$^{e}$ (7.00) | 136.00$^{f}$ (3.00) |
| 4. | L-glutamic acid | 156.50$^{e}$ (3.50) | 43.50$^{cd}$ (1.50) | 82.50$^{ef}$ (14.50) | 110.50$^{de}$ (4.50) | 77.50$^{bcd}$ (10.50) |
| 5. | L-leucine | 93.50$^{bc}$ (25.50) | 180.00$^{g}$ (2.00) | 50.50$^{bcd}$ (4.50) | 62.00$^{bc}$ (1.00) | 58.00$^{be}$ (10.00) |
| 6. | L-methionine | 69.50$^{b}$ (2.50) | 32.00$^{bc}$ (3.00) | 24.00$^{ab}$ (7.00) | 58.50$^{b}$ (0.50) | 61.00$^{bc}$ (3.00) |
| 7. | D-L- phenyl alanine | 128.00$^{cde}$ (13.00) | 50.00$^{d}$ (4.00) | 60.00$^{cde}$ (14.00) | 85.50$^{cd}$ (9.50) | 83.00$^{cd}$ (7.00) |
| 8. | L-tyrosine | 115.00$^{cd}$ (5.00) | 117.00$^{f}$ (3.00) | 100.00$^{f}$ (15.00) | 89.00$^{d}$ (3.00) | 95.00$^{d}$ (3.00) |
| 9. | Control | 16.00$^{a}$ (4.00) | 9.00$^{a}$ (3.00) | 11.50$^{a}$ (1.50) | 11.50$^{a}$ (2.50) | 5.50$^{a}$ (0.50) |

*Values in a column sharing the same superscript(s) do not differ significantly at P=0.05.

L-asparagine supported very good growth (116.00 mg) which was significantly different from all the other N sources, except L-glutamic acid. Isolate RS5 showed excellent growth in L-asparagine

(136.00 mg) while no N sources supported very good growth. L-alanine L-glutamic acid, D-L-phenylalanine and L-tyrosine supported good growth, whereas L-arginine, L-leucine and L-methionine supported only fair growth. Growth in L-asparagine differed significantly from all the other N sources tested.

Inorganic nitrogen sources including urea gave better growth of all the RS isolates than control without N sources. Urea showed excellent growth for all RS isolates, except RS5. Ammonium sulphate supported only poor to good growth of all the RS isolates. In the ANOVA, interactions of RS isolates and inorganic nitrogen sources were highly significant at P=0.50 (Table 4.28). DMRT showed significantly different groups (Table 4.29).

**Table 4.28: Analysis of variance of data on utilization of inorganic nitrogen sources by *R. solani* isolates**

| Source | df | Sum of squares | Mean square | F* |
|---|---|---|---|---|
| RS isolate | 4 | 12134.43 | 3033.61 | 32.382* |
| Inorg.nitrogen source | 5 | 104320.68 | 20864.13 | 222.709* |
| RS isolate x Inorg.nitrogen source | 20 | 10402.57 | 520.13 | 5.552* |
| Residual | 30 | 2810.500 | 93.683 | |

*Significant at P 0.05.

Isolate RS1 gave excellent growth in ammonium nitrate, potassium nitrate, sodium nitrate, and urea. Highest growth of 146.00 mg was recorded in urea. RS2 had excellent growth only in urea. Ammonium sulphate and ammonium nitrate supported poor to fair growth, while potassium nitrate and sodium nitrate had very good growth. RS3 showed excellent growth only in urea and all other inorganic N sources

supported poor to fair growth. RS5 gave no excellent growth in any of the inorganic N sources tested. Sodium nitrate, potassium nitrate and urea supported very good growth, whereas ammonium nitrate and ammonium sulphate gave only fair growth (Table 4.29).

Table 4.29: Effect of inorganic nitrogen sources on mycelial growth (mg) of five different *R. solani* isolates

| Sl. No. | Nitrogen source | Mycelial growth of *R. solani* isolates | | | | |
|---|---|---|---|---|---|---|
| | | RS1 (SE) | RS2 (SE) | RS3 (SE) | RS4 (SE) | RS5 (SE) |
| 1. | Ammonium nitrate | 125.00$^{c*}$ (14.00) | 60.00$^{b}$ (2.00) | 62.50$^{c}$ (3.50) | 84.50$^{b}$ (12.50) | 56.50$^{b}$ (2.50) |
| 2. | Ammonium sulphate | 73.00$^{b}$ (12.50) | 50.00$^{b}$ (9.50) | 27.00$^{b}$ (3.00) | 88.00$^{b}$ (7.00) | 55.50$^{b}$ (4.50) |
| 3. | Potassium nitrate | 127.00$^{c}$ (2.50) | 122.00$^{cd}$ (4.00) | 73.00$^{c}$ (9.00) | 123.00$^{c}$ (8.00) | 115.00$^{c}$ (16.00) |
| 4. | Sodium nitrate | 144.00$^{c}$ (7.00) | 106.00$^{c}$ (7.00) | 73.50$^{c}$ (1.50) | 141.00$^{c}$ (5.00) | 117.59$^{c}$ (9.50) |
| 5. | Urea | 146.00$^{c}$ (4.50) | 135.00$^{d}$ (4.00) | 132.50$^{d}$ (1.50) | 125.00$^{c}$ (4.00) | 117.00$^{c}$ (4.00) |
| 6. | Control | 7.50$^{a}$ (1.50) | 8.50$^{a}$ (2.50) | 11.50$^{a}$ (1.50) | 11.50$^{a}$ (2.50) | 4.50$^{a}$ (1.00) |

*Values in a column sharing the same superscript(s) do not differ significantly at P=0.05.

To understand the overall utilization of the carbon and nitrogen sources by the different RS isolates, cluster analysis was done on the isolates using their responses to different carbon, organic and

inorganic nitrogen sources as characters. Clustering was done using 'average linkage between groups' alogorithm. This corresponds to the "group average method" reported by Everitt (1974). The distance measure used was squared Euclidean distance. Cluster analysis revealed three distinct groups of RS isolate and the groups were (RS1,RS4), (RS3,RS5), and RS2. Dendrogram showing the structure of resemblance among the RS isolates is given in Fig.4.

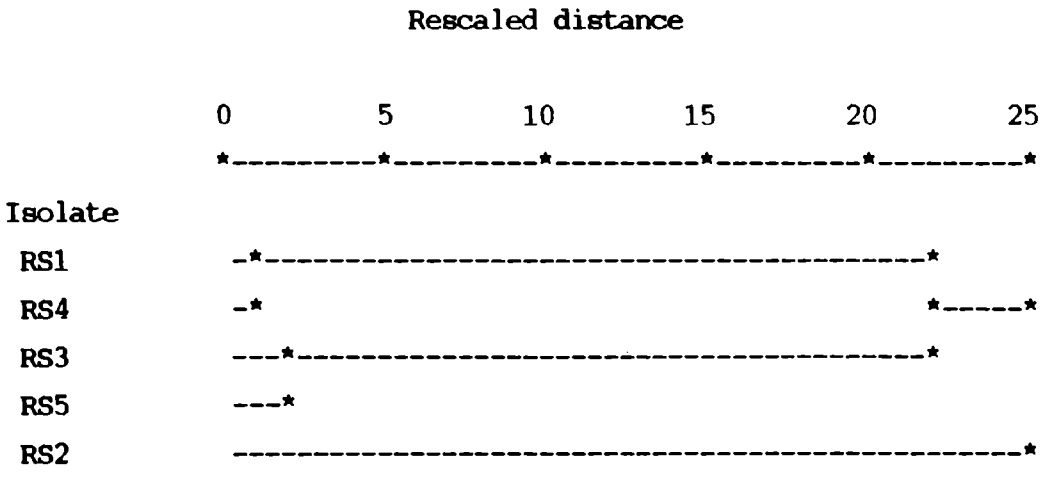



Fig. 4: Dendrogram showing average linkage (between groups) of *R. solani* isolates (RS1-RS5).

## Screening of antagonistic organisms against *R. solani* isolates

### *Petri dish bioassay*

Observations on dual culture tests showed that both the antagonists screened interacted with the five *R. solani* bamboo

isolates as evidenced by clear growth inhibition zones. Growth inhibition zone of 5-8 mm wide, was observed in all the *T. harzianum* seeded Petri dishes. However, in the case of *T. viride*, the inhibition zone was 3-5 mm. Both *T. harzianum* and *T. viride* inhibited the linear growth of all the RS isolates. Growth of *R. solani* isolates was restricted from 48 h onwards after pairing with the antagonists; inhibition rate varied between *T. harzianum* and *T. viride*. Besides inhibiting the growth, the antagonists overgrew the *R. solani* colony in all the Petri dishes. Antagonism was mainly due to hyphal parasitism. Coiling of hyphae of *R. solani* isolates by both *T. harzianum* and *T. viride* isolates was observed and abundant spores were produced over the predated colony within 3- to 4 days of incubation.

*Slide culture*

The antagonists hyperparasitized all the five *R. solani* isolates within 48 to 72 h after pairing on the glass slide. However, the level of parasitism varied among the antagonists depending on the RS isolate. Antagonistic behaviour against *R. solani* isolates was shown by hyphal coiling, penetration of *R. solani* hyphae, vacuolation, granulation, lysis and disintegration of the affected hyphae (Plate 22). The slender actively growing hyphae of *T. harzianum* and *T. viride* grew along side the broad hyphae of *R. solani*, penetrated them at certain points and grew through the inner cavity of the hyphae (Plate 22a,b). Breakage of affected hyphae at septal plates and leakage of cytoplasmic contents were also observed (Plate 22c). *T. harzianum* (TH4) nursery soil isolate (Periya) showed highest percent hyphal interaction against all the five RS isolates tested, followed by *T. viride* (TV3), nursery soil isolate (Paneli) which showed highest percent hyphal interaction among *T. viride* isolates (Table 4.30). On the basis of the efficacy of hyphal interactions, antagonists *T. harzianum* (TH4) and *T. viride* (TV3) were selected for further studies.

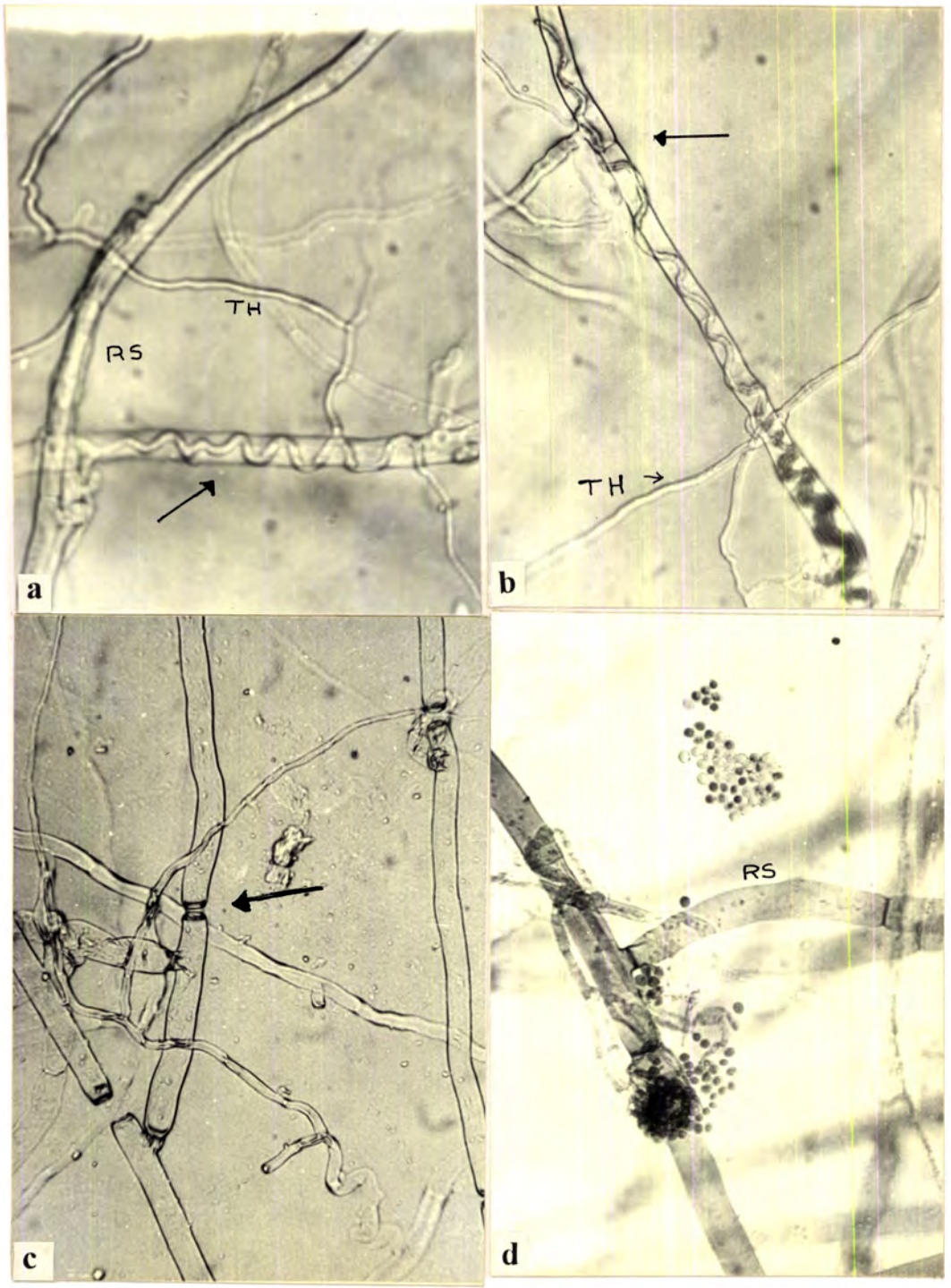



Plate 22. Hyperparasitic activity of *Trichoderma harzianum* on the hyphae of *Rhizoctonia solani* in slide culture. a,b: Coiling and penetration (see arrow) of *R. solani* hyphae by *T. harzianum* hyphae (640 x), c: Hyphal lysis and breakage of cells at septal plates (640 x), d: *T. harzianum* sporulating on the parazitized hyphae of *R. solani* (680 x).

Table 4.30: Antagonistic behaviour of *T. harzianum* and *T. viride* isolates against different *R. solani* isolates

| Trichoderma isolate | Percent hyphal interaction | | | | |
|---|---|---|---|---|---|
| | RS1 | RS2 | RS3 | RS4 | RS5 |
| *T. harzianum* (TH1)* | 53.84 | 46.88 | 53.33 | 10.00 | 31.81 |
| *T. harzianum* (TH2) | 39.13 | 23.68 | 14.28 | 36.36 | 38.09 |
| *T. harzianum* (TH3) | 31.57 | 20.00 | 48.38 | 29.67 | 36.84 |
| *T. harzianum* (TH4) | 92.59 | 93.93 | 61.76 | 81.25 | 74.19 |
| *T. viride* (TV1) | 28.00 | 12.50 | 48.78 | 39.99 | 22.58 |
| *T. viride* (TV2) | 12.90 | 32.35 | 35.29 | 50.00 | 6.66 |
| *T. viride* (TV3 | 91.17 | 72.22 | 51.42 | 90.00 | 64.70 |
| *T. viride* (TV4) | 61.29 | 43.75 | 48.38 | 44.40 | 35.48 |

* 1 TNAU isolates; 2,3,4 nursery soil isolates (Pezhad, Paneli, Periya).
RS1-RS5: *R. solani* isolates.

*Seedling bioassay*

a. Soil amendment with *Trichoderma harzianum* and *T. viride*

Treatments having antagonists viz., *T. harzianum* (TH4) and *T. viride* (TV3) in *R. solani* infested soil showed comparatively low percent seedling infection than the respective controls without antagonists. Disease incidence was high in controls, especially in a treatment where isolate RS3 was employed. Besides reducing the disease incidence, introduction of antagonists reduced severity and spread of the disease. In the ANOVA, interaction of RS isolates and antagonists was found highly significant (Table 4. 31). DMRT showed significant different groups among the various treatments (Table

4.32). Treatment with *T. viride* and isolate RS3 was found significantly different from all the other *T. harzianum* and *T. viride*, except a combination of *T. harzianum* and isolate RS5. In general, application of antagonists as soil amendment reduced the percent seedling infection and also the disease severity and spread. *T. harzianum* was more efficient than *T. viride* in controlling the *R. solani* infection of bamboo seedlings.

**Table 4.31: Analysis of variance of data on efficacy of antagonists in seedling bioassay (soil amendment)**

| Source | df | Sum of squares | Mean square | F |
|---|---|---|---|---|
| RS isolate | 4 | 12.181 | 3.045 | 61.444* |
| Antagonist | 2 | 20.25 | 10.126 | 204.324* |
| RS isolate x Antagonist | 8 | 3.427 | 0.428 | 8.644* |
| Residual | 30 | 1.487 | 0.050 | |

*Significant at P=0.05.

**b. Seed treatment with *Trichoderma harzianum* and *T. viride***

Seed-coating with *T. harzianum* (TH4) and *T. viride* (TV3) gave comparatively low percent seedling infection in all the treatments than those of the respective controls. Of these, treatment involving isolate RS3 showed 42.94 percent seedling infection. In the ANOVA, interaction of RS isolates and antagonists was found highly significant (Table 4.33) and DMRT showed significant different groups among the various treatments (Table 4.34).

Table 4.32: Efficacy of antagonists against *R. solani* isolates (soil amendment)

| Antagonist | Percent seedling infection | | | | |
|---|---|---|---|---|---|
| | RS1 | RS2 | RS3 | RS4 | RS5 |
| *T. harzianum* | $1.57^{a}$ | $2.64^{bc}$ | $3.78^{cde}$ | $3.39^{cd}$ | $3.94^{cde*}$ |
| *T. viride* | $2.25^{ab}$ | $3.29^{bcd}$ | $6.30^{f}$ | $4.39^{def}$ | $5.31^{f}$ |
| control | $4.53^{def}$ | $5.31^{f}$ | $42.49^{h}$ | $18.73^{g}$ | $26.58^{g}$ |

*Values with the same superscript(s) do not differ significantly at P= 0.05.
Control: Without antagonists; RS1-RS5 *R. solani* isolates.

Table 4.33: Analysis of variance of data on efficacy of antagonists in seedling bioassay (seed treatment)

| Source | df | Sum of squares | Mean square | F |
|---|---|---|---|---|
| RS isolate | 4 | 10.546 | 2.636 | 59.789* |
| Antagonist | 2 | 27.325 | 13.663 | 309.842* |
| RS isolate x Antagonist | 8 | 3.992 | 0.499 | 11.317* |
| Residual | 30 | 1.323 | 0.044 | |

*Significant at P=0.05.

Both *T. harzianum* and *T. viride*, applied as seed-coating biocide reduced the percent seedling infection to 1.95 and 1.65. *T. harzianum* was found more effective in reducing the percent seedling infection as compared to *T. viride*, in all the treatments, except for isolate RS5

(Table 4.34). In controls, without antagonists, percent infection ranged from 4.53 to 42.94 depending upon the virulence of the isolates.

Table 4.34: Efficacy of antagonists against *R. solani* isolates in seedling bioassay (seed treatment)

| Antagonist | Percent seedling infection | | | | |
|---|---|---|---|---|---|
| | RS1 | RS2 | RS3 | RS4 | RS5 |
| *T. harzianum* | $1.65^{a}$ | $1.72^{a}$ | $3.35^{cd}$ | $2.63^{bc}$ | $3.19^{cd*}$ |
| *T. viride* | $1.95^{ab}$ | $2.63^{bc}$ | $4.85^{e}$ | $3.22^{cd}$ | $2.94^{c}$ |
| Control | $4.53^{de}$ | $5.31^{e}$ | $42.94^{g}$ | $18.73^{f}$ | $26.58^{f}$ |

* Values with the same superscript(s) do not differ significantly at P 0.05.
Control: Without antagonist; RS1-RS5: *R. solani* isolates.

