Indian Phytopathology (2021) 74:639–647
https://doi.org/10.1007/s42360-021-00333-3

RESEARCH ARTICLE

Documentation and characterization of fungal diseases in nursery seedlings of teak (*Tectona grandis* L.f.) in Kerala, India

M. Kiran[1] · S. Gopakumar[1] · V. Reshmy[2] · K. Vidyasagaran[1]

Received: 3 June 2020 / Revised: 8 December 2020 / Accepted: 29 January 2021 / Published online: 2 March 2021

Abstract
Survey in three different seasons were conducted for collection and characterization of fungal diseases affecting nursery raised teak seedlings in central Kerala, India. Based on visual symptoms and morphological identification, nine diseases were recorded and among them six were first time records in teak from the state viz; leaf blight caused by *Curvularia eragrostidis,* leaf spots caused by *Macrophomina phaseolina* and *Botryodiplodia theobromae*, collar rot caused by *Alternaria alternata*, root rots caused by *Fusarium solani* and *Fusarium oxysporum*. Based on the investigation and assessment, leaf blight caused by *Curvularia eragrostidis* and root rot caused by *Fusarium oxysporum* were considered as two major diseases. Cultural as well as morphological characterization was made for each pathogen and molecular characterization was done for two major diseases causing pathogens. Weather correlation with disease occurrence was found to be significant for two diseases. *Curvularia* causing severe foliar disease was a new record since it was earlier reported as only of minor significance. The shift in disease spectrum due to increased virulence of minor pathogens should be further analyzed based on the changing climate scenario.

Keywords Teak · Nursery diseases · Weather correlation · Fungal pathogen

Introduction

The ability of tropical forests to mitigate climatic impacts is still largely being hampered by the rates of deforestation. By the end of this century, 1.5 °C increase in warming would likely happen through tropical deforestation even if all other sources of carbon emissions were to immediately stop (Mahowald et al. 2017). According to Kumari et al. (2019), forest cover in certain regions of India has declined although the increase by about 1% in country's forest cover for the year 2017 was reported. Government of India launched various afforestation schemes like Green India Mission (GIM) to improve quality of degraded forests as well as establishing more tree cover in non-forest areas through social and farm forestry. All these efforts need quality planting materials. But nursery diseases, especially by fungal pathogens affect planting stock production in moist tropical forest nurseries upsetting large scale afforestation programmes.

Tectona grandis L.f. commonly known as teak, is a highly durable and much priced major tropical timber yielding species naturally distributed in India and south-east Asian regions (Dadwal et al. 2013). In India, teak is used for various afforestation programmes on a large scale and fungal pathogens are a serious threat at nursery stages. Bakshi (1976) observed that in India, teak seedlings were suffering from various fungal nursery diseases like root rot (*Polyporus zonalis),* powdery mildews (*Uncinula tectonae*) and leaf rust (*Olivae tectonae*). According to Mohanan and Sharma (2005), forest nurseries in high rainfall areas like Kerala often seriously suffer from fungal diseases. Foliar diseases caused by *Curvularia* (Balasundaran 2002; Mohanan et al. 2004), *Alternaria* (Mohanan et al. 2010), *Colletotrichum* (Sharma et al. 1985; Mohanan, 2007) were reported from teak seedlings in Kerala. Collar rot of teak seedlings caused by *Rhizoctonia solani* (Ali and Florence 1994; Mohanan et al. 2010), *Fusarium solani* (Mohanan et al. 2010) were also recorded earlier from forest nurseries of Kerala. Fungal pathogens such as *Helicobasidium compactum* and

✉ M. Kiran
mohan.kiran959@gmail.com

1 Department of Natural Resource Management, College of Forestry, Kerala Agricultural University, Thrissur, Kerala, India

2 Department of Plant Pathology, College of Horticulture, Kerala Agricultural University, Thrissur, Kerala, India

Tritirachium roseum (Verma 2013), *Fusarium oxyporum* and *Rhizoctonia bataticola* (Tade and Bharathy 2011) were also reported to be causing teak root rot in nurseries in India.

Though fungal diseases in forest nurseries of Kerala were subjected to several studies (Balasundaran 2002; Mohanan et al. 1997, 2004, 2010), a rapidly changing climate affects the disease environment facilitating new pathogens and diseases. The importance of studying the influence of climate on the incidence and distribution of plant diseases need not be over emphasized (Yáñez-López et al. 2012). Since no recent studies on these lines in teak was available, a disease survey was conducted in the teak seedlings nurseries in central Kerala for evaluating the changes in disease spectrum with changing climate and characterization of the collected pathogens for developing better disease management strategies.