*In vitro* evaluation of fungicides against *R. solani* isolates

*Poison-food technique (PFT)*

Of the ten fungicides screened against five different *R. solani* isolates (RS) employing poison-food technique (PFT), MEMC, PCNB, carboxin and Ridomil gave cent percent inhibition in growth for all the RS isolates. Cent percent inhibition in growth of four isolates (RS1, RS2, RS4, RS5) was recorded in carbendazim and three isolates (RS1, RS4, RS5) in thiophanate methyl. MEMC was effective even at the lowest concentration of 0.001% a.i. and the growth of two isolates viz., RS1 and RS4 was inhibited; at higher concentration (0.003%

a.i.), cent percent inhibition of all the RS isolates was recorded. In PCNB $ED_{100}$ for isolate RS4 was at 0.05% a.i. while the growth of other four isolates was inhibited completely only at the highest concentration i.e. 0.2% a.i. Carboxin was effective even at the lowest concentration (0.025% a.i.) as cent percent inhibition of all the isolates, except isolate RS1 which gave inhibition of growth of 91.30 percent was observed; $ED_{100}$ for carboxin against all the five isolates was 0.05% a.i. Thiophanate methyl was effective against three isolates viz., RS1, RS4, and RS5 at 0.1% a.i. while, for RS2 and RS3, 76.11 and 75.74 percent inhibition respectively was recorded at higher concentration of 0.2% a.i. Cent percent inhibition of growth of RS1, RS2, RS4, and RS5 was observed in the lowest concentration (0.025% a.i.) of carbendazim, whereas even at higher concentration of 0.2% a.i. the inhibition was only 89.26 percent for RS3. Ridomil was found effective against all the RS isolates, except RS2, at 0.05% a.i; the $ED_{100}$ for Ridomil was 0.1 % a.i. for all the five isolates. Mancozeb, ziram, captafol and thiram were ineffective and gave comparatively low percent inhibition than the other fungicides. In the ANOVA, interaction of RS isolates and fungicides was found to be highly significant at P=0.05 (Table 4.35). DMRT showed significantly different groups (Table 4.36).

**Table 4.35: Analysis of variance of data on effect of different fungicides on *R. solani* isolates (PFT)**

| Source | df | Sum of squares | Mean square | F |
|---|---|---|---|---|
| Isolate | 4 | 10559.166 | 2639.791 | 326.478* |
| Fungicide | 29 | 178226.732 | 6145.749 | 760.081* |
| RS Isolate x Fungicide | 116 | 119709.451 | 1031.978 | 127.631* |
| Residual | 300 | 2425.696 | 8.086 | |

* Significant at P 0.05.

Table 4.36: Percent growth inhibition over control of *R. solani* isolates at different concentrations of fungicides (PFT)

| Sl. No. | Fungicide | Percent conc. (a.i.) | Percent inhibition over control | | | | |
|---|---|---|---|---|---|---|---|
| | | | RS1 | RS2 | RS3 | RS4 | RS5 |
| 1. | MEMC | 0.001 | $100.00^{h}$ | $44.81^{d}$ | $76.11^{ij}$ | $100.00^{h}$ | $43.33^{a*}$ |
| | | 0.003 | $100.00^{h}$ | $100.00^{l}$ | $100.00^{m}$ | $100.00^{h}$ | $100.00^{l}$ |
| | | 0.006 | $100.00^{h}$ | $100.00^{l}$ | $100.00^{m}$ | $100.00^{h}$ | $100.00^{l}$ |
| 2. | PCNB | 0.05 | $80.37^{e}$ | $81.48^{hi}$ | $83.15^{k}$ | $100.00^{h}$ | $76.67^{e}$ |
| | | 0.1 | $91.30^{g}$ | $89.44^{jk}$ | $90.56^{l}$ | $100.00^{h}$ | $81.48^{fg}$ |
| | | 0.2 | $100.00^{h}$ | $100.00^{l}$ | $100.00^{m}$ | $100.00^{h}$ | $100.00^{l}$ |
| 3. | Carboxin | 0.025 | $91.30^{g}$ | $100.00^{l}$ | $100.00^{m}$ | $100.00^{h}$ | $100.00^{i}$ |
| | | 0.05 | $100.00^{h}$ | $100.00^{l}$ | $100.00^{m}$ | $100.00^{h}$ | $100.00^{l}$ |
| | | 0.1 | $100.00^{h}$ | $100.00^{l}$ | $100.00^{m}$ | $100.00^{h}$ | $100.00^{l}$ |
| 4. | Thiophanate methyl | 0.05 | $77.78^{de}$ | $7.78^{b}$ | $0.00^{a}$ | $88.52^{g}$ | $85.19^{h}$ |
| | | 0.1 | $100.00^{h}$ | $7.22^{b}$ | $1.30^{a}$ | $100.00^{h}$ | $100.00^{l}$ |
| | | 0.2 | $100.00^{h}$ | $76.11^{fg}$ | $75.74^{i}$ | $100.00^{h}$ | $100.00^{l}$ |
| 5. | Carbendazim | 0.025 | $100.00^{h}$ | $100.00^{l}$ | $88.86^{l}$ | $100.00^{h}$ | $100.00^{i}$ |
| | | 0.05 | $100.00^{h}$ | $100.00^{l}$ | $88.89^{l}$ | $100.00^{h}$ | $100.00^{l}$ |
| | | 0.1 | $100.00^{h}$ | $100.00^{l}$ | $89.26^{l}$ | $100.00^{h}$ | $100.00^{l}$ |
| 6. | Ridomil | 0.025 | $62.78^{c}$ | $85.37^{ij}$ | $60.00^{g}$ | $70.56^{f}$ | $84.08^{gh}$ |
| | | 0.05 | $100.00^{h}$ | $77.78^{fgh}$ | $100.00^{m}$ | $100.00^{h}$ | $100.00^{l}$ |
| | | 0.1 | $100.00^{h}$ | $100.00^{l}$ | $100.00^{m}$ | $100.00^{h}$ | $100.00^{i}$ |
| 7. | Mancozeb | 0.05 | $16.85^{a}$ | $0.00^{a}$ | $0.00^{a}$ | $21.30^{a}$ | $73.15^{d}$ |
| | | 0.1 | $47.97^{b}$ | $82.04^{hi}$ | $37.59^{b}$ | $71.30^{f}$ | $78.15^{ef}$ |
| | | 0.2 | $59.63^{c}$ | $86.67^{jk}$ | $53.71^{e}$ | $75.00^{f}$ | $82.04^{gh}$ |
| 8. | Zerlate | 0.05 | $63.71^{c}$ | $33.15^{c}$ | $44.82^{c}$ | $33.89^{b}$ | $46.11^{a}$ |
| | | 0.1 | $73.89^{d}$ | $71.48^{e}$ | $48.52^{d}$ | $55.00^{cd}$ | $72.78^{a}$ |
| | | 0.2 | $86.67^{fg}$ | $90.00^{k}$ | $71.30^{h}$ | $67.96^{ef}$ | $84.07^{gh}$ |

contd.

Table 4.36: contd.

| | | | | | | |
|---|---|---|---|---|---|---|
| 9. Captafol | 0.05 | $77.78^{ef}$ | $71.67^{e}$ | $71.48^{h}$ | $21.67^{a}$ | $66.11^{c}$ |
| | 0.1 | $82.41^{de}$ | $74.26^{ef}$ | $77.78^{ij}$ | $24.08^{a}$ | $75.95^{ef}$ |
| | 0.2 | $83.33^{ef}$ | $78.89^{gh}$ | $78.33^{j}$ | $24.44^{a}$ | $78.34^{de}$ |
| 10. Thiram | 0.05 | $52.22^{b}$ | $29.63^{c}$ | $0.00^{a}$ | $0.00^{i}$ | $62.78^{fg}$ |
| | 0.1 | $58.52^{c}$ | $70.37^{e}$ | $47.59^{d}$ | $49.44^{e}$ | $69.26^{b}$ |
| | 0.2 | $60.19^{c}$ | $81.11^{hi}$ | $57.22^{f}$ | $62.44^{de}$ | $81.11^{c}$ |

*Values in a column sharing the same superscript(s) do not differ significantly at P 0.05.

Since, $ED_{100}$ was considered for selecting the best fungicide(s), MEMC (0.003% a.i.), PCNB (0.2% a.i.), carboxin (0.05% a.i.), Ridomil (0.1% a.i.) were found to be the effective fungicides against all the five *R. solani* isolates tested. Among the five RS isolates, RS4 was found to be distinct from others which had cent percent inhibition of growth at the lower concentration of MEMC, PCNB, carboxin, carbendazim and 88.52 percent and 70.56 percent in the lowest concentration of thiophanate methyl and Ridomil respectively.

*Soil fungicide screening technique (SFST)*

Of the five fungicides viz., MEMC, PCNB, carboxin, carbendazim and Ridomil, found effective in poison-food technique, MEMC, carboxin and carbendazim, gave cent percent inhibition in growth of all the five RS isolates in soil fungicide screening technique (SFST). In the ANOVA, interaction of RS isolates and fungicides was found to be highly significant (Table 4.37). DMRT performed separately for each RS isolate with fungicides showed significantly different groups among the treatments (Table 4.38).

Table 4.37: Analysis of variance of data on effect of different fungicides on *R. solani* isolates (SFST)

| Source | df | Sum of squares | Mean square | F |
|---|---|---|---|---|
| Fungicide | 14 | 352608 | 25186.321 | 4515.492* |
| RS isolate | 4 | 7156 | 1789.066 | 320.750* |
| Fungicide x RS isolate | 56 | 72781 | 1299.672 | 233.010* |
| Residual | 149 | 831 | 5.578 | |

* Significant at P=0.05.

Table 4.38: Percent inhibition of growth over control of *R. solani* isolates at different concentrations of fungicides (SFST)

| Sl. No. | Fungicide | percent concentration (a.i.) | Percent inhibition over control | | | | |
|---|---|---|---|---|---|---|---|
| | | | RS1 | RS2 | RS3 | RS4 | RS5 |
| 1. | MEMC | 0.003 | $100.00^{d}_{d}$ | $47.22^{d}_{f}$ | $0.00^{a}_{f}$ | $9.26^{cd}_{f}$ | $100.00^{d}_{d}$ * |
| | | 0.006 | $100.00^{d}_{d}$ | $100.00^{f}_{f}$ | $100.00^{f}_{f}$ | $100.00^{f}_{f}$ | $100.00^{d}_{d}$ |
| | | 0.008 | $100.00^{d}$ | $100.00^{f}$ | $100.00^{f}$ | $100.00^{f}$ | $100.00^{d}$ |
| 2. | PCNB | 0.2 | $0.00^{a}$ | $0.00^{a}$ | $0.00^{a}$ | $0.00^{a}$ | $0.00^{a}$ |
| | | 0.3 | $0.00^{a}_{b}$ | $0.00^{a}$ | $0.00^{a}$ | $0.00^{a}$ | $0.00^{a}$ |
| | | 0.5 | $14.26^{b}$ | $39.44^{c}$ | $34.26^{c}$ | $57.41^{c}$ | $49.07^{bc}$ |
| 3. | Carboxin | 0.05 | $2.78^{a}$ | $0.00^{a}$ | $0.00^{a}$ | $0.00^{a}_{bcd}$ | $0.00^{a}$ |
| | | 0.1 | $1.85^{a}$ | $11.85^{b}_{f}$ | $42.22^{d}_{f}$ | $6.48^{bcd}_{f}$ | $47.59^{b}$ |
| | | 0.2 | $100.00^{d}$ | $100.00^{f}$ | $100.00^{f}$ | $100.00^{f}$ | $100.00^{d}$ |
| 4. | Carbendazim | 0.05 | $100.00^{d}$ | $0.00^{a}$ | $0.00^{a}$ | $0.00^{a}$ | $0.00^{a}$ |
| | | 0.1 | $100.00^{d}_{d}$ | $41.85^{c}_{f}$ | $8.33^{b}_{f}$ | $0.00^{a}_{f}$ | $0.00^{a}_{d}$ |
| | | 0.2 | $100.00^{d}$ | $100.00^{f}$ | $100.00^{f}$ | $100.00^{f}$ | $100.00^{d}$ |
| 5. | Ridomil | 0.05 | $0.00^{a}$ | $0.00^{a}$ | $0.00^{a}$ | $0.00^{a}$ | $0.00^{a}$ |
| | | 0.1 | $5.55^{a}$ | $0.00^{a}_{c}$ | $0.00^{a}_{c}$ | $3.71^{ab}$ | $0.00^{a}_{c}$ |
| | | 0.2 | $51.30^{c}$ | $68.52^{c}$ | $59.26^{c}$ | $57.41^{c}$ | $51.85^{c}$ |

* Values in a column sharing same superscript(s) do not differ significantly at P= 0.05.
RS1-RS5: *R. solani* isolates.

MEMC was effective at the lowest concentration of 0.003% a.i. and as it inhibited the growth of isolates RS1 and RS5 completely, while isolate RS3 did not show any inhibition. However, at the next higher dosage of 0.006% a.i., it gave cent percent inhibition in growth for all the RS isolates. PCNB was ineffective against all the RS isolates at all the concentrations tried. $ED_{100}$ for carboxin against all the RS isolates was 0.2% a.i. Carbendazim was effective at the lowest concentration of 0.05% a.i. only against RS1 isolates, while cent percent inhibition of growth of all the other four isolates was observed at 0.2% a.i. Ridomil (Metalaxyl + mancozeb), inhibited the growth only at the high concentration of 0.2% a.i. Considering the $ED_{100}$ as the criterion for selecting the effective fungicide(s); MEMC (0.006% a.i.), carboxin (0.2% a.i.) and carbendazim (0.2% a.i.) were the most promising fungicides effective against all the five *R. solani* bamboo isolates screened.

## Discussion

### *Anastomosis grouping of R. solani isolates*

*Rhizoctonia solani* mycelial state of *Thanatephorus cucumeris* (Frank) Donk is a soilborne plant pathogen with a wide host range (Baker, 1970). In forestry tree species, it causes various diseases viz., damping-off, collar rot, web blight, stem canker, seedling wilt, root rot, foliage infection, etc. (Bakshi *et al.*, 1972; Sharma *et al.*, 1985; Farr *et al.*, 1989; Mehrotra, 1989). Among the four recorded diseases namely, damping-off, spear rot, seedling wilt and web blight caused by *R. solani*, the latter is the most widespread in bamboo nurseries and it is economically important. *R. solani* is considered to be made up of divergent populations (Parmeter and Whitney, 1970;

Adams, 1988; Liu and Sinclair, 1991). The lack of understanding of the relationship among populations within the species has often hampered the studies on the fungus including disease management. In nature, *R. solani* occurs as an aggregate of strains that differ in cultural characteristics, anastomosis grouping, physiology and virulence (Sherwood, 1969; Parmeter *et al.*, 1969; Parmeter and Whitney, 1970). Many attempts have been made to organize isolates of *R. solani* into groups based on morophological, physiological and pathological behaviours (Exner, 1953; Sherwood, 1969) and on anastomosis and intraspecific groupings (Ogoshi, 1985; 1987; Sneh *et al.*, 1991). Concepts such as forma speciales (Exner, 1953), group (Takahashi and Matsura, 1954) and type (Sherwood, 1969) have been introduced. However, anastomosis, the most meaningful and currently accepted form of grouping of *R. solani* (Anderson, 1982; Sneh *et al.*, 1991) was conceptualized by Schultz (1937). Since then, the concept has been expanded greatly and currently includes 11 anastomosis groups (AG 1 to 10 and AG-BI) based on hyphal anastomosis (Ogoshi, 1985, 1987; Carling *et al.*, 1987; Sneh *et al.* 1991), cultural morphology (Exner, 1953; Sherwood 1969), virulence, disease type (Kuninaga, 1986; Ogoshi, 1985) and DNA base-sequence homology (Kuninaga, 1986; Vilgalys, 1988; Liu and Sinclair, 1992). Subdivision of isolates of AG1 into AG1-IA, AG1-IB, and AG1-IC was based on cultural type, host range, and plant tissue affected (Ogoshi, 1985, 1987). To date, AG1,2,3 and 4 have been reported in all the areas of the world.

In the present study, of the 56 isolates of *R. solani*, all except two isolates belong to the anastomosis groups AG-1-IA, AG-1-IC and AG-2-2IV. Of these, AG-1-IA and AG-1-IC are the most widespread in the bamboo nurseries in the State. Web blight is caused by *R. solani* isolates belonging to all these anastomosis groups. Isolates belonging to AG2-2IV also caused seedling root infection and appeared to be restricted in their distribution. Earlier, Ogoshi (1987) has also

recorded AG2-2IV causing root rot of *Beta vulgaris* L. and *Juncus effusus* L. var. *dicipiens*.

Though, possibility of occurrence of two biotypes in *R. solani* based on the cultural characteristics was reported by Mehrotra (1989), there is no report on anastomosis grouping of *R. solani* affecting forestry species from India. Although, in agricultural crops like potatoes, coffee and paddy, anastomosis grouping of *R. solani* has recently been carried out (Suresh and Mall, 1982; Venkatasubbaiah *et al.*, 1984; Gokulapalan and Nair, 1992), this is the first record of anastomosis groupings of *R. solani* causing diseases of forestry species in India.

*Growth, cultural characters and relative virulence*

*R. solani* isolates vary greatly in their rate of linear growth. Linear growth capacity is associated to some extent with source/origin/host of isolate. Usually, isolates from aerial plant parts and the soil surface grow rapidly (Exner,1953; Kontani and Mineo, 1962; Luttrell, 1962) and those from subterranean plant parts grow relatively slowly (Sherwood, 1970). Among the five RS isolates from aerial plant parts of bamboo, isolate RS4 shows the highest growth of 2.16 mm $h^{-1}$ whereas isolate RS1 has comparatively slower growth rate of 1.64 mm $h^{-1}$. Since, isolates belonging to same anastomosis group show different growth rates, it indicates that growth rate alone cannot be used as strain specific character.

*R. solani* is known to grow well on a wide range of natural and semisynthetic media. On any given medium, isolates are known to differ greatly in their growth characteristics, colour and abundance of aerial mycelium, zonation and sclerotial production (Kernkamp *et al.*,

1952; Flentje and Saksena, 1957; Maier and Staffeldt, 1960; Saksena and Vaartaja, 1961). It is not known whether such differences are primarily influenced by nutritive or toxic constituents, osmotic potential, pH, or other unknown effects (Sherwood, 1970). In the present study, the five *R. solani* isolates belonging to same anastomosis group also show variation in growth characteristcs and production of sclerotia on PDA medium. This is in conformity with the observations of Muyolo *et al.* (1993) that morphology among *R. solani* isolates varies greatly within the same and among the different anastomosis groups.

Virulence among the bamboo isolates of *R. solani* varies significantly within the same and among different anastomosis groups, which appears to be related to the production and activity of hydrolytic enzymes (Barker and Walker, 1962; Papavizas and Ayers, 1965). In the present study, isolate RS3 (AG-1-IA) is proved to be the highly virulent strain causing highest percent infection at both high and low inoculum level. This isolate causes multiple infection on stem and foliage; whereas isolate RS1 (AG-1-IC) shows comparatively low virulence and causes mainly damping-off and less frequently web blight. In general, the results on anastomosis grouping, growth and virulence of bamboo isolates of *R. solani* show that the fast growth has no bearing on virulence and isolates belonging to the same anastomosis group exhibit different growth rates, cultural characteristics as well as virulence.

### *Utilization of carbon and nitrogen sources*

*R. solani* utilizes carbon and nitrogen sources very efficiently. Five different RS isolates belonging to different anastomosis groups give varying growth responses on different carbon and nitrogen

sources. However, no particular carbon or nitrogen source consistently supported the good or poor mycelial yield of all the isolates. These results are in agreement with those obtained by Forsteneichner (1931), Bianchini and Wellman (1958), Akai *et al.* (1960) and Ross, (1960). Urea supports excellent growth of all the isolates belonging to AG1. This does not agree fully with the results of Townsend (1954), who considered urea as a poor source because of excessive ammonia production. The apparent suitability of various nitrogen sources is most often related to the effect of the nitrogen source on changes in pH of the medium during growth (Sherwood, 1970).

Cluster analysis on RS isolates using their growth responses on different carbon and nitrogen sources as characters revealed three distinct groups of RS isolates viz., RS1 and RS4, RS3 and RS5, and RS2. However, this grouping does not agree with the respective anastomosis grouping of *R. solani* isolates. The variation in physiology of the isolates within the same and among the different anastomosis groups demonstrated by Sherwood (1969) may be the possible reason for this behaviour.