Materials and methods

Survey, collection and assessment of diseased samples

To study the occurrence of fungal diseases on teak seedlings, a purposive sampling survey was carried out in the government owned forest nurseries at Chettikkulam and Vellanikkara of Thrissur district, Kerala and nurseries at Pattambi, Chittur and Mekkalappara of Palakkad district of Kerala state. Diseased samples showing typical symptoms of fungal diseases were collected both from open and from poly houses. The survey was conducted during three periods, namely February–May, June–September and October–January (2016–2017) to get a complete profile on the occurrence of diseases prevailing in summer, rainy and winter seasons. The per cent disease incidence (PDI) for foliage, stem and root diseases was calculated by counting affected seedlings out of total seedlings expressed in percentage. Per cent disease severity (PDS) for foliage diseases except for obligate parasites was also documented using 0–5 scale (Nagarjun and Suryanarayanam 2016). The PDS index was used on the premise, namely Grade 0— No symptom, Grade 1— 0–1% leaf area affected, Grade 2— 1–10% leaf area affected, Grade 3— 11–25% leaf area affected, Grade 4— 26–50% leaf area affected, Grade 5— > 50% leaf area affected. The score chart of 0–3 scale developed by Sharma et al. (1985) was followed for assessment of severity of foliage diseases caused by obligate parasites which depicts Grade 0— No symptom, Grade 1— > 25% foliage affected, Grade 2— 25–50% foliage affected, Grade 3— >50% foliage affected. PDS for all foliage diseases was calculated by adopting the formula by Wheeler (1969). Symptoms observed under natural as well as artificial condition through inoculation of pathogen were recorded. Diseases recorded with higher PDI and PDS were tagged as major diseases. Similarly, the responsible pathogens for major diseases were considered as major pathogens.

Weather parameters

Data on maximum and minimum temperature, relative humidity and rainfall during the survey period were gathered separately for different locations of Thrissur and Palakkad districts from recognized government run weather stations. Using this, correlation of disease severity with different weather parameters were established and analyzed.

Isolation and pathogenicity test

Isolation, purification and storage of the pathogen from diseased samples were done. Pathogenicity of fungi was established by proving Koch's postulates through mycelial bit inoculation method, micro droplet inoculation technique and spore suspension method (Mishra and Dhar 2005; Munaut et al. 1997; Rocha et al. 1998).

Identification and characterization of pathogens

Identification of the isolates up to generic level was done based on cultural as well as morphological characters. For specific identification and confirmation, isolates were submitted to National Centre for Fungal Taxonomy (NCFT), New Delhi with different accession numbers. Molecular characterization by employing Internal Transcribed Spacers sequencing was also done for major pathogens at Rajiv Gandhi Centre for Biotechnology (RGCB), Thiruvananthapuram, Kerala. Standard protocols mentioned in Nucleospin Plant II Kit (Macherey–Nagel) were used for the study. ITS PCR primers ITS-1F (TCCGTAGGTGAA CCTGCGG) and ITS-4R (TCCTCCGCTTATTGATAT GC) were used for the amplification by adopting standard protocol (White et al. 1990). PCR amplification was using program 1st cycle at 96 °C for 2 min followed by 30 cycles at 96 °C for 30 s, 50 °C for 40 s and 60 °C for 4 min for all the primers. The sequence quality was checked using Sequence Scanner Software v1 (Applied Biosystems). Sequence analysis and nucleotide homology of the major pathogen were analyzed through the BLAST programme of NCBI (http://ncbi.nlm.nhm.gov/blast). These sequences were submitted to GenBank.

Statistical analysis

Data was subjected to analysis of variance (ANOVA) and data sets were analyzed using Statistical Package for Social Scientists (SPSS) version 21. Levels of significance, means and standard error were obtained for various data sets.

The data wherever needed was subjected to appropriate transformation.

Results and discussion

Symptomatology of fungal diseases

A total of nine fungal diseases in teak seedlings were observed from five nurseries. Six were foliar diseases, including a rust disease caused by obligate parasite. One disease from collar region and two root diseases were also recorded. Likewise an earlier survey on the fungal diseases of various plantation trees including teak in Kerala by Sharma et al. (1985) had observed 33 nursery diseases, among which, only 6 were found as stem, collar and root diseases. Based on symptoms, nine diseases were observed and categorized as leaf blight (LB) showing grey to blackish necrotic region from the margin spread across the leaf blade (Fig. 1a), leaf spot-1 (LS-1) showing small, rounded or irregular black necrotic spots between veinlet's (Fig. 1b), leaf spot-2 (LS-2) showing black, irregular spots near to midrib and veinlet's also in coalesced nature (Fig. 1c), leaf spot-3 (LS-3) showing chocolate brown, irregular, scattered spots and coalesced in certain areas (Fig. 1d), leaf spot-4 (LS-4) showing ash coloured irregular spots coalesced and spread throughout lamina (Fig. 1e), leaf rust showing orange yellow uredospore on the abaxial surface of the leaf (Fig. 1f), collar rot showing brownish discoloration of collar region, leaves gradually turned necrotic (Fig. 1g), root rot-1showing dark brown discoloration of tap root with necrotic leaves (Fig. 1h) and root rot-2 showing dark brown discoloration on lateral roots gradually spread on tap root (Fig. 1i). *Curvularia* leaf blight characterized by blackish necrotic region spread throughout the leaf balde. Similarly, Mohanan et al. (1997) reported, dark brown irregular necrotic spots spread across the lamina of teak seedlings due to *curvularia* sp. Symptoms of teak leaf rust recorded during the present study were also reported similarly by Pathak et al. (2015) from forest nurseries.