### *Antagonistic efficacy of Trichoderma harzianum and T. viride against R. solani isolates*

The development and utilization of microbial inoculants for biocontrol of diseases is highly challenging. Mycoparasites are known to produce either chitinase or cellulase degradative enzymes which break down cell wall components of host fungi (Baker, 1991). *Trichoderma* spp. are the best known mycoparasites attacking *R. solani*. Parasitization of hyphae of *R. solani* by *T. harzianum* and *T. viride* has been reported by several workers ( Barnett and Binder, 1973; Hadar *et al.*, 1979; Chet and Baker, 1980; Bell *et al.*, 1982; Elad *et al.*,

1982, 1987; Chet, 1987; Papavizas, 1985; Wu *et al.*, 1986; Lumsden and Locke, 1989; Gokulapalan and Nair, 1984). *Trichoderma harzianum* and *T. viride* have been widely used as biocontrol agents against seedling diseases caused by *R. solani* (Chet *et al.*, 1979; Hadar *et al.*, 1979; Elad *et al.*, 1980; Ruppel *et al.*, 1983; Venkatasubbaiah *et al.*, 1984). In the present study, all the *T. harzianum* and *T. viride* isolates restricted the growth of the RS isolates and later grew over and parasitized. The bamboo rhizosphere soil isolates of *T. harzianum* (TH4) and *T. viride* (TV3) prove to be highly efficient in parasitizing the *R. solani* hyphae than the others. The results confirm the generally held view that greater success in biocontrol may be achieved if isolations are made from the rhizosphere soil of the plant species which requires disease protection (Chet *et al.*, 1979).

Seedling bio-assay in greenhouse is of utmost importance in confirming the efficacy of the candidate biocontrol strains before employing them in the nursery trial. Seed treatment and soil amendments are the two delivery systems usually employed for the introduction of the biocontrol agents into the infection courts (Harman *et al.*, 1981; 1989; Chu and Wu, 1981; Elad *et al.*, 1982; Marshall, 1982). Both seed treatment as well as soil amendment are equally effective means of introducing the antagonists, *T. harzianum* (TH4) and *T. viride* (TV)3, in *R. solani* infested soil. *T. harzianum* (TH4) is comparatively more efficient in reducing the percent seedling infection than the *T. viride* (TV3) isolate. This is in agreement with the results obtained in *in vitro* assay.

### *In vitro screening of fungicides against R. solani isolates*

*R. solani* isolates showed differential response to fungicides screened by poison-food technique (PFT) as well as soil fungicide

screening technique (SFST). Differential behaviour of isolates of *R. solani* to fungicides has earlier been reported by Martin *et al.* (1984). In PFT, MEMC, PCNB, carboxin and Ridomil gave cent percent inhibition in growth of all the five RS isolates. However, the respective $ED_{100}$ of a particular fungicide against each isolate vary considerably. For example, $ED_{100}$ of MEMC against isolate RS1 and RS4 was 0.001% a.i., whereas for the other isolates it was at a higher dosage (0.003% a.i.). This is also true in the case of all the promising fungicides viz., PCNB, carboxin, carbendazim and thiophanate methyl. In general, highly virulent *R. solani* strain (RS3) shows high resistance to fungicides viz., carbendazim, MEMC, and thiophanate methyl as it could be inhibited by high concentration, whereas the growth of RS1, a comparatively less virulent strain, is inhibited even by the low dosage.

In SFST, MEMC, carboxin and carbendazim give cent percent inhibition of growth of all the RS isolates; as compared to PFT, in SFST the effective dosage is much higher for inhibiting the growth of the RS isolates. MEMC (0.003% a.i.) give cent percent inhibition of growth of RS1 and RS5, the two less virulent strains, whereas it does not inhibit the growth of other isolates. Though, carbendazim is effective against RS1 at 0.05% a.i. it inhibits the growth of other RS isolates only at higher concentration (0.2% a.i.).

It is obvious from the results of the two fungicide screening techniques that for effective control measures against soilborne, sclerotial pathogen like *R. solani*, SFST is more reliable than PFT as also has been reported earlier for *R. solani* causing diseases in *Lagerstroemea* sp. (Ali, 1993) and for *Cylindrocladium* spp. causing diseases of eucalypts (Sharma and Mohanan, 1991a).

## NURSERY TRIALS

Success of forest nursery in raising sufficient number of healthy disease-free planting stock depends largely on the nursery management practices adopted, especially during the early growth phase of seedlings. Regulation of shade over the seedbeds, selection of appropriate sowing rate, administration of water regimes in the seedbeds, etc. are some of the important nursery practices which are likely to have distinct impact upon the incidence and severity of seedling diseases.

Biocontrol agents have been recognized as a plausible means of disease control in nurseries. Addition of antagonistic organisms like *Trichoderma* spp. into the soil of seedbeds, mainly exploited in agriculture, provides an excellent approach to reduce or prevent the occurrence of seedling diseases caused by *R. solani*. Different delivery methods such as soil amendment and seed treatment are being used to introduce the antagonistic organisms into the soil to afford protection to the germinating seeds and young seedlings from pathogens. Soil solarization, another approach of biocontrol has been recently employed in controlling soilborne pathogens including *R. solani*. Mulching or tarping of the moistened soil of the seedbeds during the hot season with transparent polythene sheets, which increases the soil temperatures sub-lethal to lethal to soilborne pathogenic propagules, is the principle behind the soil solarization.

Application of effective fungicide at appropriate concentration seems to be the immediate practical measure to check the disease havoc in a forest nursery. Economic feasibility of chemical control of forest nursery disease, which may attain epidemic status is also justifiable.

Nursery trials were conducted to evolve an integrated control package for Rhizoctonia web blight of bamboo, using optimal combinations of cultural, chemical and biocontrol measures of disease management. Effect of shade, different water regimes, seed rates, soil solarization, soil amendment and seed treatment with *T. viride* and *T. harzianum*, etc. on incidence and severity of web blight were studied. Furthermore, the efficacy of the fungicides screened in the laboratory employing poison-food technique (PFT) and soil fungicide screening technique (SFST), was further tested in the nursery beds.

## EXPERIMENTAL SEEDBED NURSERY AND THE MICROCLIMATE

Bamboo nursery, comprising of 80 seedbeds, was raised at Chandhanathodu, Wynad during the month of April, 1992 (Plate 23). The nursery site received pre-monsoon showers of 25 mm and 181 mm, respectively during the months of April and May. South-west monsoon (June-September) began during the month of June, recorded a total of 6,784 mm rainfall with a maximum monthly rainfall of 1,857 mm in the month of June (Fig. 5).

Microclimate of the bamboo nursery was affected considerably by the shade regulation over the seedbeds, administration of different water regimes and seedling density in the seedbeds. Conventional coconut leaf thatch (CLT) shade provided over the seedbeds reduced the intensity of incident light received by the seedlings. Seedlings grown in seedbeds without shade (NS) received much more sun light (av. 68,456 lux) than those in seed-beds under CLT (av. 4,469 lux). The average light intensity over the seedbeds having coir mat shade (CM) was 14,625 lux (Fig. 6).


Plate 23. Nursery trials. a: A general view of the experimental bamboo nursery raised at Chandhanathodu, b: Seedbeds under coconut leaf thatch shade, coir mat shade and without shade.

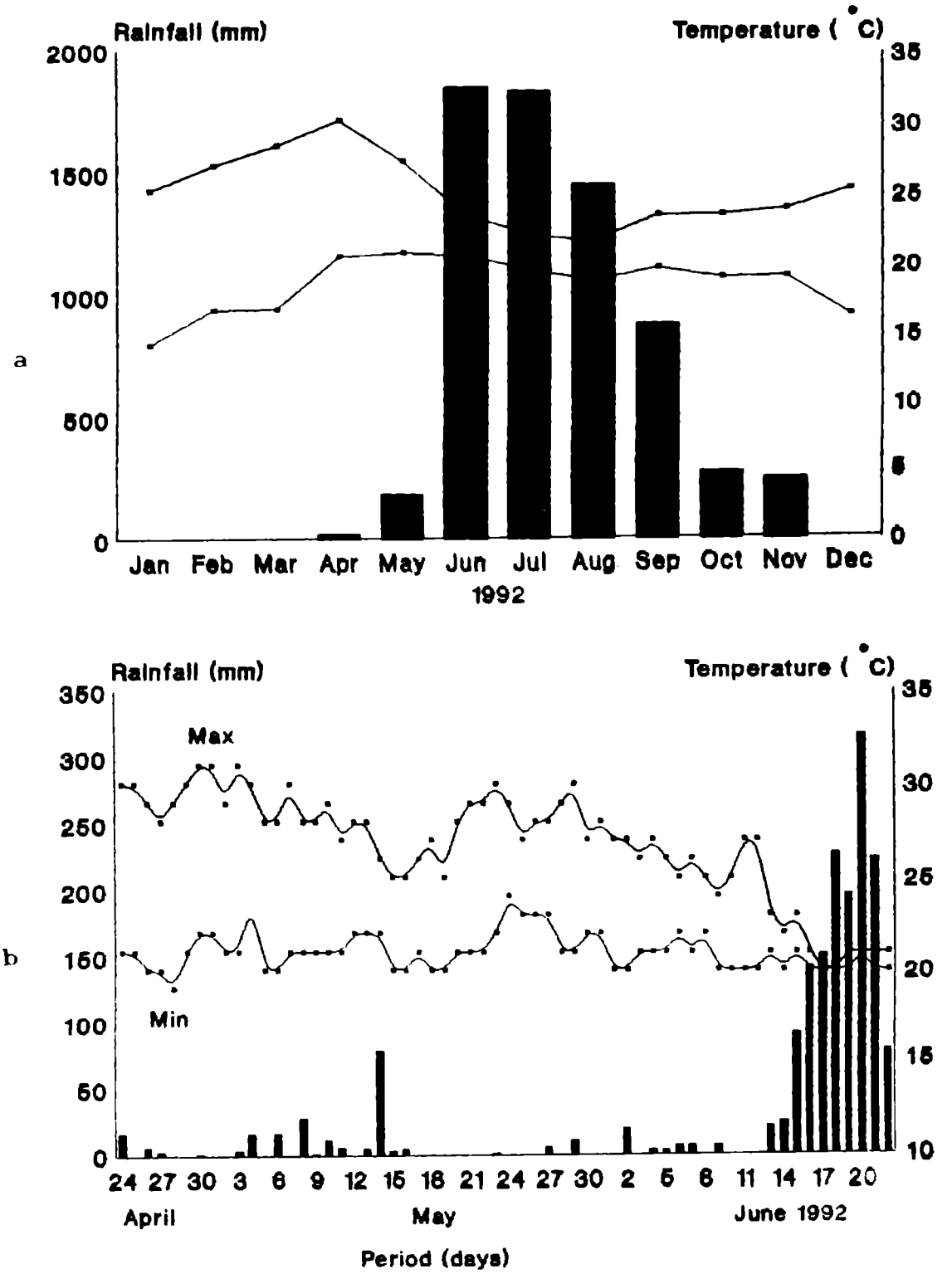



Fig. 5a: Monthly rainfall and average maximum and minimum temperatures at the nursery site (Chandhanathodu).
b: Daily rainfall and average maximum minimum temperatures at the nursery site during April-June, 1992.

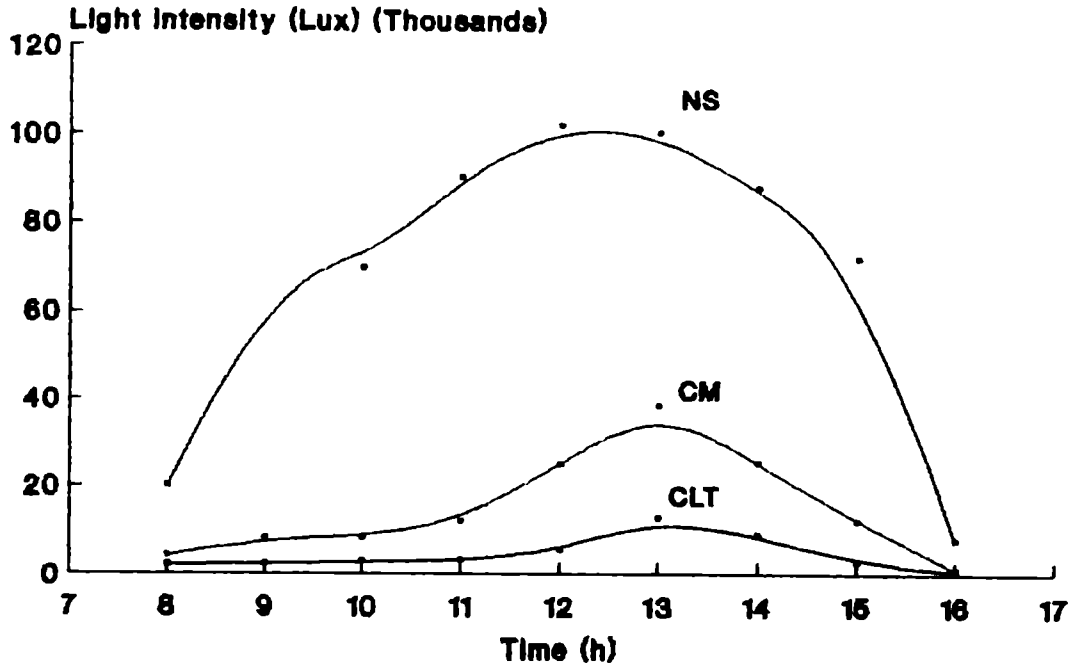



Fig. 6. Average light intensity over the nursery beds during May, 1992, CLT: Coconut leaf thatch shade, CM: Coir mat shade, NS: without shade

The shade over the seedbeds also affected the soil temperature as well as soil water potential. Soil water potential was found generally higher in seedbeds without shade (NS) than those under CLT shade. Soil water potential was comparatively higher in seedbeds provided with low water regime (W1) than in high water regime (W2). Average soil water potential in seedbeds provided with low and high water regimes, and without shade was 0.019 and 0.016 MPa, respectively. In CLT shaded seedbeds, the corresponding average soil water potential for low and high water regimes was 0.012 and 0.009 MPa, respectively (Fig.7).

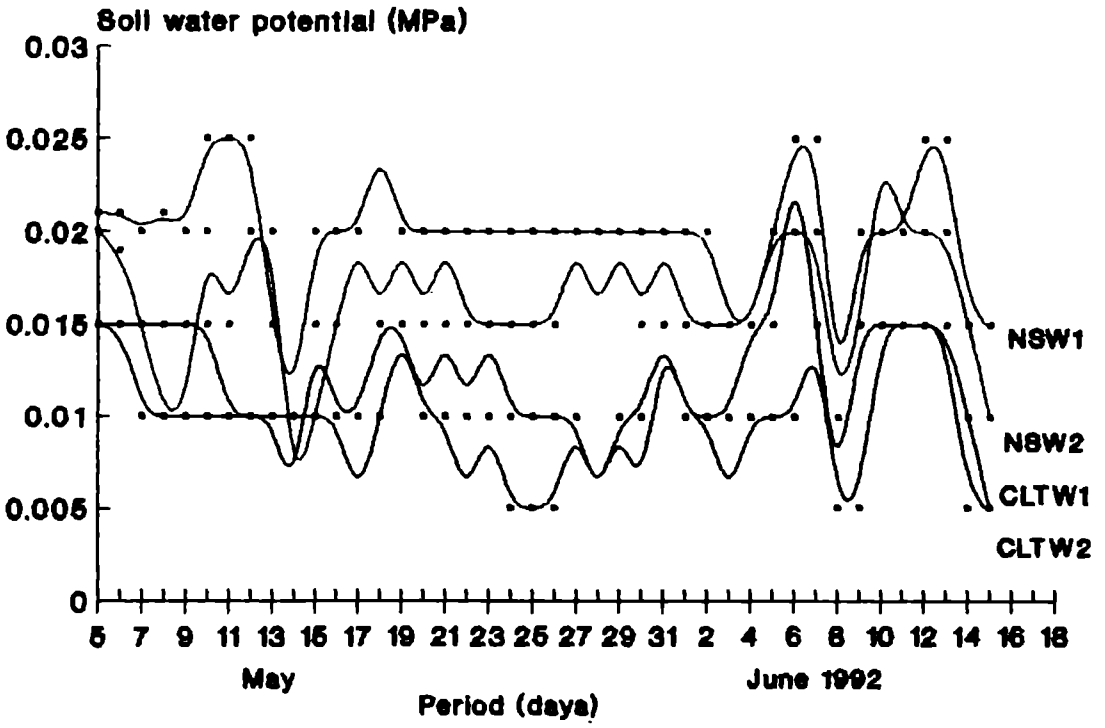



Fig. 7. Average soil water potential of seedbeds under different water regimes and shade. CLTW1, CLTW2: Coconut leaf thatch shade with water regime 1 and 2 respectively, NSW1, NSW2: Without shade and water regime 1 and 2 respectively.

Average soil temperature in seedbeds without shade (NS) was higher than those under CLT shade. In seedbeds provided with different water regimes, daily average soil temperature was slightly higher in low water regime (W1) (27.7$^0$C) than in high water regime (W2) (27$^0$C). In CLT shaded seedbeds also, low water regime showed higher daily average soil temperature (25$^0$C) than in high water regime (23$^0$C) (Fig.8). The ambient temperature measured in the nursery showed that daily average minimum and maximum temperatures during the study period were 18$^0$C and 36$^0$C, respectively; the daily average relative humidity (r.h.) varied from 66 to 100% (Fig. 9).

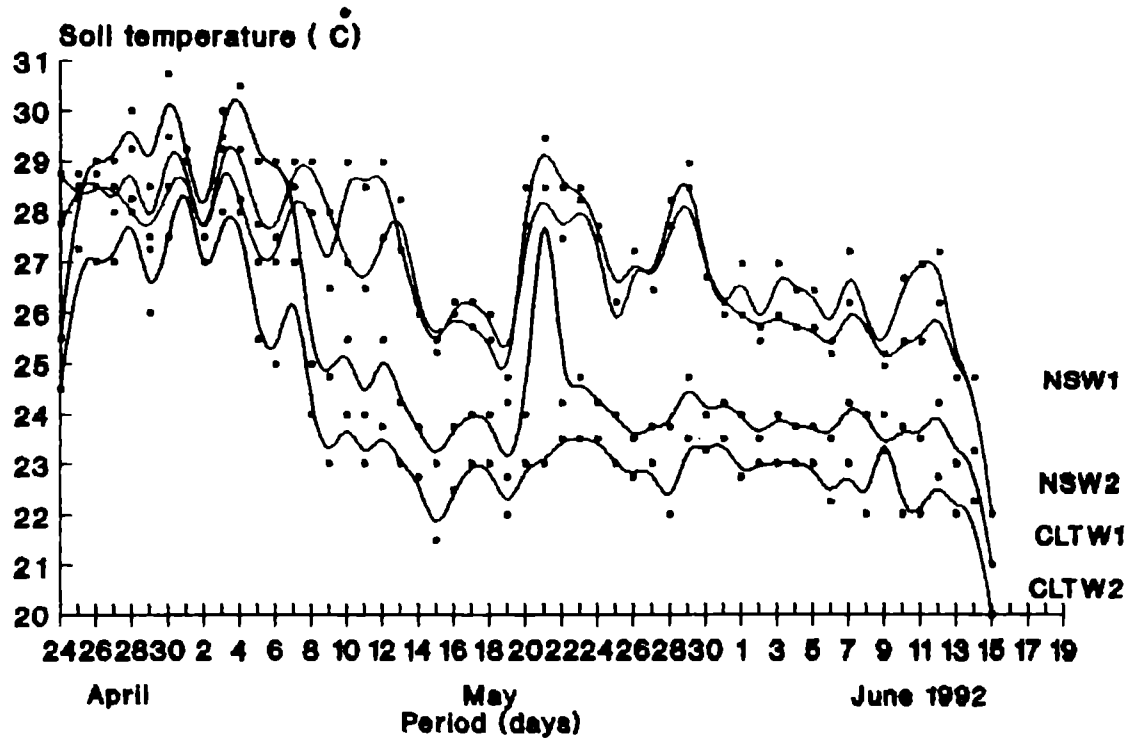



Fig. 8. Average soil temperature in the seedbeds under different water regimes and shade. CLTW1, CLTW2: Coconut leaf thatch shade and water regime 1 and 2 respectively, NSW1, NSW2: Without shade and water regime 1 and 2 respectively.

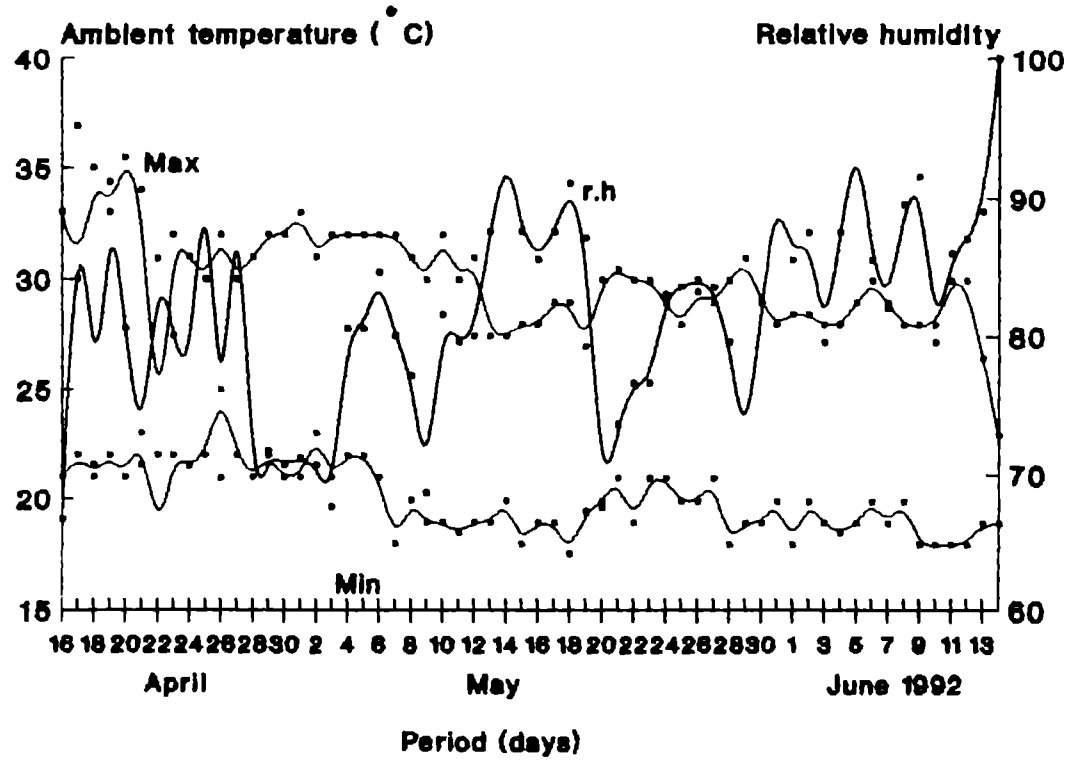



Fig. 9. Daily average temperature and relative humidity in the nursery. Max: Maximum temperature, Min: Minimum temperature, r.h.: Relative humidity.

**Effect of shade, water regimes and seed rates on incidence and severity of web blight**

Web blight occurred in seedbeds after 15 to 18 days of seedling emergence. Once the disease appeared, its spread and persistence depended upon the favourable microclimatic conditions prevailing in the nursery (Plate 24). Systematic observations on incidence, spread and severity of the disease were recorded from 36 seedbeds with different shade, water and seed rate treatments.

Area under disease progress curve (AUDPC) and disease progress rates (r) in respect of web blight in each treatment are given in Tables 4.39-4.43. ANOVA of AUDPC-fc (number of infection foci as disease parameter) indicated the effect of seed rate as highly significant at P=0.05 (Table 4.40). Interactions of seed rate and water regime, and seed rate and shade were also found highly significant. However, interaction of water regime and shade, and three-way interactions of seed rate, water regime and shade were not significant. In the ANOVA of AUDPC-ds (number of diseased seedlings as disease parameter), seed rate was highly significant (Table 4.42); interaction of seed rate, water regime and shade was not significant.

Values of AUDPC-fc of treatment combinations with low seed rate (SR1), both the water regimes (W1, W2), and with and without shade (S,NS) were significantly different from rest of the treatments; average number of infection foci and AUDPC were comparatively lower in these treatments than in other treatments. Lowest AUDPC of 21.333 was observed in SR1W1NS treatment with low seed rate, low water regime and without shade. Treatments with medium seed rate (SR2), low water


Plate 24. Nursery trials. a: *Bambusa bambos* seedbed showing web blight patches, b: An expanding web blight patch (focus) (coloured splints used for studying the spread of disease within the focus).

regime and CLT shade (SR2W1S) had high AUDPC of 621.333 which was significantly different from SR2W1NS and SR2W2NS, the treatments with low and high water regimes, and without shade Highest AUDPC of 868.000 was obtained in SR3W2NS treatment having high seed rate (SR3), high water regime and without shade, which was significantly different from all other treatments, except two treatments SR2W1S and SR3W1S. The latter two treatments had high AUDPC of 621.333 and 621.000, respectively.

**Table 4.39: Effect of different water regimes, seed rates, and shade on incidence and severity of web blight**

| | | Shade | | | |
|---|---|---|---|---|---|
| | | NS | | S | |
| Water regime | Seed rate | Av. No. of foci | AUDPC-fc (SE) | Av. No. of foci | AUDPC-fc* (SE) |
| W1 | SR1 | 2.00 | 21.333 (13.532) | 2.00 | 26.667 (22.784) |
| | SR2 | 20.33 | 338.667 (77.643) | 30.66 | 661.333 (120.473) |
| | SR3 | 23.00 | 460.000 (66.090) | 36.00 | 621.000 (97.289) |
| W2 | SR1 | 2.33 | 34.667 (7.4243) | 5.00 | 88.000 (45.078) |
| | SR2 | 20.66 | 369.33 (89.034) | 26.00 | 436.000 (99.92) |
| | SR3 | 35.33 | 868.000 (56.000) | 34.00 | 562.667 (63.764) |

*Significant at P 0.05.

AUDPC-fc: Area under disease progress curve calculated from number of infection foci; NS: Without shade; S: Coconut leaf thatch shade; W1,W2: Water regimes 1 and 2; SR1, SR2,SR3: Seed rate 1, 2 and 3.

Table 4.40: Analysis of variance of data on AUDPC-fc

| Source | df | Sum of squares | Mean square | |
|---|---|---|---|---|
| Seed rate | 2 | 2033365.170 | 1016682.585 | 54.765 |
| Water regime | 1 | 5974.770 | 5594.770 | 0.301 |
| Shade | 1 | 8149.818 | 8149.818 | 0.439 |
| Seed rate x water regime | 2 | 114890.267 | 57295.133 | 3.088* |
| Seed rate x shade | 2 | 197374.190 | 98687.095 | 5.316 |
| Water regime x shade | 1 | 21770.889 | 21770.889 | 1.173 |
| Seed rate x water regime x shade | 2 | 28616.667 | 14308.333 | 0.173 |
| Residual | 24 | 445546.667 | 18564.444 | |

Significant at P = 0.05.

AUDPC-ds also showed almost a similar trend (Table 4.41). Except one treatment (SR2W1S) with high AUDPC of 15910.667, all other treatments having seed rates, SR1 and SR2, were significantly different from the rest of the treatments. In general, treatments with low seed rate (SR1), low or high water regimes, with (S) or without shade (NS) showed lowest AUDPC. Among the four SR3 treatments, treatment with high water regime (W2) differed significantly from other treatments with low water regime (W1). Lowest AUDPC of 154.667 was in SR1W1NS, the treatment having low seed rate, low water regime and without shade. Highest AUDPC of 40,270.00 was obtained in SR3W2NS, the treatment with high seed rate, high water regime and without shade.

Table 4.41: Effect of different water regimes, seed rates, and shade on incidence and severity of web blight

| | | Shade | | | |
|---|---|---|---|---|---|
| | | NS | | S | |
| Water regime | Seed rate | Av. No. of seedlings | AUDPC-ds (SE) | Av. No. of seedlings | AUDPC-ds* (SE) |
| W1 | SR1 | 18.67 | 154.667 (115.247) | 19.67 | 204.000* (160.219) |
| | SR2 | 821.00 | 12517.333 (5000.1612) | 1125.33 | 15910.667 (3430.286) |
| | SR3 | 1021.00 | 18757.333 (6641.611) | 1974.33 | 26564.000 (5676.010) |
| W2 | SR1 | 25.33 | 290.667 (18.667) | 85.00 | 1289.333 (854.704) |
| | SR2 | 531.00 | 9988.000 (3673.695) | 1144.00 | 12116.000 (3554.005) |
| | SR3 | 1626.33 | 40270.000 (698.000) | 3995.00 | 53157.333 (9124.095) |

*Significant at P 0.05.
AUDPC-ds: Area under disease progress curve calculated from number of diseased seedlings; NS: Without shade; S: Coconut leaf thatch shade.

In general, different seed rates significantly affected the disease incidence and consequently the AUDPC. Medium and high seed rates (SR2 and SR3) had significantly higher disease severity than low seed rate (SR1). Comparatively higher disease incidence and disease severity calculated in terms of AUDPC, were recorded for treatment with high water regimes than those with low water regime. All the treatments with different seed rates and water regimes with CLT shade showed comparatively higher disease incidence and AUDPC than those without shade.

Table 4.42: Analysis of variance of data on AUDPC-ds

| Source | df | Sum of squares | Mean square | |
|---|---|---|---|---|
| Seed rate | 2 | 4823882866.08 | 24311941433.000 | 35.348 |
| Water regime | 1 | 83168419.929 | 83168419.929 | 1.219 |
| Shade | 1 | 20649465.892 | 20649465.892 | 0.303 |
| Seed rate x water regime | 2 | 422431076.767 | 211215538.38 | 3.095 |
| Seed rate x shade | 2 | 62285756.881 | 31142878.440 | 0.456 |
| Water regime x shade | 1 | 5708820.500 | 5708820.500 | 0.084 |
| Seed rate x water regime x shade | 1 | 15912234.167 | 7956117.083 | 0.117 |
| Residual | 24 | 1637618965.33 | 68234123.556 | |

* Significant at P 0.05.

Disease progress rate determined for each treatment using the exponential function taking both the disease parameters viz., number of infection foci and number of diseased seedlings in the infection foci separately, showed almost similar trends (Table 4.43) which indicate that the two parameters selected for the determination of disease progress are equally efficient. Generally, treatments with CLT shade showed comparatively low disease progress rate than those without shade. Most of the treatments with high water regime had higher disease progress rate than those with low water regime.

High $R^2$ values were obtained for the exponential curves of all the treatments, except in the case of SR1W1S and SR1W1NS treatments. The pattern of disease progress for each treatment under CLT shade (S) and without shade (NS) is given in Figs. 10-11.

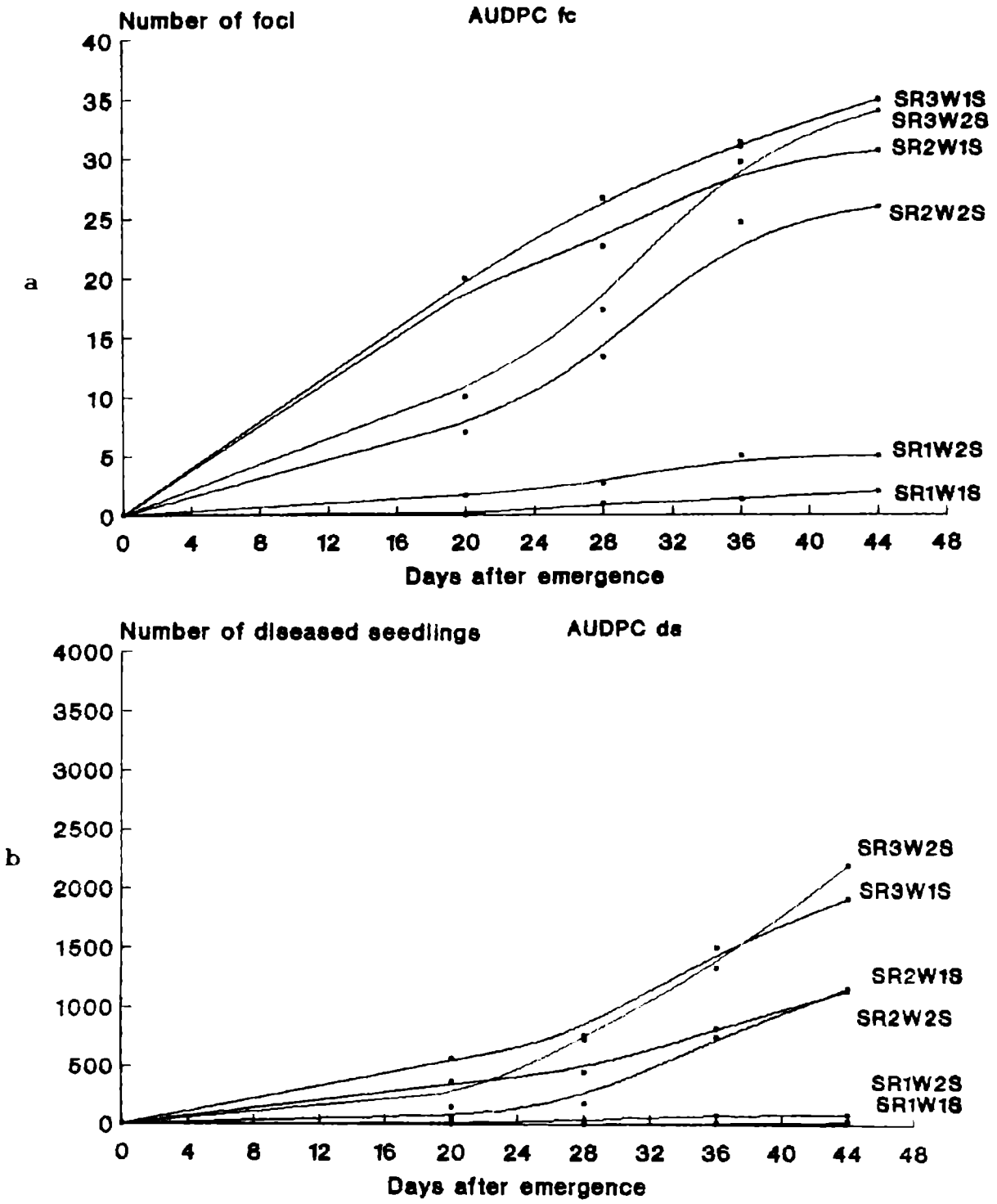



Fig. 10. Patterns of disease progress curve in different treatments under coconut leaf thatch shade. a: Area under disease progress curve (AUDPCfc) based on number of infection foci, b: Area under disease progress curve (AUDPCds) based on number of diseased seedlings, SR1, SR2, SR3: Seed rate 1,2,3 respectively, W1,W2: Water regimes 1 and 2 respectively, S: CLT shade

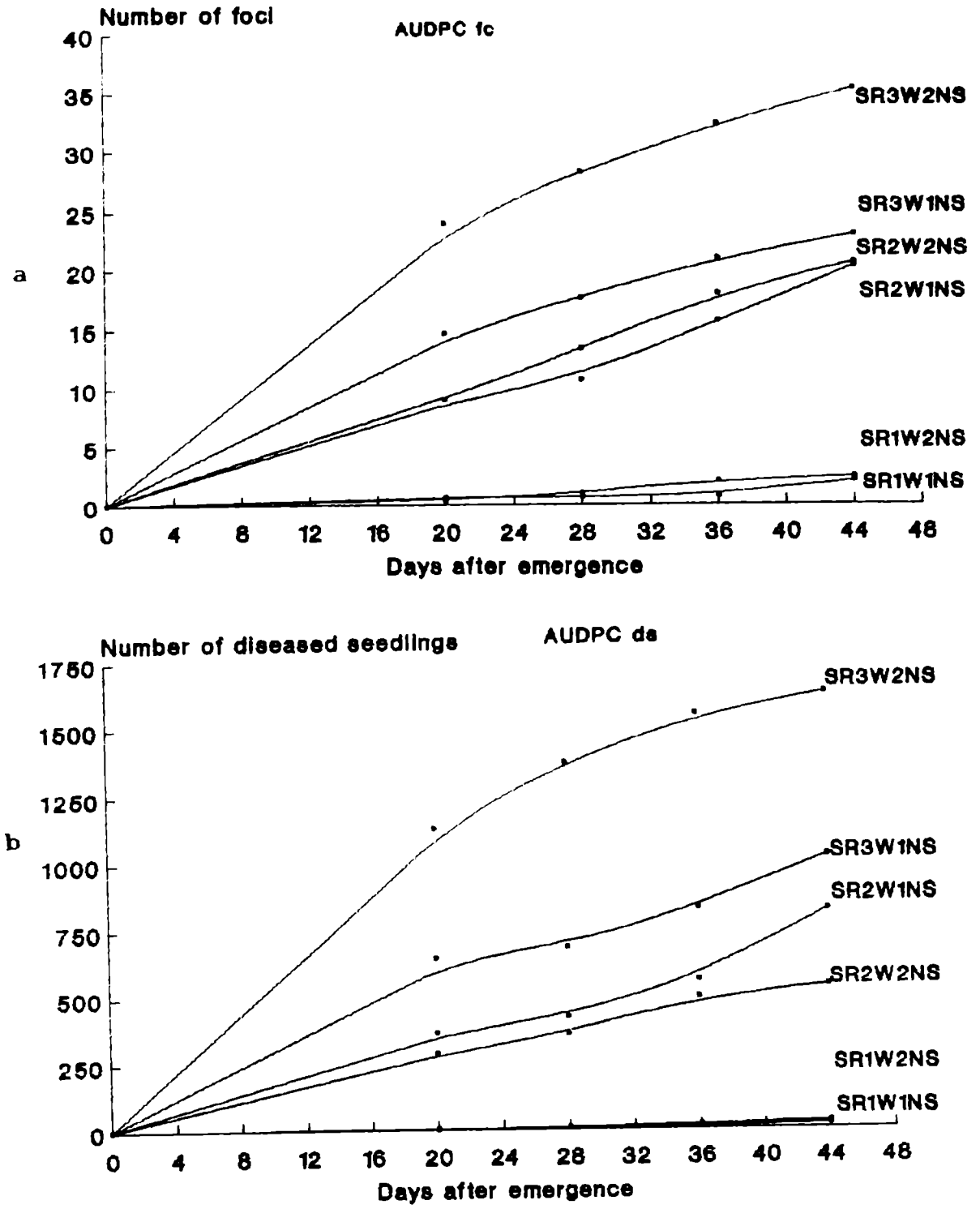



Fig. 11. Patterns of disease progress curve in different treatments without shade. a: Area under disease progress curve (AUDPCfc) based on number of infection foci, b: Area under disease progress curve (AUDPCds) based on number of diseased seedling, SR1, SR2, SR3: Seed rate 1,2 and 3 respectively, W1,W2: Water regimes 1 and 2, NS: Without shade.

Correlation between the two disease parameters viz., number of infection foci and number of diseased seedlings in the foci was found to be highly significant (r=0.9349) in the logarithmic scale. A graphical representation of the relationship is provided in Fig. 12.

**Table 4.43: Disease progress rate of Rhizoctonia web blight of *B. bambos* in different treatments**

| Treatment* | Disease parameter | | | | | |
|---|---|---|---|---|---|---|
| | No. of foci (fc) | | | No. of diseased seedlings (ds) | | |
| | Disease progress rate (r) | SE | $R^2$ | Disease progress rate (r) | SE | $R^2$ |
| SR1W1NS | 0.0411 | 0.0238 | 0.6000 | 0.0520 | 0.0253 | 0.6787 |
| SR1W2NS | 0.0814 | 0.0186 | 0.9054 | 0.1044 | 0.0160 | 0.9558 |
| SR2W1NS | 0.0338 | 0.0005 | 0.9995 | 0.0341 | 0.0097 | 0.9594 |
| SR2W2NS | 0.0349 | 0.0051 | 0.9585 | 0.0277 | 0.0046 | 0.9475 |
| SR3W1NS | 0.0190 | 0.0020 | 0.9789 | 0.0197 | 0.0031 | 0.9524 |
| SR3W2NS | 0.0162 | 0.0053 | 0.9824 | 0.0152 | 0.0029 | 0.9342 |
| SR1W1S | 0.2212 | 0.1029 | 0.6986 | 0.3156 | 0.1278 | 0.7530 |
| SR1W2S | 0.0490 | 0.0116 | 0.8993 | 0.0839 | 0.0197 | 0.9009 |
| SR2W1S | 0.0194 | 0.0038 | 0.9280 | 0.0500 | 0.0055 | 0.9668 |
| SR2W2S | 0.0569 | 0.0126 | 0.9106 | 0.1292 | 0.0175 | 0.9645 |
| SR3W1S | 0.0233 | 0.0039 | 0.9464 | 0.0564 | 0.0086 | 0.9559 |
| SR3W2S | 0.0532 | 0.0102 | 0.9321 | 0.1322 | 0.0180 | 0.9641 |

* For explanation see Table 3.8 under Materials and Methods.