Fig. 1 Fungal diseases of *Tectona grandis* observed during the survey with symptom description. **a** Leaf blight, **b** Leaf spot-1, **c** Leaf spot-2, **d** Leaf spot-3, **e** Leaf spot-4, **f** Leaf rust, **g** Collar rot, **h** Root rot-1, **i** Root rot-2

Cultural and morphological characterization of pathogens

Cultural and morphological characters of each pathogen were described (Table 1; Fig. 2a–i). The description of *Curvularia eragrostidis* made by Archana (2014) from poplar leaf spot was comparable with present findings. Ai et al. (2015) had described characters of *Alternaria alternata* causing foliar disease in teak and this was found to be similar with the features of *Alternaria alternata* causing leaf spot-1 (LS-1). *Macrophomina* was found to cause leaf spot-2 (LS-2) which was a first record from Kerala. Even though, no sporulation was observed during the study period, presence of sclerotia was noticed in culture plates. Sclerotia formation by *Macrophomina* in culture plates was observed earlier (Sayyad et al. 2015). *Botryodiplodia* leaf spot of teak (LS-3) was also found to be a first report of the occurrence of this disease from Kerala. Very fast growth on PDA medium was observed and within two days full growth in culture plates was attained. Mycelial as well as conidial characters were found to be similar to the same pathogen isolated from *Ailanthus tryphysa* (Sharma et al. 1985). LS-4 was caused by *Colletotrichum gloeosporioides*. Similar to the pathogen characters recorded, Sharma et al. (1985) found the same pathogen causing leaf spot in teak for the first time from forest nurseries of Kerala with cottony white mycelium, condia 9.3–15.2 µm long and 1.2–4.47 µm wide.

Collar rot caused by *Alternaria alternata* observed from Chettikkulam was not reported earlier from forest nurseries of Kerala. Collar rot caused by *Rhizoctonia solani* (Ali and Florence 1994) as well as *Rhizoctonia solani* and *Fusarium solani* (Mohanan et al. 2010) were only reported previously from teak seedlings. Hence, this was also a first record of the disease from this state. In Kerala, *Fusarium* causing diseases in teak was reported only from plantations earlier (Balasundaran and Sankaran 1991). *Fusarium solani* was isolated from root of teak seedlings (root rot 1) and was found to be the first report from Kerala. Characteristic features noticed during the present study were agreeable with the features of the soil borne pathogen, *Fusarium solani* causing root rot of teak (Verma et al. 2008). Another root rot disease observed in teak seedlings (root rot-2), caused by *Fusarium oxysporum* was also not reported from nurseries of the state earlier. Sharma et al. (1985) reported *Fusarium oxysporum* from *Eucalyptus* seedlings in forest nurseries of Kerala. The cultural and morphological characters recorded were similar to the present findings. Pathogen produced white mycelia with pinkish tinge at later stages, microconidia of 6.05–7.08 × 1.26–4.17 µm size. The teak obligate parasite, *Olevea tectonae* was recorded earlier from forest nurseries of Kerala (Mohanan et al. 1997, 2010; Mohanan 2007; Sharma et al. 1985). The typical features of uredospore described by Cabral et al. (2010) were similar to present findings. The presence of hyperparasite on teak rust, *Acremonium recifei* was also observed during the study. Uredinia of rust fungus covered by *Acremonium recifei* which appeared white in colour was reported earlier (Cabral et al. 2010; Sharma et al. 1985).

Molecular characterization of major pathogens

Molecular characterization was carried out for major pathogens viz., *Curvularia* causing leaf blight and *Fusarium solani* causing root rot. Sequence homology of *Curvularia* revealed that among the 100 hits in the blast, cent per cent identity was noticed with *Curvularia eragrostidis* strain 1290 with accession numbers KT933678.1, KT933677.1, KT933676.1, KT933675.1, KT933674.1, and KT933673.1 and all the strains showed 100 per cent query coverage as well as cent per cent identity (Table 2). Even though the pathogen was initially identified as *Curvularia lunata* based on the cultural and morphological characters, later molecular investigations confirmed it as *Curvularia eragrostidis*. GeneBank accession number of this culture was MG571759.1. Sequence comparison of nucleotide of *Fusarium* isolate recorded hundred per cent identity with different strains of *Fusarium solani*. Different strains of *Fusarium* viz., FsDAG40, FsDAG37, FsDAG30, FsDAG54, FsDAG53, FsDAG52 also had cent per cent query coverage with nucleotide sequences of *Fusarium* isolate (Table 3). Hence the isolate already identified as *Fusarium solani* based on the cultural as well as morphological characters was also confirmed by molecular characterization. GenBank accession number of this culture was MG576120.1. There are no specific studies available for molecular characterization of fungal pathogens causing diseases in forest nurseries.