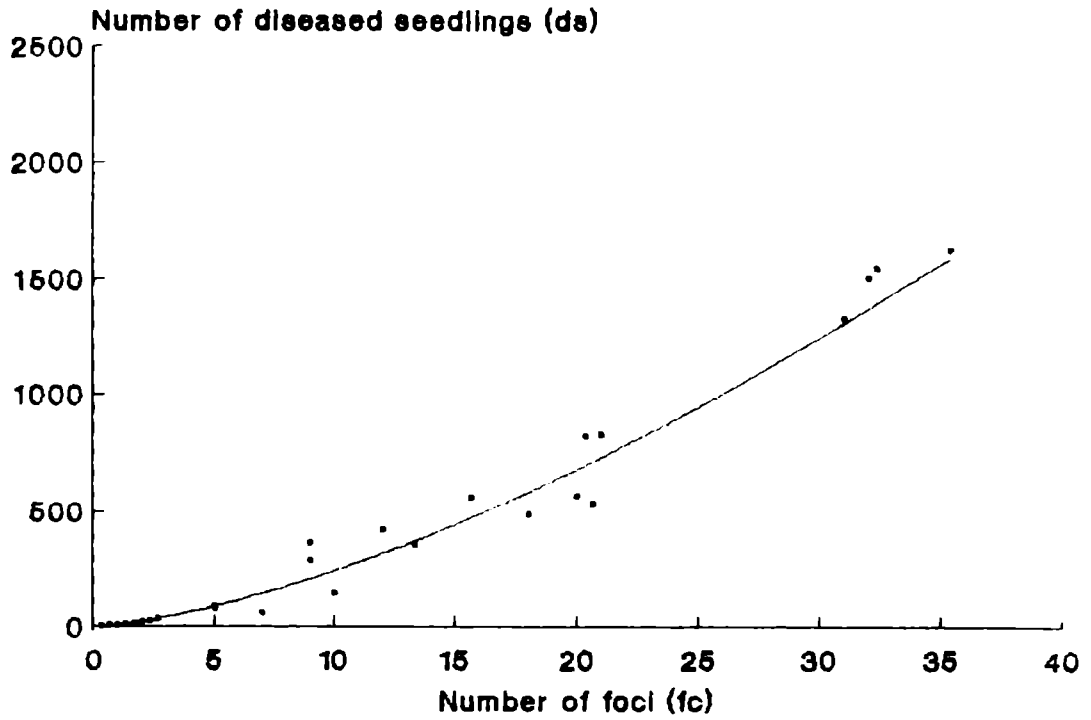



Fig. 12. Relation between number of infection foci and number of diseased seedlings.

**Effect of shade on growth of seedlings and their susceptibility to disease**

The growth and development of seedlings were affected due to considerable variation in the microclimatic condition viz., light intensity, soil temperature, soil water potential, ambient temperature and humidity under the CLT shade (S) and without shade (NS). Seedling emergence was much faster in seedbeds without shade and germination completed within eight days of sowing, whereas seedling emergence was very slow as it took 12 to 16 days to complete the emergence in CLT shaded seedbeds. In general, growth and development of seedlings was much faster in seedbeds without shade than under CLT shade.

Development of seedling rhizome and its growth was very prominent in seedlings under NS treatment. New shoots developed from rhizome after 20 to 25 days of emergence in NS whereas in CLT shaded seedbeds seedlings remained without rhizome production as well as new shoots (Fig. 14). Even after 90 days of seedling emergence the root system was poorly developed in seedlings under CLT shade. Seedling rhizome was found well developed in NS and an average of 2.66 new shoots emerged from the seedling rhizome within 90 days. Seedling biomass determined after 20 days of emergence up to 90 days with 10 days interval showed that shoot and root biomass were significantly higher under without shade than CLT shaded seedbeds. Growth pattern of shoot and root in all the treatments was sigmoid. A logistic growth curve of the form $Y = \frac{B}{1+Ke^{-LBt}}$ was fitted to the data (Fig. 13a,b).

**Table 4.44: Logistic regression equation fitted to shoot root biomass relationship with age of bamboo seedlings in seedbeds under CLT shade and without shade**

| Sl.No. | Treatment | B | K | L | $R^2$ |
|---|---|---|---|---|---|
| 1. | Shoot (S)* | 0.032217 | 6.701833 | 1.37328 | 0.95424 |
| 2. | Shoot (NS) | 0.127078 | 28.29627 | 0.650399 | 0.99648 |
| 3. | Root (S) | 0.023937 | 7.016104 | 1.165256 | 0.85883 |
| 4. | Root (NS) | 0.062352 | 28.506540 | 1.034160 | 0.97840 |

*S: Coconut leaf thatch shade (CLT); NS: Without shade.

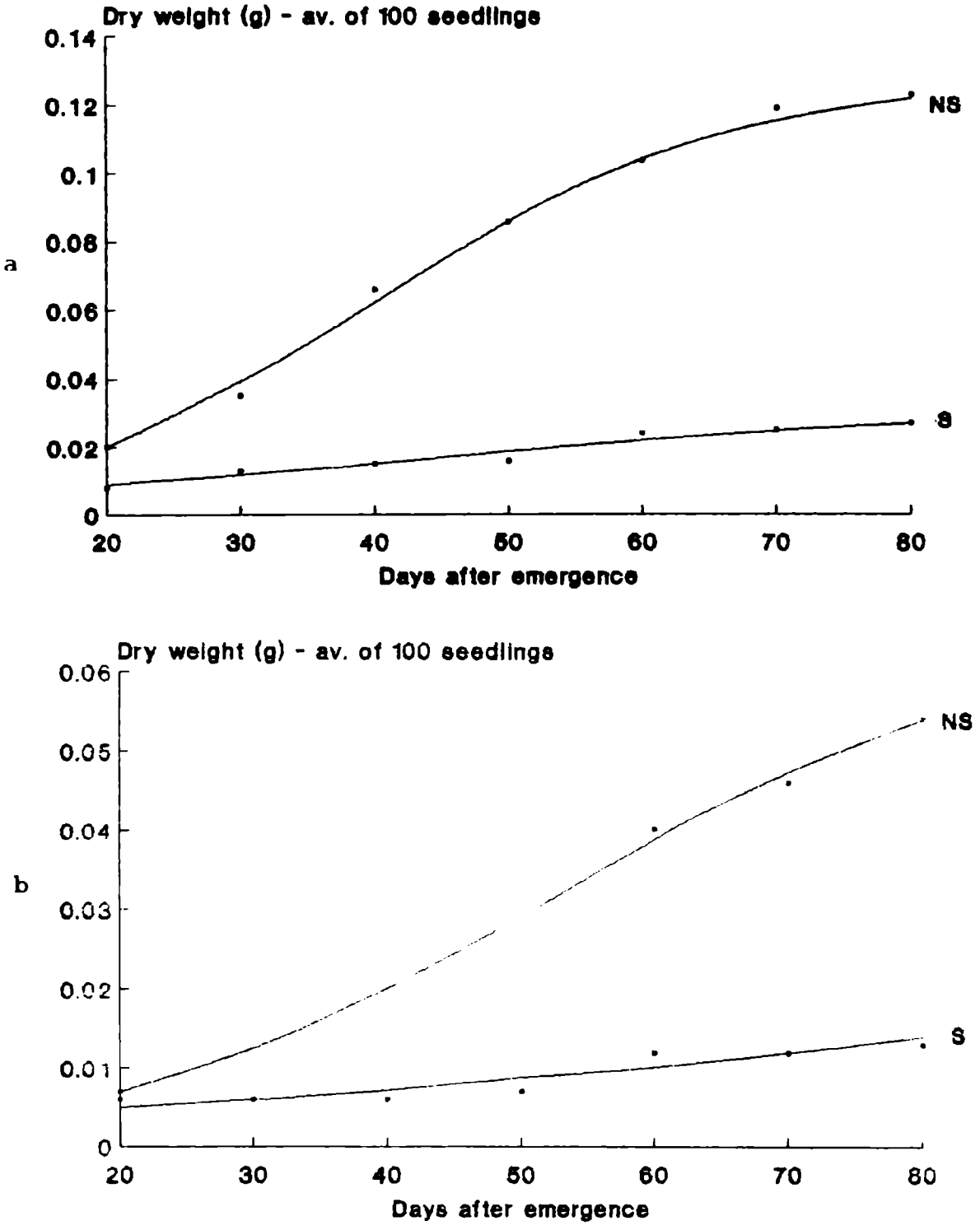



Fig. 13. Shoot and root biomass of *B. bambos* seedlings of different ages. a: Shoot biomass under coconut leaf thatch shade and without shade, b: Root biomass under coconut leaf thatch shade and without shade, S: Coconut leaf thatch shade, NS: without shade.

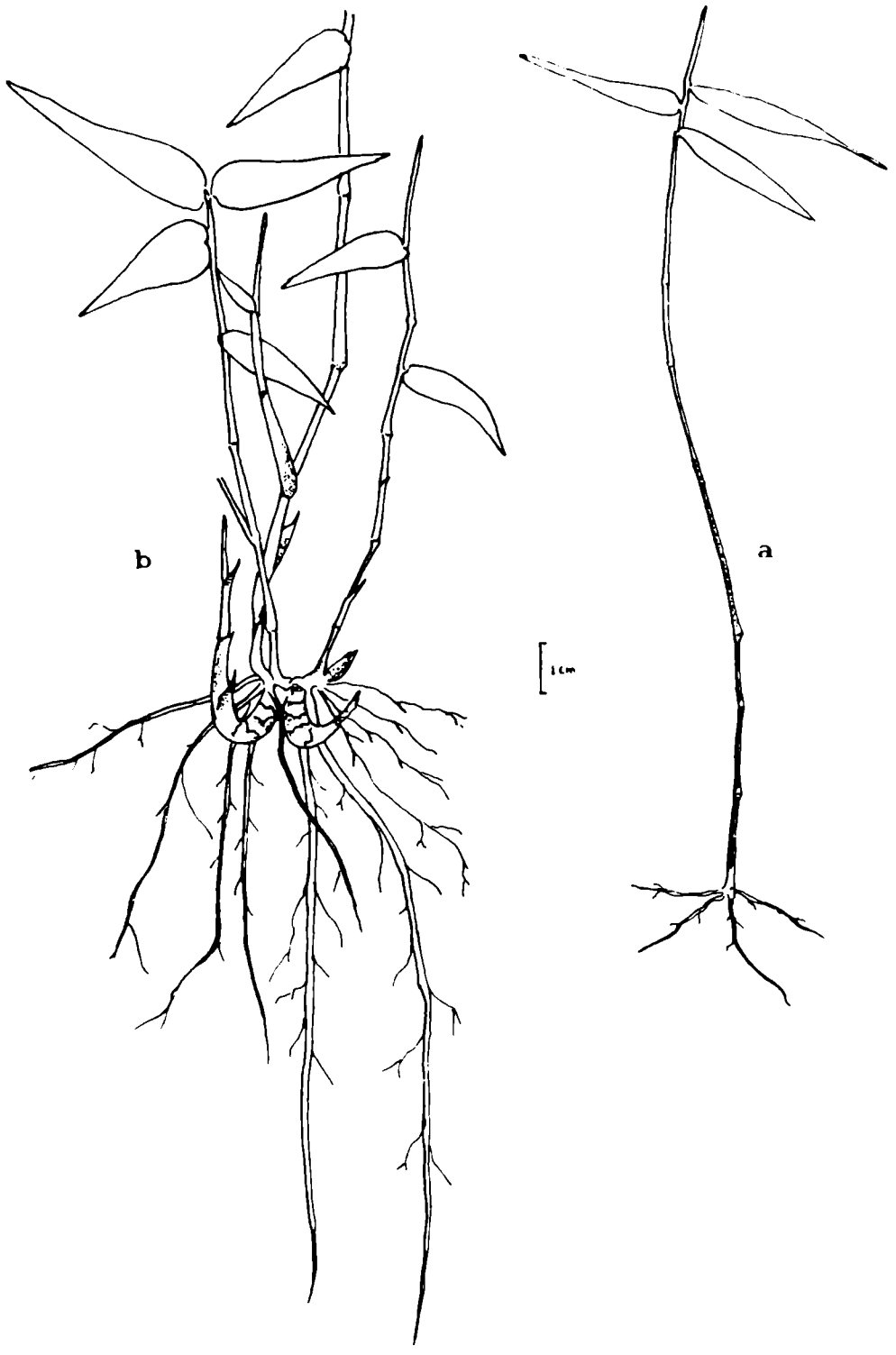



Fig. 14. Line drawing to show comparison of *B. bambos* seedlings (60-day-old) under coconut leaf thatch shade (a) and without shade (b). Note the differences in the development of rhizome and shoots.

Difference in the growth and development of seedlings in seedbeds with and without shade also reflected upon the incidence, spread and severity of web blight. In CLT shaded seedbeds, though, web blight appeared later than in NS, the disease persisted for a long period. Since, the seedlings in CLT shaded seedbeds were poorly developed with thin stem and small leaves, poorly developed rhizome and root system having few laterals, web blight infection caused outright killing of the affected seedlings. In general, the results indicate that for better growth and development of bamboo seedlings, shade over the seedbed is not at all required.

## BIOLOGICAL CONTROL OF WEB BLIGHT

### Soil solarization

#### *a. Soil temperature*

Soil temperature recorded from solarized seedbeds showed an average maximum of $47^0$C at 2.5 cm soil depth, followed by $45^0$C at 5 cm and $41.5^0$C at 15 cm depth (Fig. 15). Maximum soil temperature was recorded in the upper 2.5 cm layer of soil. Soil temperature recorded during 8.00 h to 19.00 h showed gradual increase and decrease at all the three soil depths. Peak temperature was attained between 13.00 h and 14.00 h.

#### *b. Disease incidence and severity*

Web blight was recorded after 15 to 20 days of seedling emergence in all the four solarized seedbeds, as in the case of other

treatments. However, damping-off, the disease which appeared first in the seedbeds did not occur in solarized seedbeds, except an erratic small disease patch in one out of the four replications. Incidence of web blight and its severity as expressed by AUDPC was found to be much less in the solarized seedbeds than controls. Average number of foci (4.25) and average number of diseased seedlings (161.75) and their respective AUDPC values were 87.00 and 3000.00 (Table 4.44). In the ANOVA, AUDPC-fc and AUDPC-ds of solarized seedlings were not significantly different from other biocontrol treatments excluding control (Tables 4.45, 4.46).

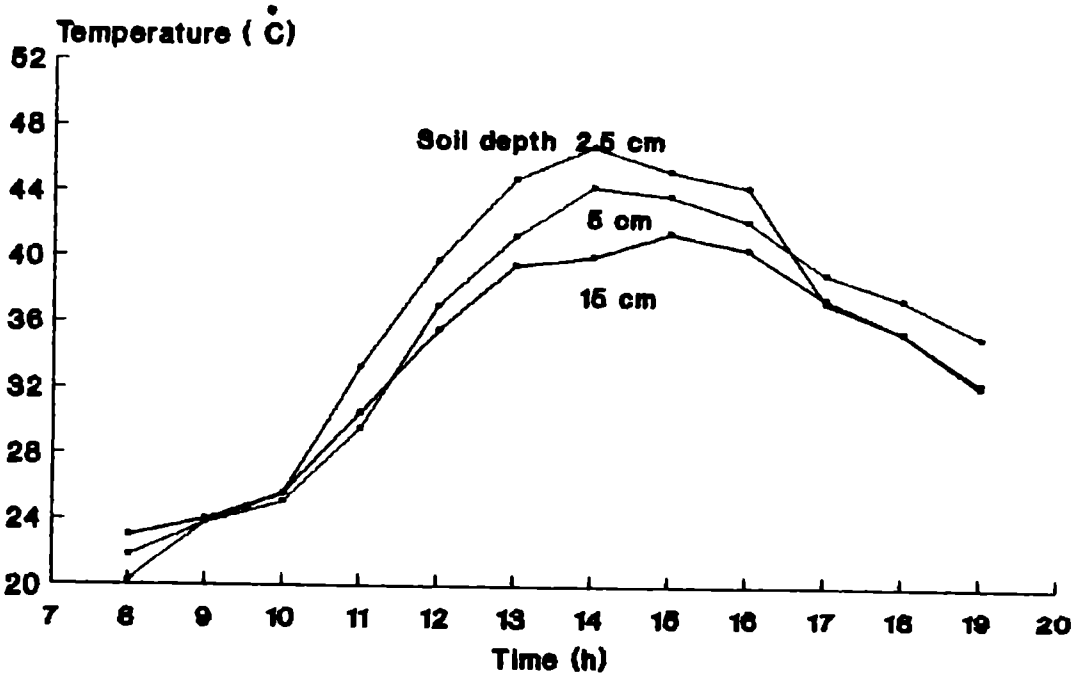



Fig. 15. Average soil temperature at different depths in seedbeds during solarization (April, 1992)

Table 4.45: Effect of soil solarization and treatment of antagonistic organisms on incidence and severity of web blight

| Treatment | Disease parameter | | | |
|---|---|---|---|---|
| | No. of foci (fc) | | No. of diseased seedlings (ds) | |
| | Av. No. of foci | AUDPC-fc (SE) | Av. No. of diseased seedlings | AUDPC-ds (SE) |
| TVSA | 5.00 | 112.000 (44.542) | 44.00 | 900.000* (343.418) |
| THSA | 3.00 | 64.000 (28.844) | 51.33 | 912.00 (222.998) |
| TVST | 10.00 | 220.000 (83.235) | 142.333 | 3136.000 (1266.731) |
| THST | 5.00 | 116.000 (14.422) | 83.33 | 1856.000 (376.374) |
| SOL | 4.25 | 87.000 (27.000) | 161.75 | 3000.000 (1583.1134) |
| C | 24.66 | 414.367 (115.156) | 1154.33 | 188890.607 (5977.743) |

*Significant at P 0.05; TVSA: *Trichoderma viride* soil amendment; THSA: *T. harzianum* soil amendment; TVST: *T. viride* seed treatment; THST: *T. harzianum* seed treatment; SOL Soil solarization; C Control.

Table 4.46: Analysis of variance of data on AUDPC-fc in biological control treatments (excluding common control)

| Source | df | Sum of squares | Mean squares | F |
|---|---|---|---|---|
| Between Groups | 4 | 43923.000 | 10980.750 | 1.7644$^{ns}$ |
| Within Groups | 11 | 68460.000 | 6223.636 | |

$^{ns}$Nonsignificant at P=0.05.

Table 4.47: Analysis of variance of data on AUDPC-ds in biological control treatments (excluding common control)

| Source | df | Sum of squares | Mean squares | F |
|---|---|---|---|---|
| Between Groups | 4 | 15104319.000 | 3776079.750 | 0.9995$^{ns}$ |
| Within Groups | 11 | 41559456.000 | 3778132.364 | |

$^{ns}$:Nonsignificant at P=0.05.

**Soil amendment and seed treatment with antagonistic organisms**

*Disease incidence and severity*

Web blight appeared after 16 to 19 days of seedling emergence in all the seedbeds treated with *T. harzianum* and *T. viride*. However, the disease incidence and severity were comparatively less than those of control (Table 4.45). Average number of infection foci, average number of diseased seedlings in the foci and their respective AUDPC were found to be less for *T. viride* both in soil amendment as well as seed treatment than those of *T. harzianum* which indicated that *T. viride* is slightly superior to *T. harzianum* in controlling Rhizoctonia web blight in the nursery. Introduction of *Trichoderma viride* and *T. harzianum* in the seedbeds as soil amendment before sowing as well as by seed treatment were very effective in controlling damping-off of bamboo seedlings.

CHEMICAL CONTROL OF WEB BLIGHT

Of the six fungicides viz., MEMC, mancozeb, carbendazim, Ridomil, thiram and carboxin screened, MEMC and carboxin were found effective in controlling the web blight. Lowest disease incidence and severity were recorded for MEMC. Out of the three seedbeds treated with MEMC, two seedbeds were completely free from the disease. In one replicate seedbed a single patch of web blight was recorded on the 20th day of seedling emergence which increased to three patches by 44th day. Of the three systemic fungicides, viz., carboxin, carbendazim and Ridomil tested, carboxin was highly effective next to the mercurial fungicide, MEMC in controlling the web blight.

Effective the treatment lowest were the values for fc, AUDPC-fc, ds and AUDPC-ds. In MEMC treatment, average number of infection foci (fc) and diseased seedlings (ds) in foci were 1.00 and 16.00 with corresponding AUDPC 13.33 and 2118.667, respectively. Mancozeb and thiram treatments were not effective in controlling the web blight and fc, AUDPC-fc, ds, and AUDPC-ds values were very high (Table 4.48, 4.49, 4.50).

Table 4.48: Analysis of variance of data on AUDPC-fc in chemical control treatments

| Source | df | Sum of squares | Mean square | F |
|---|---|---|---|---|
| Between Groups | 6 | 389423.238 | 64903.873 | 2.802* |
| Within Groups | 14 | 324256.000 | 23161.143 | |

*Significant at P=0.05.

Table 4.50: Effect of fungicidal treatment on incidence and severity of web blight of *B. bambos* caused by *R. solani*

| Treatment | Disease parameter | | | |
|---|---|---|---|---|
| | No.of foci (fc) | | No. of diseased seedlings (ds) | |
| | Av. No. of foci | AUDPC-fc* (SE) | Av. No. of diseased seedlings | AUDPC-ds (SE) |
| MEMC | 1.00 | 13.333$^{a**}$ (13.333) | 16.00 | 218.667$^{a}$ (218.667) |
| Mancozeb | 15.33 | 321.333$^{bc}$ (99.662) | 249.33 | 5182.667$^{a}$ (1912.349) |
| Carbendazim | 10.33 | 213.333$^{abc}$ (77.299) | 120.33 | 2404.000$^{a}$ (1067.456) |
| Ridomil | 12.66 | 264.00$^{abc}$ (126.996) | 229.33 | 4944.000$^{a}$ (2330.865) |
| Thiram | 15.33 | 341.333$^{bc}$ (91.282) | 237.66 | 5209.33$^{a}$ (970.433) |
| Carboxin | 3.00 | 66.667$^{ab}$ (15.37) | 76.00 | 1557.333$^{a}$ (397.352) |
| Control | 24.66 | 414.667$^{c}$ (115.155) | 1154.33 | 18890.667$^{b}$ (5977.713) |

*AUDPC-fc: Area under disease progress curve calculated from number infection foci.
AUDPC-ds: Area under disease progress curve calculated from number of diseased seedlings.

**Values in a column sharing the same superscript(s) do not differ significantly at P = 0.05.

Table 4.49: Analysis of variance of data on AUDPC-ds in chemical control treatments

| Source | df | Sum of squares | Mean square | F |
|---|---|---|---|---|
| Between Groups | 6 | 698476053.3 | 116412675.6 | 5.7658* |
| Within Groups | 14 | 282660981.3 | 20190070.1 | |

*Significant at P=0.05.

## Discussion

Since there is a possibility of occurrence of different strains of web blight pathogen, *R. solani*, disease management requires an integrated strategy. These strains differ in their virulence and show varying degree of resistance to different fungicides, and also sensitiviy to microclimatic conditions. Since, the pathogen is soilborne with sclerotia as resting structures, disease management strategies should be directed either to reduce the pathogen population in the soil or prevent the infection. Cultural operations in the nursery, right from the selection of the nursery site offer much scope for the effective management of the disease in nursery. The nursry management practices include preparation of the seedbeds, pre-treatment of seeds, shade regulation over the nursery, judicious watering, timely weeding, transplanting, proper prophylatic treatments, etc. (KFRI, 1984; Sharma and Mohanan, 1986). Though, various fungicides are effective against *R. solani*, control of web blight is not always completely effective due to many unexplained

reasons. Biocontrol employing antagonistic microorganisms as well as soil solarization of seedbeds prior to sowing are the possible alternative strategy for the management of web blight in bamboo nurseries.

## Cultural control

Cultural control is the chief means of management of diseases in traditional farming system (Thurston, 1990). It provides a resilient skeleton for crop protection in many cropping systems and serves to reduce problems that require intervention with pesticides or other alternatives. The important cultural practices used in forestry to reduce the probability of losses from seedling diseases are: adjusting seedling density and depth and time of sowing; altering soil fertility, soil pH; manipulating shade, irrigation, using pathogen free planting materials, etc. Knowledge on biology of the pathogen and epidemiology of disease is required to adopt appropriate cultural practices. Cultural practices that reduce primary inoculum or reduce infection frequency are often highly effective and adaptable in forest nurseries. In the case of web blight caused by *R. solani*, the period for disease development is often short. The pathogen is operatiing in a widely fluctuating environment, and its activity is dependent on a certain combinations of environmental conditions. In the present study, manipulation of the shade over the seedbeds, different seedling densities and water regimes are used for controlling the web blight.

### *Shade, soil water potential and seedling density*

Manipulation of shade over the seedbeds during the early phase of the seedling growth in order to prevent sun scorching appears to be

the most important factor influencing the microclimate in the nursery and consequently the incidence and severity of seedling disease. Since, bamboo is a fast growing monocot, it requires high soil moisture and sufficient light right from the seedling emergence. In shaded beds, seedlings show etiolation and poor development of root and shoot system. High light intensity increases the dryness of the soil which in turn decreases the incidence of seedling disease (Vaartaja, 1952; Sharma and Mohanan, 1991a). However, in bamboos, web blight occurs after 15 to 18 days of seedling emergence both in shaded as well as without shade and the incidence and severity of disease are much higher in former than in the latter. In general, seedbeds which receive low light intensity, low temperature and low moisture potential show low disease progress rate than beds without shade.

Soil moisture in seed beds, which is influenced by the level of irrigation, type of the soil texture and type of shading, is another factor influencing the incidence and severity of web blight. The quantity of water required depends upon the local climatic conditions, plant species, texture of soil and type of shade provided. The soil water regime has many interacting components and factors which singly or in combination, directly or indirectly, exert a selective pressure on soil microorganisms as well as seedlings. These include matric and osmotic or solute potentials, solute diffusion, concentrations and diffusion rates of gases and vapours, and pore size distribution (Griffin, 1972). Disease severity measured in terms of AUDPC is more in seedbeds provided with high moisture regime (20 l $m^{-2}$) than in low moisture regime both in CLT shaded as well as seedbeds without shade. Occurrence of increased disease incidence with high soil moisture has also been reported by various workers (Cook, 1973; Cook and Papendick, 1974; Papendick and Campbell, 1975). Sharma and Mohanan (1991a) have also reported high incidence of web blight of eucalypts caused by *R. solani* with increased soil moisture. On the contrary, adverse effect

of soil moisture on mycelial growth of *R. solani* and development of web blight of *Paraserianthes falcata* has been reported by Sharma and Sankaran (1987,1991). This type of behaviour of *R. solani* could be due to the involvement of different strains differring in water and oxygen requirements (Baker, 1970). The complex role of soil water potential in disease development has been reviewed by Griffin (1978) and Cook and Duniway (1981).

Positive correlation between increased incidence and severity of web blight and high seedling density is observed. These results are in agreement with the earlier recommendations that seedling density in forest nurseries may need to be modified in accordance with the degree of risk of damping-off and web blight (Burdon and Chilvers, 1982). High seed rates viz., SR2 (330 g $m^{-2}$) and SR3 (500 g $m^{-2}$), which are respectively two and three times of low seed rate, SR1 (165 g $m^{-2}$) gave correspondingly high incidence and severity of web blight. The seedbeds under CLT shade and without shade also show similar trend. These observations conform to the results obtained by Sharma and Mohanan (1991a) for web blight of eucalypts. Lateral spread of web blight is mainly by the physical contact of the mycelial strands from diseased seedlings to the neighbouring healthy seedlings; high seedling density favours the quick spread of the disease. Moreover, high seedling density influences the microclimate for the development of basidial as well as sclerotial stages of the fungus on the affected basal parts of the seedlings, which consequently affect the disease severity as well as disease persistence.

Seedling density not only affects the seedling health but also seedling vigour. Since, bamboo seedlings require more space for the development and growth of rhizome, and also for the development of new shoots from the rhizome, conjestion of seedlings affect the normal growth which often end up with seedlings having only the primary shoot.

*Disease progress rate*

Only few records of disease progress rates in forest nurseries are available (Bloomberg, 1985; Sharma and Mohanan, 1991a,1992). Disease progress rate in forest nurseries varies greatly among pathogen species, tree species or provenance within species, and especially from year to year (Bloomberg, 1985). The present study provides enough evidence that AUDPC and disease progress rates of web blight are greatly influenced by the forest nursery practices such as shading, moisture regime and seed rate (seedling density). Increase in seed rate and moisture regime also increase both the parameters of disease severity. The light intensity, depending upon the shade provided over the seedbeds, also affects AUDPC and disease progress rate. In general, shaded seedbeds which receive low light intensity, low temperature and low moisture potential show higher disease incidence but a low disease progress. On the contrary, in open seedbeds less disease and higher disease progress rate are observed. Hence, it is likely to be a combined effect of incident light and soil as well as ambient temperatures controlling the disease progress rate. With regard to host density, Sharma and Mohanan (1992) have reported that both the infection rate and spread of advancing disease fronts of seedling blight of eucalypts caused by *Cylindrocladium* spp. have similar curvilinear relationship to host density. The results obtained by using AUDPC as a measure of severity of web blight over a period of time are comparable well with the disease progress rates. Thus, AUDPC provides an excellent and simple measure of disease severity influenced by various nursery practices.

*Influence of nursery practices on growth of seedlings and their susceptibility to disease*

It is evident from the results that the seedling growth is greatly influenced by various nursery practices, especially the manipulation of shade, soil moisture regime and seedling density. Seedlings under CLT shade show lower shoot and root biomass than those without shade. This possibly indicates that the effect of light intensity is more pronounced on seedling biomass than the moisture regime. High seedling biomass of eucalypts seedlings has also been reported by Sharma and Mohanan (1991a, 1992) under coirmat than under CLT shade. The S:R ratio of seedlings shows a gradual increase in the seedbeds without shade. The initiation and development of new shoots from seedling rhizome depend on the available photosynthate. Growth of seedlings in seedbeds without shade allows production of more photosynthate than can be used by primary shoot; hence, development of rhizome and new shoots occur in these seedlings. Whereas the seeedlings under CLT shade, utilize all the available photosynthate, hence production of new shoots get arrested. Soil fertility level and seedling density also affect the new shoot production. The results on incidence, spread and persistence of web blight in CLT shaded seedbeds suggest that for raising bamboo seedlings having well developed root, rhizome and shoot systems, shade over the seedbeds has to be avoided. Also, appropriate sowing rate (< 165 g $m^{-2}$), depending on the germinability of seeds has to be selected inorder to minimize the incidence and lateral spread of web blight as well as to obtain well developed seedlings.

## Biological control

Biological control of plant diseases has gained considerable attention over the last 20 years. Much of this interest stems from the

desire to decrease the use of pesticides in agricultural, forest and urban environments. Major concepts and principles of biocontrol of plant diseases have been highlighted by Baker and Cook (1974), Papavizas and Lumsden (1980), Cook and Baker (1983), Adams (1990), Bolland (1990) and Axelrood (1991). Biocontrol of seedling diseases of various agricultural crops has been extensively studied, whereas, such information on biocotrol of forest nursery diseases is almost nil in tropical climate. In the present study soil solarization and introduction of antagonistic organisms are tried.

*Soil solarization*

Heat treatment of soil has been used for many years to control soilborne plant pathogens in green house plant culture (Baker, 1991). Recently, soil solarization, the process of heating soils under transparent plastic tarps to temperature lethal to soilborne pathogens, was reported to be successful in controlling several plant diseases (Katan *et al.*, 1976; Grinsten *et al.*, 1979, Katan, 1980, 1981; Pullman *et al.*, 1981; Sharma and Mohanan, 1991a). In the present study, soil temperature in the solarized seedbeds reached upto 47$^{O}$C, which is sufficient to inactivate spores of many pathogens as has been recorded by several workers (Pullman *et al.*,1981; Katan,1987), where soil solarization for 4- to 6-wk periods at temperatures between 40 and 50$^{O}$C was effective to kill pathogens like *R. solani*, *Sclerotium rolfsii* Sacc., *Verticillium dahliae* Kleb., *Pythium* spp., etc. *R. solani* is reported to be injured by temperature of 45$^{O}$C or within five minutes at 50$^{O}$C (Sherwood, 1970). Elad *et al.* (1980, 1981) reported a time-temperature (dosage) relationship for the thermal killing of soilborne fungi in biocontrol mechanism as shown with *R. solani* and *Fusarium* sp. In the solarized beds soil temperature of 47$^{O}$C at a depth of 2.5 cm usually lasted for several hours with an average of nine

hours per day. and was greater than or close to thermal death temperature reported by Sherwood (1970). The results provide ample evidence that soil solarization is effective but only to a certain extent against web blight. Probably, *R. solani*, a very efficient saprophytic competitor, is not suppressed completely and is able to recolonize quickly and cause infection.

*Antagonistic organisms as soil amendment and seed treatment*

In forest nurseries the 'biological balance' is likely to be drastically upset either by raising monocultures extensively year after year or by introducing broad spectrum pesticides that disrupt microrganism populations. Introduction of antagonistic organisms into the nursery soil is a plausible approach in biocontrol of seedling diseases. The genera of fungi most commonly evaluated for potential as biocontrol organisms are *Trichoderma* and *Gliocladium*. Several species of *Trichoderma* including *T. hamatum* (Bonord.) Bain., *T. harzianum* Rifai and to a lesser extent *T. koningii* Oudem, *T. polysporum* (Link ex Pers.) Rifai and *T. viride* Pers. ex Gray have also been used against seedling disease caused by several pathogens in the laboratory, greenhouse and field (Papavizas and Lewis, 1981; Papavizas, 1985). So far, there have been no reported success in treating forest seed with microbes to control seedling diseases. In the present study, seed treatment as well as soil amendment with *T. harzianum* (TH4) and *T. viride* (TV3) show partial success. Supression of web blight occurs in the antagonist treated seedbeds. One major problem confronted particularly with seed treatent is the induction of rhizosphere competence by biocontrol agents, defined as the ability of the agent to grow and proliferate in host plant rhizosphere (Liu and Baker, 1980; Ahmad and Baker, 1987). This is the zone where protection against pathogens is most critical. Most of the antagonists are not

rhizosphere competent as reported by Beagle-Ristanino and Papavizas (1985). However, recent work shows that *Trichoderma* spp. exhibit the ability to multiply in the rhizosphere (Ahmad and Baker, 1987; Baker, 1991). The tapioca rinder medium used for mass multiplication of the antagonists proved to be efficient for large-scale soil application. Incidence of web blight in antagonist-treated seedbeds indicates their inefficacy to control the pathogen multiplication beyond a certain limit. This also reflects the inability of multiplication of the introduced antagonists in the changed environment. Various reports on biocontrol also indicate variation in the effectiveness of biological control strains under different environmental conditions and among differrent trials (Cook and Baker, 1983; Bolland, 1990; Baker, 1991). The study suggests that for management of web blight the promising antagonists can be utilized to favour disease suppression along with cultural measures.

## Chemical control

As in agriculture, protection of seedlings in forest nurseries against diseases has been much relied on chemical pesticides. Such reliance has often led to repeated, widespread application of pesticides during the seedling production cycle. Even though, recent problems with pesticide resistance, toxicity to non-target organisms, environmental contamination, and other unforeseen effects have greatly reduced the desirability of chemical pesticides (Campbell, 1986), out break of disease epidemics in forest nurseries, especially in high rainfall areas often forced to depend heavily on chemical pesticides. In addition to the newly formulated fungicides, which have restricted mode of action, with effectiveness on relatively few target organisms (Lyr, 1987; Thomson, 1988), the first generation copper and mercurial based fungicides are still extensively used in forest nurseries in the

State, since they are readily available and economical for forestry seedlings. In the present study application of mercurial fungicide, MEMC and systemic fungicide, carboxin as soil and foliar drench after 7, 21 and 42 days of seedling emergence controlled the web blight in seedbeds. The first two treatments of MEMC are sufficient to control the seedling diseases. Carboxin and MEMC have also been earlier recommended for controlling the diseases of forestry crops caused by *R. solani* in Kerala (Sharma and Sankaran, 1987; Sharma *et al.*, 1985; Mohanan and Sharma, 1989; Sharma and Mohanan, 1991b; Ali, 1993). Recently, use of the mercurial based fugicides in sensitive habitat like forest nurseries is restricted due to their high mammalian toxicity and possible environmental hazards. Hence, though expensive, application of carboxin, a systemic fungicide, after 7 and 21 days of seedling emergence is much desirable in managing the web blight in bamboo nurseries.

# GENERAL DISCUSSION

# 5. GENERAL DISCUSSION

Recently, bamboos have emerged as the most important non-wood forest produce in the country, playing an important role in the rural economy. The natural forests have been the main source of bamboos. Over the years, bamboo resources have dwindled considerably from the natural habitats due to over-exploitation, gregarious flowering and other biotic and abiotic pressures. Since, further extension of the area under production forestry in the State is not possible, restocking of bamboo forests by regeneration, afforestation and rehabilitation of degraded bamboo growing areas is the only alternative. Hence, augmenting the stand productivity by intensive management of the existing bamboo stands and also by undertaking underplanting with bamboos in teak plantations and understocked soft wood/miscellaneous plantations is being taken up.

Due to lack of information on diseases affecting bamboos, it made difficult to assess the role of diseases and their impact on seedling production, stand establishment and stand productivity. As protection of bamboo stands from diseases is the most important part of the production oriented stand management, a thorough knowledge on this limiting factor is indispensable for boosting the stand productivity. Forest disease survey is aimed at periodical or continuous surveillance of forest stands with the objectives (i) to assess the disease situations, generally, (ii) to detect or even predict disease outbreaks, (iii) to assess the actual and potential threat of diseases, appraise damage and diagnose the cause with a view to suggest measures to control them. Above all, disease survey forms the factual basis for assigning priorities for intensive research on

specific disease problems. In India, Bakshi *et al.* (1972) initiated the first forest disease survey. Later, in Kerala, Sharma *et al.* (1985) conducted a systematic disease survey covering a large number of industrially important forest plantation species. Unfortunately, the above syrveys excluded bamboos. In the present study, disease survey carried out during 1987-'92 has generated a wealth of qualitative as well as quantitative data on diseases of bamboos in nurseries, plantations and natural stands. This disease survey has also led to identify economically important diseases and to conduct intensive research on web blight, the most important nursery disease of bamboos caused by *Rhizoctonia solani*.

## DISEASE SURVEY

The disease survey carried out in representative bamboo plantations (8), natural stands (14), nurseries (27), bamboo trial plots, Bambusetum, etc., facilitated a comprehensive coverage of as many bamboo species as possible grown in Kerala, and also to record a large number of diseases of bamboos of both major or minor significance. The survey records a total of 40 pathogenic diseases including one of unknown etiology, possibly a virus, affecting different species of bamboos in nurseries, plantations and natural stands. Altogether 37 fungi and one mycoplasma-like organism (MLO) are found associated with these diseases (Table 5.1). Of these 30 fungal pathogens, including ten hitherto undescribed species and one MLO, are recorded for the first time on bamboos; 17 fungi including ten hitherto undescribed species are recorded for the first time from India. Of these eight fungal pathogens are common to nursery, plantation and natural stand, whereas 20 fungi are common both in plantations and natural stands. Six fungal pathogens and one of unknown etiology (possibly a virus) restricted their occurrence in

Table 5.1: List of pathogens recorded on different species of bamboos during the survey in Kerala and their status

| Sl. No. | Pathogen | Nursery | Planta-tion | Natural stand | New pathogen record for bamboos | First record from India | New species |
|---|---|---|---|---|---|---|---|
| 1. | *Alternaria alternata* | + | + | + | + | | |
| 2. | *Apiospora* sp. | | + | | | | |
| 3. | *Ascochyta* sp. | | + | + | + | + | + |
| 4. | *Balansia linearis* | | | + | + | + | |
| 5. | *Bipolaris* sp. | + | + | + | + | + | + |
| 6. | *B. maydis* | + | + | + | + | | |
| 7. | *B. urochloae.* | + | | | + | + | |
| 8. | *Botryobasidium salmonicolor* | | + | + | + | | |
| 9. | *Chaetospermum carneum* | | + | + | + | + | |
| 10. | *Coccodiella* sp. | | + | + | + | + | + |
| 11. | *Colletotrichum gloeosporioides* | + | + | + | | | |
| 12. | *Curvularia lunata* | | + | + | + | | |
| 13. | *C. pallescens* | + | | | + | | |
| 14. | *Dactylaria* sp. | + | + | + | + | + | + |
| 15. | *Dasturella divina* | + | + | + | | | |
| 16. | *Exserohilum holmii* | + | + | + | + | + | |
| 17. | *E. rostratum* | + | + | + | + | | |
| 18. | *Fusarium equiseti* | | + | + | | | |
| 19. | *F. moniliforme* | + | | | + | | |
| 20. | *F. moniliforme var.intermedium* | | + | + | + | | |
| 21. | *F. oxysporum* | + | | | + | | |
| 22. | *F. pallidoroseum* | | + | + | | | |
| 23. | *Pestalozziella* sp. | | + | + | + | + | + |
| 24. | *Petrakomyces indicus* | | + | + | | | |
| 25. | *Phoma* sp. | | + | + | + | + | + |
| 26. | *P. herbarum* | | + | + | + | | |
| 27. | *P. sorghina* | | + | + | + | | |
| 28. | *Phomopsis* sp. | | + | + | + | + | + |
| 29. | *Phyllachora ischaemi* | | + | + | + | + | |
| 30. | *P. longinaviculata* | | + | + | + | + | |
| 31. | *P. shiraiana* | | + | + | | | |
| 32. | *Pythium middletonii* | | + | | + | | |
| 33. | *Rhizoctonia solani* | + | | | + | | |

contd.