Disease assessment and correlation with weather parameters

The effect of temperature, relative humidity and rainfall on the disease incidence and severity were studied by many workers (Agrios 2005; IPCC 2001; Yáñez-López et al. 2012). But literature on correlation between weather parameters and nursery diseases were scanty for tree crops. Leaf blight and leaf spots were found to be distributed throughout the nurseries during the three seasons surveyed compared to collar as well as root rots (Table 4).

First reports of teak seedling foliar diseases from the state viz., leaf blight caused by *Curvularia eragrostidis* and leaf spot caused by *Botryodiplodia theobromae* was found to be significantly correlated with weather parameters. Even though *Curvularia sp*. causing leaf spot disease in teak seedlings was reported earlier from Kerala (Balasundaran 2002; Mohanan 2000; Mohanan et al. 1997, 2004), severe leaf blight disease by *Curvularia*

Table 1 Cultural and morphological characters of identified fungal pathogens of *Tectona grandis*

Disease	Fungal pathogen (Accession no.)	Days for full growth in petri plates	Mycelial character	Spore shape	Spore colour	Spore dimension (450 µm field)
Leaf Blight (LB)	*Curvularia lunata* (ID. No. 8235.16)	7	Initially white colonies later become blackish green	Conidia curved or crescent with four cells and three septa	Dark brown with darkly banded central septa	22.38 × 13.54 µm
Leaf Spot-1 (LS-1)	*Alternaria alternata* (ID. No. 8243.16)	9	Ash coloured mycelial growth with definite concentric rings and blackish tinge in later stages	Conidia form long chains with horizontal septation (3to 4) and transverse septation (1–2)	Olivaceous dark brown	(22.3–62.8) µm × (7.02–17.53) µm
Leaf Spot-2 (LS-2)	*Macrophomina phaseolina* (ID. No. 8237.16)	11	Blackish to violet velvety mycelia. Later stages sclerotia was observed	No sporulation	–	–
Leaf Spot-3 (LS-3)	*Botryodiplodia theobromae* (ID. No. 8242.16)	2	White, cotton-like, raised, fluffy, undulate, dense, filamentous and after one week become grey in colour	Conidia with two cells separated by septa	Brown coloured conidia and thick dark band septa	14.26 × 29.18 µm
Leaf Spot-4 (LS-4)	*Colletotrichum gloeosporioides* (ID. No. 8234.16)	8	Cottony white growth of the mycelium small watery pebbles on the top	Conidia cylindrical, obtuse at both ends, single celled	Hyaline	(9.3–15.2) µm × (1.2–4.47) µm
Collar rot	*Alternaria alternata* (ID. No. 8241.16)	7	Grayish colony with concentric rings with distinct blackish violet in the centre of the petri plates	Obclavate and muriform, moderately long beaks, septate, not in long chains	Dark or pale coloured	(29.45–56.74) µm × (9.6–13.9) µm
Root rot 1	*Fusarium solani* (ID. No. 8239.16)	9	White minute thread like mycelia with lesser degree of concentric zonation later become pinkish tinged	Macroconidia sickle shaped, two or more celled. Microconidia pyriform to fusiform two celled	Both Macro and micro conidia are hyaline	Macroconidia- (26–51) µm x (3.4–5.8) µm, Microconidia- (7.5–18) µm × (1.5–5) µm
Root rot 2	*Fusarium oxysporum* (ID. No. 8240.16)	10	White mycelia with uniform growth and dark tinge in the centre later pinkish tinge appear on reverse of petri plates	Macroconidia 2–3 celled, falcate and microconidia 2 celled, ovoid or slightly elongated	Both Macro and micro conidia are hyaline	Macroconidia- (11.3 –19.9) µm × (1.8 4.8) µm, Microconidia- (6.05 –7.08) µm × (1.26–4.17) µm
Leaf rust	*Olevea tectonae*		–	Uredospore smaller	Yellowish orange postules	(16.0–22) µm × (15.8–22.4) µm