Table 5.1: contd.

| | | | | | | |
|---|---|---|---|---|---|---|
| 34. *Rhizostilbella hibisci* | + | | | + | + | |
| 35. *Rosenscheldiella* sp. | | + | + | + | + | + |
| 36. *Septoria* sp. | | + | + | + | + | + |
| 37. *Stagonospora* sp. | | + | + | + | + | + |
| 38. MLO | | | + | + | | |
| 39. Unknown etiology | + | | | | | |
| Total | 15 | 30 | 30 | 31 | 17 | 10 |

nurseries, whereas one fungus causing witches' broom and MLO causing little leaf recorded exclusively in natural stands. Since, the survey was exhaustive and intensive, it facilitated to assess the overall impact of diseases on bamboo production, besides it helped to expand the host list of pathogen(s) earlier recorded on bamboos. Majority of the pathogens recorded on bamboos are already established on a number of forestry as well as agricultural crops in the State. However, the pathogens like *Bipolaris urochloae, Exserohilum holmii, Rhizostilbella hibisci, Dactylaria* sp., *Balansia linearis*, etc. are new ones.

Diseases in bamboo nurseries

In Kerala, seeds serve as the main source of propagule for raising bamboo nurseries. Usually, forest nurseries are raised close to either forest or agricultural fields, that may provide source of infection as well as conditions favourable for disease intensification. The spatial distribution of forest nurseries in the State as well as the species grown in a nursery during a particular year, determined mainly by logistic considerations, have also important implications for

conditions governing the incidence and spread of disease in the nurseries.

Disease survey in 27 bamboo nurseries situated in 18 localities during 1987-'92 revealed a total of 13 seedling diseases affecting 12 species of bamboos. The disease incidence and severity vary among localities depending on the microclimatic conditions, age of seedlings and the nursery practices. Seedlings of *B. bambos*, raised on a large-scale throughout the State, are found affected by most of the diseases recorded. *Rhizoctonia solani*, a facultative pathogen, has come to the forefront as the most destructive major nursery pathogen of bamboos causing four nursery diseases viz., damping-off, seedling spear rot, seedling wilt and web blight. Among these web blight is the most widespread and economically important disease capable of causing high mortality under conducive microclimatic conditions. Due to seriousness of the web blight and different strains of *R. solani* being associated with it, detailed study on its management was undertaken which is discussed later. Though, web blight has been recorded on various other forestry species in the country, it is a new disease record for bamboos.

Among the foliar diseases, leaf rust caused by *Dasturella divina* is an important disease recorded in bamboo nurseries. It causes considerable loss of nursery stock due to severe infection as recorded at Chandhanathodu during 1991-'92. The sudden outbreak of leaf rust in a nursery at Chandhanathodu, where bamboo seedlings were raised for the first time during the past two decades, indicates the potential of the rust pathogen. *D. divina* is being recorded for the first time from Kerala as well as it is a new pathogen record on *Thyrsostachys siamensis* and *Dendrocalamus brandisii*. Though, *D. divina* was recorded on bamboos in India long time back there is not much information available on this pathogen. Considering the serious nature of the

disease in Kerala, epidemiology of the leaf rust and control measures are needed. *Bipolaris maydis, B. urochloae, Bipolaris* sp., *Exserohilum rostratum* and *E. holmii*, which cause leaf blight and leaf spot diseases of minor significances are also new pathogen records. Other new disease records include an undescribed species of *Dactylaria* causing leaf infection, and leaf stripping and stunting of bamboo seedlings caused by an unknown etiology, possibly a virus. The symptoms, occurrence and spread of the latter indicate that it is possibly transmitted through seeds. Since, information on seed transmitted diseases of tropical forestry species is lacking, the leaf stripping and stunting disease of bamboo seedlings offers detailed investigations.

The survey has clearly demonstrated that there is a heavy pressure of different types of diseases of bamboo seedlings in Kerala which affect them to varying degrees depending upon the various factors including microclimatic conditions in the nursery, seedling age, etc. Nurseries located in the high rainfall areas of the State (Wynad Forest Divn.) recorded high disease severity as well as maximum number of diseases; intensive observations at periodic intervals possibly helped to record numerous diseases. In general, high incidence and spread of diseases in certain bamboo nurseries, which resulted in heavy mortality of seedlings, appears to be mainly due to the improper nursery practices followed. As pre-treatment of seeds can minimize the incidence of damping-off, this has to be followed prior to sowing. Many of the nursery diseases can be checked by adopting proper nursery management practices, and prophylactic chemical control measures depending on the local climatic and edaphic conditions. The control measures to be adopted in a particular nursery have to be specific for a particular disease e.g. the strategy for web blight control may prove to be ineffective against the leaf rust.

**Diseases in plantations and natural stands**

A total of 27 pathogenic diseases caused by 32 different fungi belonging to 23 genera and one mycoplasma-like organism (MLO) are recorded from bamboo plantations and natural stands. Most of these diseases are common in plantations and natural stands; witches' broom and little leaf diseases occur exclusively in natural stands while rhizome rot occurs only in young plantations. The diseases affect all the parts viz., rhizome, root, culm, sheath, branch and foliage, but their incidence, severity and spread vary in plantations and natural stands depending on the bamboo species, the microclimatic conditions prevailing in the locality and cultural and management practices followed; in natural stands, where bamboo clumps are left unmanaged, the disease incidence is high possibly because of the incidence of annual ground fire and activities of wild animals.

In bamboo plantations and natural stands, rot of emerging and growing culms caused by *Fusarium moniliforme* var. *intermedium* and *F. equiseti*, respectively are the most widespread and economically important diseases affecting the stand productivity considerably. The former disease is soil-borne affecting the emerging culms of 15 to 30 cm in height, while the latter is an air-borne disease, probably predisposed by the injuries made by the sap sucking insect, *Purohitha cervina* on the growing and expanding culms. Though, emerging culms of seven species of bamboos are affected by the disease, *B. bambos*, the widely occurring species in the State, is the one severely affected. These culm diseases recorded in the present study are different from the bamboo blight, the most dreaded disease of bamboos earlier recorded from Bangladesh and recently from coastal belts of Orissa in India, in etiology and symptomatology. Rot of emerging and growing culms have to be treated as potential diseases of bamboos, as they affect the stand productivity as well as pose threat to the

establishment of young bamboo plantations. But, considering the practical problems involved, it may not be easy to control them in natural stands.

Rhizome rot, though recorded only in a few plantations may pose problem in young plantations during the establishing phase. As the study indicates, the mechanical injuries during and after the planting, predispose the fungal infection, the planting stock have to be handled properly in order to minimize the disease hazards. Witches' broom and little leaf diseases which occur exclusively in natural stands are new disease records as well as pathogen records on bamboos. Though, witches' broom caused by *Balansia linearis* is widespread in reed bamboo growing areas, the overall disease incidence and severity at present are low; since, the disease appears to be systemic and the inoculum is produced in large quantities in the affected areas, possibility of its further spread attaining economic dimensions can not be ruled out. Little leaf of *D. strictus* occurring in the dry tracts of the State is found to be caused by MLO. It also affects the stand productivity considerably. The present study shows that more than 90 percent of the clumps of *D. strictus* in the plots at Mannarkkad Forest Division succumbed to little leaf infection with a medium severity. Since, the disease incidence of little leaf is very high, further detailed investigations on its nature of spread, epidemiology and control measures are needed, so that appropriate measures may be adopted, should it become a serious problem in future.

Branch die-back caused by *Fusarium pallidoroseum* and thread blight caused by *Botryobasidium salmonicolor* are the other important diseases recorded both in plantations and natural stands. Though, the severity of branch die-back is low in all the areas surveyed, percent incidence is comparatively high in plantations affecting mostly the new culms. Thread blight is found widespread both in plantations and natural

stands, especially in the high rainfall areas of the State affecting more than 15 species of bamboos. Necrosis of culm internodes caused by *Curvularia lunata* is encountered only in a plantation of *Thyrsostachys oliveri* and the disease is unimportant since it affects only the culms emerged late in the season.

Among the foliar diseases affecting the bamboos in plantations and natural stands, foliage blight caused by *Bipolaris maydis* and *Bipolaris* sp., and leaf rust caused by *Dasturella diviana* are widespread which affect most of the bamboo species in the State. *B. maydis* and *Bipolaris* sp., the foliar pathogens recorded in bamboo nursery cause infection in plantations and natural stands. Similarly, *D. divina*, the leaf rust pathogen recorded in nursery seedlings, also cause infection of 14 species of bamboos in plantations and natural stands. Among these, *B.bambos, B. vulgaris, B. ventricosa, O. monostigma* and *D. strictus* are the severely affected bamboos; eleven bamboo species are new host record for the leaf rust.

Since, the disease survey was carried out extensively for a period of five years, quite a large number of fungi causing diseases of minor importance also could be recorded. Altogether 22 species of fungi belonging to 17 genera causing leaf spot, culm sheath spot, culm staining and die-back were recorded. Leaf spot diseases of minor significance are found to be caused by 20 different species of fungi belonging to 15 genera. Among these, *Exserohilum rostratum, E. holmii, Dactylaria* sp., *Colletotrichum gloeosporioides* are widespread in occurrence in bamboo plantations and natural stands in the State. These fungi are also recorded as causing seedling diseases in bamboo nurseries.

Disease survey in plantations and natural stands clearly demonstrated that the bamboo species raised in plantations as well as

growing in natural stands are equally vulnerable to various diseases. Diseases like little leaf and witches' broom are found host specific and occur only in natural stands. The former disease restricted in dry tracts of the State, affects the stand productivity to a great extent, while the latter is widespread and occurs in almost all the reed bamboo growing areas of the State; on account of its serious nature, the witches' broom disease may pose threat to culm production in future. Among the culm diseases, rot of emerging culms, which occurs in most of the bamboo species surveyed, is the economically important disease affecting the stand productivity considerably. The incidence and severity of the disease vary depending on the bamboo species and locality. A detailed study on the epidemiology and disease management is warranted. Since, rot of growing culms in plantations and natural stand is predisposed by the injury caused by the sap sucking insect, disease incidence can be managed by taking appropriate steps in reducing the build up of the insect population in the plantation or natural stand during the period of culm production. Among the bamoo species raised in plantations, *T. oliveri* is affected by only a few pathogens that too of minor significance. This may possibly be due to the resistant nature of the species as well as the proper stand managemnet. In general, the severity of culm diseases is recorded low in plantations than in natural stands where bamboos are unmanaged. These observations suggest that by proper stand management the disease can be minimized to a greater extent.

The wide spectrum of pathogens of both major or minor significance found associated in the nursery, plantation and natural stand indicates that bamboos are very susceptible to various diseases, and possibly because of their peculier growth habit and phenology, the impact of diseases is not very evident.

## MANAGEMENT OF RHIZOCTONIA WEB BLIGHT

In bamboo nurseries, Rhizoctonia web blight, has emerged as a widespread and economically important disease. It is capable of causing considerable seedling mortality and thereby affects the planting programme. Since, etiology and epidemiology of a disease form one of the important components of the disease control strategy, detailed investigation on various aspects were carried out leading to the control of the disease in forest nurseries.

In nature, *R. solani* occurs as an aggregate of strains which differ in cultural characteristics, physiology and virulence. From India, this is the first attempt on anastomosis grouping of *R. solani* affecting forestry species. Web blight of bamboos is found to be caused by *R. solani* belonging to AG 1-IA, AG 1-IC and AG 2-2IV. Studies on growth, cultural characters and relative virulence of selected isolates of *R. solani* reveal a great deal of variation among the isolate of different anastomosis groups and within the same anastomosis group which suggests that these characters alone cannot be depended upon for strain differentiation. Considerable variation in utilization of different carbon and nitrogen sources as well as resistance to different fungicides is also observed in *R. solani* isolates belonging to the same as well as different anastomosis groups. Slow growing isolate of *R. solani* exhibits high virulence than the fast growing ones. In general, the results on anastomosis grouping, growth and virulence of bamboo isolates of *R. solani* reveal that the fast growth has no bearing on virulence and isolates belonging to the same anastomosis group exhibit different growth rates, cultural characteristics as well as virulence. It seems that from the taxonomical point of view, anastomosis grouping may be the most acceptable way of differentiating the *R. solani* isolates in the natural population. However, the varying degrees of virulence

exhibited by the isolates belonging to the same anastomosis group poses problem in effective disease mangement.

As the pathogen as well as disease exhibit complexity, various approaches were attempted to manage it. In an experimental bareroot nursery, raised at Chandhanathodu, cultural control, biocontrol and chemical control of web blight were studied. Cultural measures that reduce primary inoculum or minimize infection frequency and boost the growth and development of seedlings are often highly desirable and adaptable in forest nurseries. The results clearly demonstrate that shade over the seedbeds, water regime and seedling density in the seedbeds are the main factors influencing the disease incidence and severity. The present study also proves that area under disease progress curve (AUDPC) as an excellent measure of disease severity influenced by various nursery practices. By optimizing the cultural measures in the bamboo nurseries, web blight can be managed effectively to a great extent.

In India, this is the first attempt on biocontrol of disease in a forest nursery, employing the antagonistic organisms viz., *Trichoderma harzianum* and *T. viride*. Soil solarization, a noval approach to reduce the inoculum in the seedbeds and thereby minimizing the infection was also tried. However, the results of these biocontrol experiments in the nursery beds are not very promising as obtained in the *in vitro* and greenhouse experiments.

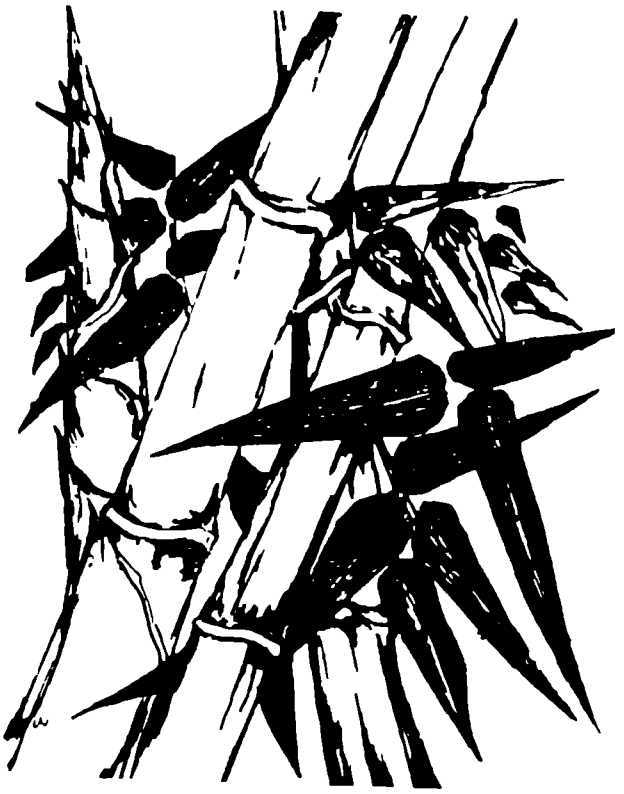
For chemical control, various fungicides screened in *in vitro* and in the nursery, a systemic fungicide, carboxin is found as the most effective one in affording protection to the bamboo seedlings from web blight. Though, mercurial fungicide, MEMC, was more effective than carboxin, its use in forest environment is not advisable due to pollution hazards and hence it is not recommended for the control of

web blight.

From the foregoing discussion on disease survey and nursery management of Rhizoctonia web blight of bamboos, the following conclusions can be drawn. Bamboos are vulnerable to a large number of diseases which affect them right from the germling stage in the nursery to clump stage in the plantation and natural stands. The survey recorded altogether 37 fungi, one mycoplasma-like organism (MLO) and a causal agent, possibly a virus, associated with various diseases of bamboos. Among these, 30 fungi including ten hitherto undescribed species and MLO are recorded for the first time on bamboos; 17 fungi including ten hitherto undescribed species are recorded for the first time from India. Of the nursery diseases, web blight caused by *R. solani* has emerged as the economically important disease causing considerable mortality of seedlings. Rot of emerging and growing culms caused by *F. moniliforme* var. *intermedium* and *F. equiseti*, respectively are the important diseases among the various diseases recorded in plantations and natural stands, which affect the stand productivity considerably. Little leaf caused by MLO and witches' broom of reed bamboos caused by *B. linearis* are the potential diseases of serious consequences which occur only in the natural stands.

*R. solani*, causing web blight of bamboos, belongs to different anastomosis group viz., AG1-IA, AG1-IC, AG2-2IV. It shows variation in growth, cultural characteristics, carbon and nitrogen utilization, virulence, resistance to different fungicides and antagonistic organisms. Studies on management of web blight incorporating biological, cultural and chemical control reveal that biocontrol employing antagonists (*T. harzianum*, *T. viride*) as soil amendment and seed treatment and solarization of seedbeds does not appear to be very promising solution in forest nurseries in managing the web blight.

Cultural control by manipulating shade over the seedbeds (without shade), reducing seedling density (<165 g $m^{-2}$), and regulating water regime in the seedbed (10 l $m^{-2}$ per day) not only reduces the disease incidence and spread but also results in healthy vigorous seedlings. By optimizing the cultural measures along with prophylactic fungicidal application (carboxin 0.2% a.i.) after 7 and 21 days of seedling emergence, web blight in bamboo nurseries can be effectively managed.



# SUMMARY

# 6. SUMMARY

Bamboos are regarded as one of the most important non-wood forest produce mainly due to their fast growth, adaptability to different eco-climatic conditions and myriads of end uses. Improper stand management, unscientific harvesting together with over-exploitation have resulted in depletion of the bamboo resource bases in many States. In Kerala, *Bambusa bambos, Dendrocalamus strictus* and *Ochlandra* spp. (reed bamboos), which occur extensively in natural stands, are the commercially exploited bamboos. Of these, only *B. bambos* and *D. strictus* are raised in plantations on a large-scale.

Besides the biotic interference, disease are considered to be one of the important factors limiting the growth and stand productivity. Since there was no information available on diseases of bamboos in Kerala, a systematic disease survey was carried out during 1987-'92, in bamboo nurseries, plantations and natural stands in Kerala state to assess the incidence and severity of diseases and their economic importance. As Rhizoctonia web blight was found to be the most economically important disease in nurseries affecting the bamboo seedlings, a detailed investigation was carried out on its management by employing cultural, biological and chemical measures.

The results of the disease survey are presented in the first part of the thesis and that of management of web blight in the second part. Diseases in bamboo nurseries, plantations and natural stands are described under disease survey, while characterization of isolates of the web blight pathogen, *Rhizoctonia solani*, their relative virulence, utilization and growth in different carbon and nitrogen sources, their responses to antagonistic organisms and different fungicides, and

nursery trials related to the management of web blight are dealt with in the second part.