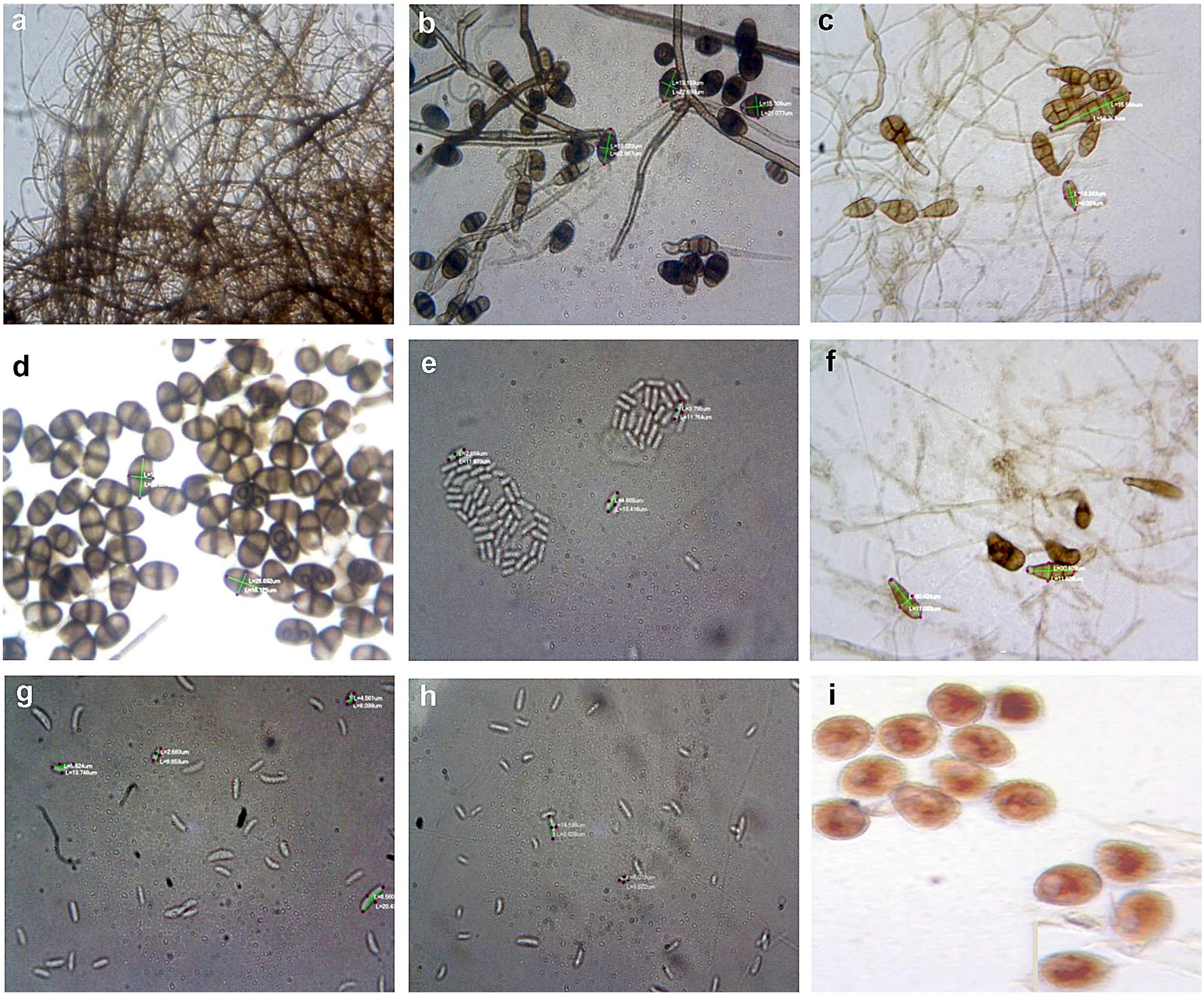

Fig. 2 Microphotographs of mycelia of *Macrophomina phaseolina* (**a**), conidia of *Curvularia eragrostidis* (**b**), *Alternaria alternata* (**c**), *Botryodiplodia theobromae* (**d**), *Colletotrichum gloeosporioides* (**e**), *Alternaria alternata* (**f**), *Fusarium solani* (**g**), *Fusarium oxysporum* (**h**) and uredospore of *Olevea tectonae* (**i**)

Table 2 Sequence homology observed for *Curvularia lunata* (LB) in BLAST analysis as per BLAST results

Sl. no.	Description	Max. score	Query coverage (%)	*E* value	Identity (%)	Accession
1	*Curvularia eragrostidis* Strain 1290	1018	100	0.0	100	KT933678.1
2	*Curvularia eragrostidis* Strain 1290	1018	100	0.0	100	KT933677.1
3	*Curvularia eragrostidis* Strain 1290	1018	100	0.0	100	KT933676.1
4	*Curvularia eragrostidis* Strain 1290	1018	100	0.0	100	KT933675.1
5	*Curvularia eragrostidis* Strain 1290	1018	100	0.0	100	KT933674.1
6	*Curvularia eragrostidis* Strain 1290	1018	100	0.0	100	KT933673.1

Table 3 Sequence homology observed for *Fusarium solani* (root rot 1) in BLAST analysis as per BLAST results

Sl. no.	Description	Max. score	Query coverage (%)	*E* value	Identity (%)	Accession
1	*Fusarium solani* FsDAG40	977	100	0.0	100	KX583248.1
2	*Fusarium solani* FsDAG37	977	100	0.0	100	KX583246.1
3	*Fusarium solani* FsDAG30	977	100	0.0	100	KX583245.1
4	*Fusarium solani* FsDAG54	977	100	0.0	100	KX583244.1
5	*Fusarium solani* FsDAG53	977	100	0.0	100	KX583243.1
6	*Fusarium solani* FsDAG52	977	100	0.0	100	KX583242.1

Table 4 PDI and PDS of fungal diseases with weather parameters in teak seedlings

Location	Disease (poly-house /open field)	Correlation coefficient			Period					
		Tempe-rature	Relative humidity	Rainfall	Feb–May		June–Sep		Oct–Jan	
					PDI	PDS	PDI	PDS	PDI	PDS
Vellanikkara	LB (O)	0.734**	−0.642**	NS	63.50	18.72	12.00	4.8	23	10.2
	LS-4 (P)	NS	NS	NS	48.85	4.96	15.50	3.2	18.50	4.2
	Leaf rust (P)	NS	NS	NS	18	7.6	16.50	6.53	17	7.4
Chettikkulam	LB (O)	0.938**	−0.684**	NS	56	18.08	8	2.8	13.8	5.6
	LS-2 (O)	NS	NS	NS	45	7	28.50	5.3	26	6.6
	LS-3 (O)	NS	0.638**	0.687**	28.5	3.6	19	3.18	22	3.38
	Collar rot (O)	NS	NS	NS	18	–	–	–	–	–
Pattambi	LB (O)	0.688**	−0.725**	−0.552**	25.50	7.2	9.50	1.33	16.50	4.6
	LS-1 (O)	NS	NS	NS	30	6.08	35	6.88	22.50	48
Chittur	LB (O)	0.716**	NS	NS	38.5	12.4	10.5	4.26	20.5	7.98
	Root rot 1 (O)	NS	NS	NS	34.5	–	–	–	–	–
Mekkalappara	Root rot 2 (O)	NS	NS	NS	13.5	–	–	–	–	–

**—Significant at 5% level; *PDI* Per cent disease incidence, *PDS* Per cent disease severity, *LB* Leaf blight, *LS-1* Leaf spot 1, *LS-2* Leaf spot 2, *LS-3* Leaf spot 3, *LS-4* Leaf spot 4, *O* Open field, *P* Polyhouse

eragrostidis was a first record with highest PDI and PDS from both districts. In this study, leaf blight caused by *Curvularia* was positively correlated with temperature and PDS during the summer season with high mean temperature (Table 4). The disease positively correlated with temperature and negatively correlated with both relative humidity and rainfall in Thrissur district. It could be connected with the absence of this disease in polyhouses of Thrissur district since relative humidity was high in the mist chamber compared to open field condition. Finding of the present study is in line with the observations made by Xie et al. (2017) that under warmer climate, fungal pathogen *Curvalaria lunata* cause foliar diseases. It is important to note that, the minor significance of *Curvularia sp.* causing teak foliar disease was only reported from Kerala earlier (Mohanan et al. 1997, 2004).

Leaf spot-1 due to *Alternaria alternata* was noticed only from Pattambi in Palakkad district with maximum severity of 6.88 per cent which was observed during the rainy season. However, no significant correlation was obtained with the weather parameters. Mohanan et al. (2010) too had reported that severity and spread of leaf spot disease of teak caused by *Alternaria sp.* was lower in forest nurseries. Teak leaf spot-2 (LS-2) caused by *Macrophomina phaseolina* from Chettikkulam was a first record from Kerala and the disease was severe during October–January. Namitha (1989) had reported *Macrophomina* in the months of January in forest nurseries of Madhya Pradesh. In the case of *Botryodiplodia theobromae* leaf spot of teak (LS-3) reported from Chettikkulam, even though the mean temperature is not significantly correlated with the severity of the disease, there was a strong positive correlation existing between relative humidity as well as rainfall with disease severity. It is to be noticed that there was no earlier record of *Botrydiplodia* foliar disease in teak from Kerala. Sharma and Sankaran (1987) had reported *Botryodiplodia* incidence in *Albizzia* which they said severe during dry-warm period and declined during the monsoon period in Kerala. Low disease severities coupled with no significant correlation with climatic factors were the reasons for the minor significance of the disease leafspot-4 caused by *Colletotrichum gloeosporioides* from Vellanikkara. The incidence as well as low severity of *Colletotrichum* leaf spot was reported by different researchers from forest nurseries of Kerala (Mohanan 2007; Mohanan et al. 2010; Sharma et al. 1985). During the survey, teak leaf rust (*Olivea tectonae*) was found throughout the season in Vellanikkara with low severity (maximum 7.6%) in the summer season. Similar to the present observation, Pathak et al. (2015) also reported the severity of the teak rust fungus in forest nurseries from October to February. Sine, Collar and root diseases of teak were reported only in the summer season, no significant correlation of weather parameters with the disease occurrence was obtained during the present study. In forest nurseries up to 50 per cent mortality of seedlings was due to the root rot caused by *Fusarium sp*. (Verma et al. 2013).