## DISEASE SURVEY

### Bamboo nurseries

A total of 27 bamboo nurseries, comprising of *Bambusa bambos, B. vulgaris, Dendrocalamus brandisii, D. longispathus, D. membranaceus, D. strictus, Ochlandra travancorica, O. scriptoria, O. wightii, Phyllostachys pubescens, Thyrsostachys oliveri* and *T. siamensis*, raised in 18 different localities in the State, were surveyed during the period 1987 to 1992. Thirteen seedling diseases were found to affect both bareroot (in the seedbed) as well as container seedlings at different growth phases. With these diseases, altogether 14 fungi belonging to 11 genera were found associated; one disease, seedling foliage stripping and stunting was of unknown etiology, possibly caused by a virus. Of the 14 fungi recorded as the causal organisms of various diseases in bamboo nurseries, *Rhizoctonia solani* emerged as the most dominant nursery pathogen, causing four diseases viz., damping-off, seedling spear rot, seedling wilt and web blight at different growth phases of bamboo seedlings.

Damping-off was the first disease which appeared in the seedbed nursery. With pre-emergence damping-off, *Fusarium moniliforme* and *F. oxysporum* were associated, while post-emergence damping-off was mainly caused by *Rhizoctonia solani* state of *Thanatephorus cucumeris*. Another disease caused by *R. solani* was seedling spear rot which affected emerging seedling plumule. The disease occurred within two to five days of emergence. *R. solani* also caused seedling wilt of 20- to 40-day-old bareroot as well as container seedlings of *B. bambos* and *D.*

*strictus*. The disease resulted in physiological wilting due to browning and decay of feeder roots, and severe canker at the basal stem.

Web blight caused by *R. solani* affected 20- to 30-day-old seedlings of *B. bambos, D. strictus, D. brandisii,* and *T. siamensis*. Multiple infections of seedling stem, leaf sheath and leaf by mycelial web of *R. solani* resulted in mortality of the affected seedlings. The disease was widespread in nurseries and the disease severity ranged from low to medium; highest disease severity index (DSI) of 1.25 was recorded in a nursery at Periya (South Wynad Forest Divn.) during 1990-'91.

Of the foliage diseases affecting nursery seedlings, leaf rust caused by *Dasturella divina* was widespread in occurrence which was recorded on seedlings of almost all the bamboo species raised in nurseries in the State. Both uredinial and telial stages were observed on bamboo seedlings. In a *B. bambos* nursery at Chandhanathodu, cent percent rust incidence was recorded during 1991-'92. Severe infection occurred in 8-month-old seedlings and 14 seedbeds were completely devastated by the disease. *Bipolaris maydis, B. urochloae* and *Bipolaris* sp. caused leaf blight of *B. bambos, D. brandisii, D. membranaceus, D. strictus, O. wightii, T. siamensis* and *P. pubescens*. *Exserohilum holmii* and *E. rostratum* caused leaf spot on *B. bambos, D. strictus* and *P. pubescens* seedlings. Some of the leaf spot diseases of minor importance were caused by *Dactylaria* sp., *Colletotrichum gloeosporioides, Alternaria alternata* and *Curvularia pallescens*.

Seedling rhizome rot of *B. bambos* caused by *Rhizostilbella hibisci* state of *Nectria mauritiicola* was recorded in container seedlings. The disease caused four to five percent seedling mortality in the nursery. The pathogen attacked rhizome buds and surrounding tender tissues. The

incidence of leaf stripping and stunting of bareroot as well as container seedlings of *B. bambos* was found to be up to 5.60 percent. The symptoms of the disease were found characteristic of those produced by a virus.

**Bamboo plantations and natural stands**

Disease survey was conducted in 22 representative plots selected in eight bamboo plantations and 14 natural stands and various trial plots in the State during 1987 to 1991. A total of 27 pathogenic diseases caused by 32 fungi and one mycoplasma-like organism (MLO) were recorded. Of these only rhizome bud rot occurred exclusively in plantations, while witches' broom and little leaf diseases were recorded only in natural stands. Rest of the diseases were found both in plantations as well as natural stands.

In plantations and natural stands, diseases affected almost all the plant parts such as underground rhizome, emerging culm, growing culm, culm sheath, foliage, and branches. In one-year-old *B. bambos* plantations, rhizome bud rot caused by *Pythium middletonii* resulted in 15.62 percent to 71.42 percent mortality.

Witches' broom disease caused by *Balansia linearis* was widespread in the reed bamboo growing areas of the State and was recorded on *Ochlandra travancorica, O. travancorica* var. *hirsuta, O. scriptoria* and *O. ebracteata*; the disease incidence varied from 5.98 to 24.65 percent. Little leaf disease, which produced a large number of abnormal highly reduced bushy shoots from the nodes of the newly emerged culms of *D. strictus*, was recorded in natural stands in the dry tracts of the State. The disease severity ranged from low to medium and percent disease incidence varied from 9.30 to 90. The

disease affected the stand productivity considerably. Histopathological, fluorescence and transmission electron microscopic studies of diseased and healthy tissues of *D. strictus* showed presence of MLO in the phloem of diseased tissues. Tetracycline hydrochloride ($0.5g\ ml^{-250}$) therapy showed temporary remission of disease in the treated shoots for a period of three months.

Rot of emerging culms caused by *Fusarium moniliforme* var. *intermedium* occurred both in plantations and natural stands and was widespread in the State. In *B. bambos* plantations, disease incidence was low, ranging from 4.03 to 15.11 percent during 1988-'91. On the contrary, in natural stands, the disease incidence was comparatively high (33.69%). Among the bamboo species surveyed, *B. bambos, D. longispathus* and *D. strictus* were the most affected species. Since, the disease affected the culm production in plantations and natural stands, it was treated as an economically important one.

Rot of growing culms caused by *Fusarium equiseti* was observed both in bamboo plantations and natural stands. In plantations, highest percent incidence of 12.12 was recorded during 1988. In natural stands the disease incidence was comparatively low; however, in *B. bambos* plots at Noolpuzha, 14.65 percent disease incidence was recorded during 1989. In a Bambusetum at Nilambur, five species of bamboos viz., *B. balcooa, B. bambos, B. polymorpha, D. longispathus* and *D. strictus* were found affected with the disease. The infection was predisposed by injuries made by the sap sucking insect, *Purohitha cervina* on the culm sheaths at the nodal region. As the disease affected culm production and caused deformity to culms both in plantations and natural stands, it was considered as a potential one.

Die-back of branches caused by *Fusarium pallidoroseum* was recorded in *B. bambos* and *D. strictus* in plantations as well as natural stands.

Severe infection occurred in young developing clumps (2- to 3-year-old) of *D. strictus* and *B. bambos*. Though, the disease severity was low in all the plots surveyed, percent disease incidence was found comparatively high in plantations than natural stands. *Curvularia lunata* caused necrosis of culm internodes in plantation of *T. oliveri*; disease incidence was low and usually affected the late emerged culms.

Thread blight caused by *Botryobasidium salmonicolor* affecting foliage, culms and branches was recorded from almost all the bamboo species surveyed in plantations and natural stands. Disease severity was low in all the localities surveyed. In a Bambusetum at Nilambur, of the eleven species of bamboos affected with the disease, *B. vulgaris* recorded medium severity with >94 percent disease incidence during the years 1990 and 1991. Free water on the plant surface and high ambient humidity favoured the mycelial growth of the fungus on the host and spread of the disease.

Foliage blight caused by *Bipolaris maydis* and *Bipolaris* sp. occurred in plantations as well as in natural stands. The disease affected most of the bamboo species surveyed. Disease severity was low in all the plots except in a plantation at Nilambur where it was found to be medium during the years 1990 and 1991 with percent disease incidence of 97.05 and 80.39, respectively.

*Dasturella divina*, causing leaf rust, was widespread in bamboo plantations and natural stands surveyed. *B. bambos* and *D. strictus* were the severely affected species in natural stands and plantations, while *B. bambos, B. ventricosa, B. vulgaris, D. strictus* and *Oxytenanthera monostigma*, suffered most in trial plots. More than 14 species of bamboos were found affected by the rust.

There were several foliar diseases of minor significance caused by various fungi which were also recorded on different species of bamboos in plantations and natural stands. A total of 17 such diseases were recorded on different species of bamboos with which twenty two species of fungi belonging to 17 genera were found associated. These diseases include, Exserohilum leaf spot caused by *Exserohilum holmii* and *E. rostratum*, zonate leaf spot caused by *Dactylaria* sp., leaf spots caused by *Colletotrichum gloeosporioides*, *Ascochyta* sp., tar spot caused by *Phyllachora longinaviculata*, *P. shiraiana* and *P. ischaemi*, leaf spots caused by *Petrakomyces indicus*, *Phoma sorghina*, *P. herbarum*, *Phoma* sp., *Phomopsis* sp., *Stagonospora* sp., *Septoria* sp., *Chaetospermum carneum*, *Curvularia lunata*, leaf tip blight caused by *Alternaria alternata*, leaf spots caused by *Rosenscheldiella* sp., *Coccodiella* sp., culm sheath spot caused by *Pestalozziella* sp., and culm staining and die-back caused by *Apiospora* sp.

**MANAGEMENT OF RHIZOCTONIA WEB BLIGHT**

High mortality of bamboo seedlings due to web blight, a component of the disease complex caused by *R. solani*, necessitated its management in the nursery to circumvent loss of planting stock. However, possible occurrence of different strains of *R. solani* within the given population posed practical challenge in successful management of this pathogen. Hence, studies were carried out in the laboratory to characterize the *R. solani* bamboo isolates and to select promising antagonists as biocontrol agents and fungicides for screening in the nursery.

## LABORATORY TRIALS

### Anastomosis grouping

Fifty six isolates of *R. solani*, obtained from 15 bamboo nurseries surveyed in the State, were screened against the authentic tester isolates of *R. solani* received from Dr. A. Ogoshi, Hokkaido University, Japan. The bamboo isolates belonged to different anastomosis groups viz., AG1-IA (28), AG1-IC (17) and AG2-2IV (9), the most widespread group in bamboo nurseries being AG1-IA.

### Cultural characters and linear growth of *R. solani* isolates

Based on the morphological and cultural characters, all the *R. solani* isolates could be separated into five distinct groups. One isolate each from these groups was selected (RS1,RS2,RS3, RS4,RS5) for further studies. Colony characters of these isolates on PDA medium varied from submerged to cottony growth and colour from whitish brown to dark brown. Isolate RS1 and RS2 produced scanty, small sclerotia (0.25-0.80 mm dia), whereas RS4 and RS5 produced abundant large (1.0-4.0 mm dia) dark brown to blackish brown sclerotia. Among the five isolates, the growth of RS4 was the fastest, attaining a diameter of 90 mm within 46 h (2.16 mm $h^{-1}$) and isolate RS3 the slowest, attaining a diameter of 66.2 (1.45 mm $h^{-1}$) within the same duration.

### Relative virulence of *R. solani* isolates

Five isolates of *R. solani* were selected on the basis of cultural and morphological characteristics. The symptoms produced and the disease severity in respect of these isolates varied appreciably in bamboo seedlings. Isolate RS3 was found to be the most virulent one

which resulted in 42.94 percent seedling infection and mortality of the affected seedlings within 7 to 10 days of infection, while least virulent isolate RS1 caused only 4.53 percent seedling infection.

**Utilization of carbon and nitrogen sources by *R. solani* isolates**

For differentiating the selected five *R. solani* isolates into possible strains, on the basis of utilization of carbon (C) and nitrogen (N) sources, ten carbon and 12 nitrogen sources were screened. All the C and N sources supported better growth of all the five RS isolates than the control without C or N sources. However, significant variation occurred among the five RS isolates in utilizing the C or N sources; interaction of RS isolates and different carbon and nitrogen sources was significant at P=0.05. A cluster analysis revealed three distinct groups of RS isolates viz., RS1 and RS4, RS3 and RS5, and RS2, based on the utilization of different C and N sources.

**Screening of *Trichoderma harzianum* and *T. viride* against *R. solani* isolates**

For selecting most efficient antagonistic organisms as biocontrol agents, four different isolates each of *Trichoderma harzianum* and *T. viride* were screened against five *R. solani* bamboo isolates by Petri dish bioassay and slide culture technique. In Petri dish bioassay, interactions were observed in all the five *R. solani* isolates. In the slide culture, hyphal parasitism of all the five RS isolates by all the isolates of *T. harzianum* and *T. viride* was observed. Among the antagonists, *T. harzianum* (TH4) isolate and *T. viride* (TV3) showed highest percent hyphal interaction against all the five *R. solani* isolates.

Biocontrol of web blight employing *T. harzianum*(TH4) and *T. viride* (TV3) by soil amendment and seed treatment was carried out in the greenhouse. When *T. harzianum* (TH4) and *T. viride* (TV3) were used as amendment in soil infested with different *R. solani*, percent seedling infection was low (2.64 to 6.30) as compared to control (5.31 to 42.49). In seed-coating experiment, *T. harzianum* (TH4) was more effective in reducing the percent seedling infection (av.2.50) than *T. viride* (TV3) (av. 3.18) in all the treatments involving five *R. solani* isolates, except isolate RS5. *T. harzianum* (TH4) was proved more efficient than *T. viride* (TV3) in checking the web blight.

**_In vitro_ evaluation of fungicides against *R. solani* isolates**

For the chemical control of web blight, various fungicides were screened in the laboratory against five different *R. solani* bamboo isolates employing poison-food technique (PFT) and soil fungicide screening technique (SFST). Among the ten fungicides screened at different concentrations employing PFT, MEMC (0.003% a.i.), PCNB (0.2% a.i.), carboxin (0.05% a.i.), and metalaxyl + mancozeb (Ridomil) (0.1% a.i.) inhibited completely the growth of all the five RS isolates. Of the five fungicides (carboxin, carbendazim, Ridomil, MEMC, PCNB) screened employing SFST, MEMC (0.006% a.i.), carboxin (0.2% a.i.) and carbendazim (0.2% a.i.) were the most effective fungicides, as cent percent inhibition of growth was recorded for all the five RS isolates.

## NURSERY TRIALS

An experimental bamboo nursery, consisting of 80 seedbeds (4 x 1 x 0.25 m), was raised at Chandhanathodu, Wynad during 1991-1992. Studies on the effect of various cultural practices on incidence and severity of web blight, and biocontrol and chemical control of the diseases were carried out.

## CULTURAL CONTROL OF WEB BLIGHT

### Shade, soil water potential and seedling density

Web blight of bamboos, caused by *R. solani*, was recorded in seedbeds after 15 to 18 days of seedling emergence. Types of shade used over the seedbeds, different water regimes and seed rates influenced the incidence and severity of web blight. Different seed rates had significant effect on the disease incidence and also the disease severity, measured as area under disease progress curve (AUDPC) using disease parameters viz., number of infection foci and number of diseased seedlings in the foci. Medium (330 g $m^{-2}$) and high (500 g $m^{-2}$) seed rate showed significantly high disease severity than low seed rate (165 g $m^{-2}$). Seedling density not only affected the seedling health but also seedling vigour. Comparatively higher disease incidence and AUDPC were recorded in seedbeds with high water regime (20 l $m^{-2}$) than those with low water regime (10 l $m^{-2}$). All the seedbeds with different seed rates and water regimes provided with coconut leaf thatch (CLT) shade showed comparatively higher disease incidence, higher AUDPC and low disease progress rate than those without shade. Disease progress rate determined for each treatment

combination using the exponential function taking into account both the disease parameters viz., number of infection foci and number of diseased seedlings in the foci separately showed almost similar trend. Correlation between the two disease parameters in determining AUDPC was found highly significant (r=0.9349) in the logarithmic scale. The results obtained by using AUDPC as a measure of disease severity over a period of time are comparable well with the disease progress rate. Thus, AUDPC provides an excellent and simple measure of disease severity influenced by various nursery practices.

**Effect of shade on growth of seedlings and their susceptibility to disease**

Seedling growth was considerably affected by the prevailing microclimatic conditions in the nursery such as light intensity, soil temperature and soil water potential which were governed by the nursery practices followed. Of these, shade over the seedbeds appeared to be the most important as seed germination and seedling emergence were much slower in CLT shaded beds than open beds. Shoot and root biomass of seedlings (90-day-old) were significantly high in seedbeds without shade (0.123 0. 054g) than CLT shaded beds (0.026 0. 013g). Formation of rhizome and emergence of new shoots from rhizome were only observed in seedlings in seedbeds without shade.

The incidence, spread and persistence of web blight in seedbeds were found to be correlated to the growth and development of bamboo seedlings. In CLT shaded beds, though, web blight appeared later than in open beds, the disease persisted for a longer period; poorly developed seedlings were killed outright due to infection. The study revealed that for minimizing the incidence and severity of web blight as well as for obtaining well developed vigourous bamboo seedlings,

appropriate sowing rate (<165 g $m^{-2}$) and water regime (10 l $m^{-2}d^{-1}$) have to be selected. Shade over the seedbeds was not at all required.

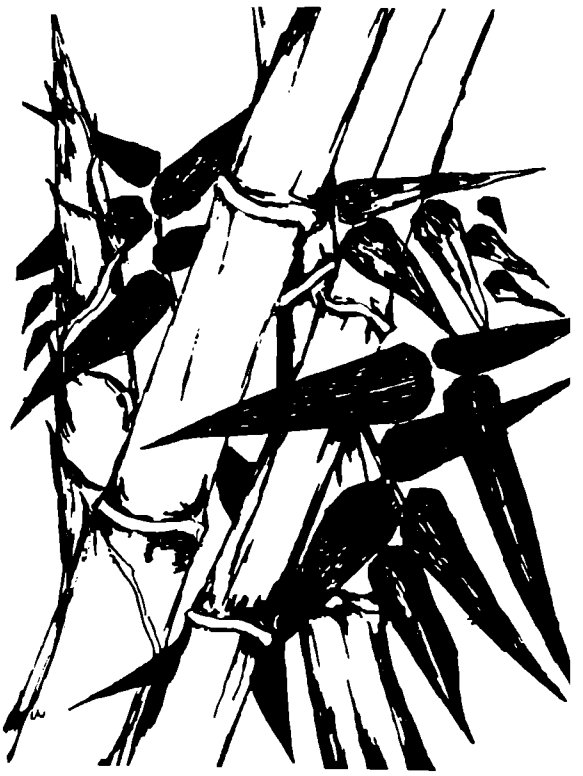
## BIOLOGICAL CONTROL OF WEB BLIGHT

Promising results were obtained in soil solarization treatment of seedbeds. Solarized seedbeds recorded an average maximum of 47°C at 2.5 cm soil depth, followed by 45°C at 5 cm and 41.5°C at 15 cm depth. Damping-off did not occur in any of the four solarized seedbeds. Though, web blight appeared in all the four solarized seedbeds, the disease incidence and severity as expressed by AUDPC were found much less than the control seedbeds. Average number of foci (4.25) and average number of seedlings affected (161.75), and respective AUDPC for these two parameters viz., 87.00 and 3000.00 were found significantly (P=0.05) different from the control.

Antagonistic organisms viz., *Trichoderma harzianum* (TH4) and *T. viride* (TV3) had considerable effect on the incidence and severity of web blight as well as other seedling diseases caused by *R. solani*. Damping-off did not appear in treatments of both the antagonists, while, web blight was recorded in the treated seedbeds; however, the disease incidence and severity were comparatively less than those of control. Average number of infection foci and number of diseased seedlings in the foci and their respective AUDPC were found to be comparatively less for *T. viride* in both soil amendment and seed coating than *T. harzianum*. This indicated that *T. viride* was more efficient than *T. harzianum*. Since, only partial disease suppression was observed through soil solarization and using of antagonistic microorganisms, the biocontrol method of disease control did not offer much promise.

## CHEMICAL CONTROL OF WEB BLIGHT

Of the six fungicides viz., MEMC, carboxin, carbendazim, Ridomil, thiram and mancozeb applied as soil drench in the seed beds, MEMC and carboxin were significantly effective in controlling the web blight of bamboos. Average number of infection foci and diseased seedlings in the foci in MEMC treatment were 1.00 and 16.00 with corresponding AUDPC 66.67 and 1557.00, respectively. In controls, the figures for AUDPC were 414.67 and 18890.67 respectively for number of infection foci and disease seedlings in the foci. Of the three replicate seedbeds treated with MEMC, two were completely free from the disease while the third had only very few disease patches. Of the three systemic fungicides viz., carboxin, carbendazim and Ridomil used in the nursery trial, carboxin was highly effective next to the mercurial fungicide. Mancozeb and thiram treatments were ineffective in controlling the web blight of bamboos. Since, the use of mercurial based fungicides is restricted in the sensitive habitat like forest nurseries due to their mammalian toxicity and possible environmental hazards, application of carboxin after 7 and 21 days of seedling emergence is much desirable in managing the web blight in bamboo nurseries.



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