All the disease observed in Palakkad district was from open field condition (Leaf blight, leaf spot-1, Root rot-1 and Root rot-2). In the case of Thrissur district, except leaf spot-4 and rust disease, all others were noticed from open field conditions. Based on the per cent disease incidence (PDI) and per cent disease severity (PDS) of fungal diseases documented during the field survey, two major pathogens were identified. Leaf blight caused by *Curvularia eragrostidis* and root rot caused by *Fusarium solani* were identified as the major foliar pathogen and root pathogen respectively from teak seedlings during the experiment.

Conclusion

During this investigation, nine fungal diseases were recorded. Interestingly, six diseases were first records from the state viz; leaf blight caused by *Curvularia eragrostidis,* leaf spot-2 caused by *Macrophomina phaseolina*, leaf spot-3 caused by *Botryodiplodia theobromae*, Collar rot caused by *Alternaria alternata*, Root rot-1 caused by *Fusarium solani* and Root rot-2 by *Fusarium oxysporum*. Other diseases recorded were leaf spot-1 (*Alternaria alternata*), leaf spot-4 (*Colletotrichum gloeosporioides*) and leaf rust (*Olevea tectonae*). Based on the PDI and PDS, the most severe foliar disease was leaf blight caused by *Curvularia eragrostidis* and severe root disease was root rot-1 by *Fusarium solani.* Leaf blight caused by *Curvularia eragrostidis* and leaf spot caused by *Botryodiplodia theobromae* was found to be significantly correlated with weather parameters.

Most of the common fungi reported earlier were not observed in this study and fungi recorded with minor significance earlier were observed to be causing severe diseases now. More number of first disease reports also highlights the importance of extensive and continuous surveys throughout the Kerala state with detailed study on link between weather parameters and disease occurrence. It will contribute to the better understanding, management and production of disease free tree nursery stock, the key feature of any successful afforestation programme.

Acknowledgements The authors would like to acknowledge the financial and technical backing provided by Kerala Agricultural University for this research work and for the support and cooperation extended by the Social Forestry Wing of Kerala state Forests and Wildlife Department for the field survey and data collection. The authors also graciously remember the service of Dr. P. N. Chowdhary, National Centre for Fungal Taxonomy, New Delhi for his sincere taxonomic service.

Funding This research work was carried out with the financial support of Kerala Agricultural University.

Data availability Not applicable.

Code availability Not applicable.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

References

Agrios GN (2005) Plant pathology, 5th edn. Elsevier, Amsterdam

Ai C, Wu F, Sun S, Shan T, Wang J (2015) First report of brown leaf spot caused by *Alternaria alternata* on teak in China. Plant Dis 99(6):887

Ali MMI, Florence EJM (1994) Studies on collar rot of teak seedlings. Indian For 120:69–71

Archana B (2014) Morphological and physiological studies on curvularia leaf spot disease of poplar. Ph. D. thesis, Forest Research Institute, Dehradun, 179p

Bakshi BK (1976) Forest pathology principle and practice in forestry. Controller of Publications, Delhi, p 400p

Balasundaran M (2002) Diseases of tropical forest trees. Kerala Forest Research Institute, Peechi

Balasundaran M, Sankaran KV (1991) *Fusarium solani* associated with stem canker die-back of teak in southern India. Indian For 117:147–149

Cabral PGC, Capucho AS, Pereira OL, Maciel-Zambolim E, Freitas RL, Zambolin L (2010) First report of teak leaf rust disease caused by *Olivea tectonae* in Brazil. Australas Plant Dis Notes 5:113–114

IPCC [International Panel on Climate Change] (2001) IPCC third assessment report: climate change 2001. Cambridge University Press, Cambridge

Kumari R, Banerjee A, Kumar R, Kumar A, Saikia P, Khan, ML (2019) Deforestation in India: consequences and sustainable solutions. In: forest degradation around the world. https://doi.org/10.5772/intechopen.85804

Mahowald NM, Ward DS, Doney SC, Hess PG, Randerson JT (2017) Are the impacts of land use on warming underestimated in climate policy? Environ Res Lett 12(9):094016

Mishra S, Dhar V (2005) Efficient methods of inoculation by *Fusarium* the incitant of pigeon pea wilt. Indian Phytopathol 58:332–334

Mohanan C (2000) Status of forest nursery diseases in India and emerging trends in seedling disease management. In: Lilja, Sutherland (eds) Proc. 4th IUFRO WP. 7.03.04. Diseases and Insects in Forest Nurseries, Finnish Forest research Institute, Suonenjoki, Finland, pp 107–121

Mohanan C, (2007) Diseases of teak in India and their management. In: Bhat KM, Balasundaran M, Bhat KV, Muralidharan EM, Thulasidas, PK, (eds) Processing and marketing of teak wood products of planted forests. Proceedings of the regional workshop, Kerala Forest research Institute, Peechi, Kerala, India, 25–28 September, 2007. pp 214–222

Mohanan C, Sharma JK (2005) Improvement of seedling production system in forestry sector and its impact on seedling health. In: Diseases and insects in forest nurseries—Proceedings of the 5th Meeting of IUFRO WorkingParty S7.03.04, 6–8 May 2003, Kerala

Mohanan C, Sharma JK, Florence EJM (1997) Nursery diseases of teak in India. In: Basha CS, Mohanan C, Sankar S, (eds) Proceedings of International Teak Symposium, 4–6 December 1991, Peechi. Kerala Forest Department and Kerala Forest Research Institute, Peechi, pp 107–112

Mohanan C, Ratheesh N, Laya PN, Kumar RKC (2004) Disease problems and their management in teak root trainer nurseries in Kerala, India. In: Bhat KM, Nair KKN, Bhat KV, Muralidharan EM, Sharma JK (eds) Quality timber products of teak from sustainable forest management. Proceedings of the International Conference, Kerala Forest research Institute, Peechi, Kerala, India, 2–5 December, 2003. pp 462–466

Mohanan C, Ratheesh N, Kumar KCR (2010) Teak (*Tectona grandis* L.f.) root trainer nurseries: diseases and their management. Indian J Forestry 33(4):519–523

Munaut F, Hamide N, Marate H (1997) A standardized microdroplet inoculation technique for analysis of the interaction between *Colletotrichum gloeosporioides* and *Stylosanthes guianensis*. Parasit 53(4):117–125

Nagarjun N, Suryanarayana V (2016) Documentation, characterization and management of leaf spot of *Syzygium cumini* (L.) Skeels. J Farm Sci 29(3):381–385

Namitha J (1989) Ecology and control of some forest tree species in nurseries. Ph.D. (Botany) thesis, Dr. Harisingh Gour Vishwavidyalaya University, Madhya Pradesh, 313p

Pathak H, Maru S, Satya HN, Silawat SC (2015) Fungal diseases of trees in forest nurseries of Indore. India J Plant Pathol Microbiol 6(8):1–4

Rocha JRS, Oliveira NT, Menezes M (1998) Comparison of inoculation methods efficiency for evaluation of *Colletotrichum gloeosporioides* isolates pathogenicity on passion fruits (*Passiflora edulis*). Braz Arch Biol Technol 41:145–153

Sayyad SI, Mogle TR, Sonkamble MM (2015) Cultural characteristics of *Macrophomina phaseolina*. Ann Plant Prot Sci 23(2):390–417

Sharma JK, Sankaran KV (1987) Diseases *of Albizia falcataria* in Kerala and their possible control measures. KFRI Res Report 47:1–33

Sharma JK, Mohanan C, Florence E JM (1985) Disease survey in nurseries and plantations of forest tree species grown in Kerala. KFRI research report No. 36. Kerala Forest Research Institute, Peechi, Kerala. 275p

Tade and Bharathy (2011) Prevalence and management of root and collar rot of teak (*Tectona grandis* Linn. F.) seedlings in nurseries. J Plant Dis Sci 6(2):128–130

Verma RK (2013) Outbreak of a nursery disease of teak in central India. Indian For 139(8):750–752

Verma RK, Sharma N, Soni KK, Jamaluddin (2008) Forest fungi of central India. International Book Distributing Company, Lucknow, p 418p

Verma RK, Hanwat RH, Rajput PST, CK (2013) Status of Khair mortality in central India. Indian For 139(9):790–796

Wheeler BEJ (1969) An introduction of plant disease. John Wiley and Sons Ltd, London

White TJ, Bruns T, Lee S, Taylor JW (1990) Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics. In: Innis MADH, Gelfand JJ, Sninsky, White TJ (eds) PCR protocols: a guide to methods and applications. Academic Press Inc, New York, pp 315–322

Xie CP, Ma R, Zheng FQ, Liu PP (2017) First report of leaf spot caused by *Curvularia lunata* on *Plumeria rubra* in Hainan. China Plant Dis 101(1):252

Yáñez-López R, Torres-Pacheco I, GuevaraGonzález RG, Hernández-Zul MI, Quijano-Carranza JA, Rico-García E (2012) The effect of climate change on plant diseases. Afr J Biotechnol 11(10):2417-a2428. https://doi.org/10.5897/AJB10.2442