Chapter

New and Emerging Disease Threats to Forest Plantations in Sarawak Borneo, Malaysia

Annya Ambrose, Jack Liam and Razak Terhem

Abstract

The planted forest area in Sarawak is the largest planted forest in Malaysia, which has been developed since 1997 to sustain the decline in the production of natural forests. As of December 2021, the total area of plantation forests reached 551,704 hectares (ha), dominated by fast-growing exotic species mainly Acacia species (55%), Falcataria moluccana (15%) and Eucalyptus (14%). The study showed Acacia was infected with red root rot disease of Ganoderma philippii and brown root rot of Phellinus noxius, Ceratocystis wilt disease caused by Ceratocystis. fimbriata sensu stricto (s.s) complex and pink disease caused by Erythricium salmonicolor, while F. moluccana was infected by gall disease namely Uromycladium falcatarium. Eucalyptus pellita diseases were infected namely by G. philippii red root rot disease, stem canker disease caused by Botryosphaeriaceae pathogen and bacterial wild disease caused by Ralstonia solanacearum. Ceratocystis wilt disease of Acacia mangium shows disease incidence (DI) accounted at 68% (serious) as compared with other diseases observed in this study. This will be the first baseline study that is conducted to observe and assess the diversity of the present, new and emerging pathogens and the damage they cause to exotic planted species of Sarawak.

Keywords: Acacia diseases, baseline study, disease incidence, Eucalyptus diseases, fast-growing exotic species, *Falcatria* disease

1. Introduction

The timber and timber-based products are the fourth largest contributor to Sarawak's export earnings after natural gas, petroleum and palm oil products. The timber industry, in particular, contributed to RM6.31 billion (USD 1.43 billion) in royalty, premium and cess revenue over a ten-year period, from 2010 to 2021. In addition, it also provides employment, creates business opportunities and facilitates road access for the rural communities that subsequently support eradication of poverty and sustainable development of the country.

Log supply from the natural forests peaked in the 1990s at about 20 million m^3 and declined to 4.07 million m^3 in 2019. The concern for the sustainability of natural forests has become a major topic of discussion these days. Sarawak is committed to conserving a healthy forest environment for the long term, including biodiversity conservation and ecosystem functioning with an aim to strike balance between the development and economic needs of the nation. Sarawak has a total land area of approximately 12.4 million hectares of which 7.7 million hectares or 62 per cent is under forest cover. Under the 'Sarawak Land Use Policy,' 7 million hectares have been allocated for sustainable forestry and conservation. Out of these, 6 million hectares are Permanent Forest Estates (PFEs) and 1 million hectares are Totally Protected Areas (TPAs). The remaining 5.4 million hectares are for agriculture and other development purposes. Under the Sarawak Forest Policy, the key component is sustainable forest management (SFM). SFM is implemented based on the guidelines in the Forest Statement Policy 1954.

Sarawak embarked on large-scale forest plantations in 1996 as a long-term strategy to provide a new source of wood material for the State's wood-based industries. Hitherto, Sarawak is the main player in Malaysia's forest plantation industry in the county where the total area of its plantation forests reached 551,704 hectares with three (3) main species planted, dominated by *Acacia* (55%), *Falcataria moluccana* (19%) and *Eucalyptus* (14%). Sarawak hopes to establish one (1) million hectares of industrial forest by 2025 by planting fast-growing species. It is hoped to produce 15 to 25 million m^3 a year when the target is achieved. In addition, the planted forest will relieve pressure on logging in natural forests in terms of both area size and intensity.

Currently, the forest plantation area could only produce an average production yield per ha of 70–120 m^3 assuming fully stocking at the age of 8 years trees. However, to better secure the future wood supply that Sarawak needs for its domestic and international markets, the production yield per ha should be increased to an average of 120–210 m^3 to be on par with other timber-producing countries such as Vietnam, China and Indonesia. One of the major attributes that had been identified in contributing to the poor growth and performance is the occurrences of disease attacks as well as the unavailability of genetically improved planting materials that are disease-resistant.

The research effort on forest health in Sarawak is still in the infant stage; however, its capacity has increased over the past decade. Surveys and basic quantitative evaluations were conducted during the period 2015—2020 in response to the plantation development observed in Sabah and Indonesia. Surveys and evaluations for forest health are crucial, and they should be conducted immediately and systematically in order to obtain related information such as disease incidence, signs and symptoms, contributing factors, and pathogens as well as silviculture treatments.

This information is expected to be used by stakeholders and policy-makers in developing an appropriate disease management strategy to control the disease infection on their plantations. Hence, this is the first baseline study conducted to identify and evaluate the incidence and the damages of the known major diseases as well as the emerging disease that could pose a threat to the vitality of forest plantation tree species in Sarawak.

The significant information gathered from this study will definitely provide an overview of the risk and threats of the pathogens and the management options that could be undertaken for a countermeasure.

2. Materials and methods

2.1 Forest health surveillance (FSH)

Forest health surveillance (FHS), a formal and regular inspection of the planted forest, was performed in this study through the establishment of permanent sampling plot (PSPs) surveillance and monitoring plots to assess the disease incidences and occurrences. FSH was undertaken between the period years 2015–2020, in various plantations selected randomly from the four forestry administration regions of Sarawak namely Miri, Bintulu, Sibu and Kuching (**Figure 1**). Field observations were carried out on forests planted with three major exotic tree species (**Table 1**).

We relied on information gathered by local foresters as well as our own observations to select the surveyed plantations in each studied forest region. Basically, the largest operational forest plantations were selected to better represent each forest region.

The plots were established by 30 × 30 m plot (the size of a plot varies in order to obtain a minimum of 100 living trees per plot) * or alternatively by line transect with 10 planting rows and 10 trees per rows approach, which subsequently 100 trees will be assessed, assuming every tree were still alive (full stocking). All the trees assessed were labelled accordingly. GPS coordinates were recorded at every corner of the plot

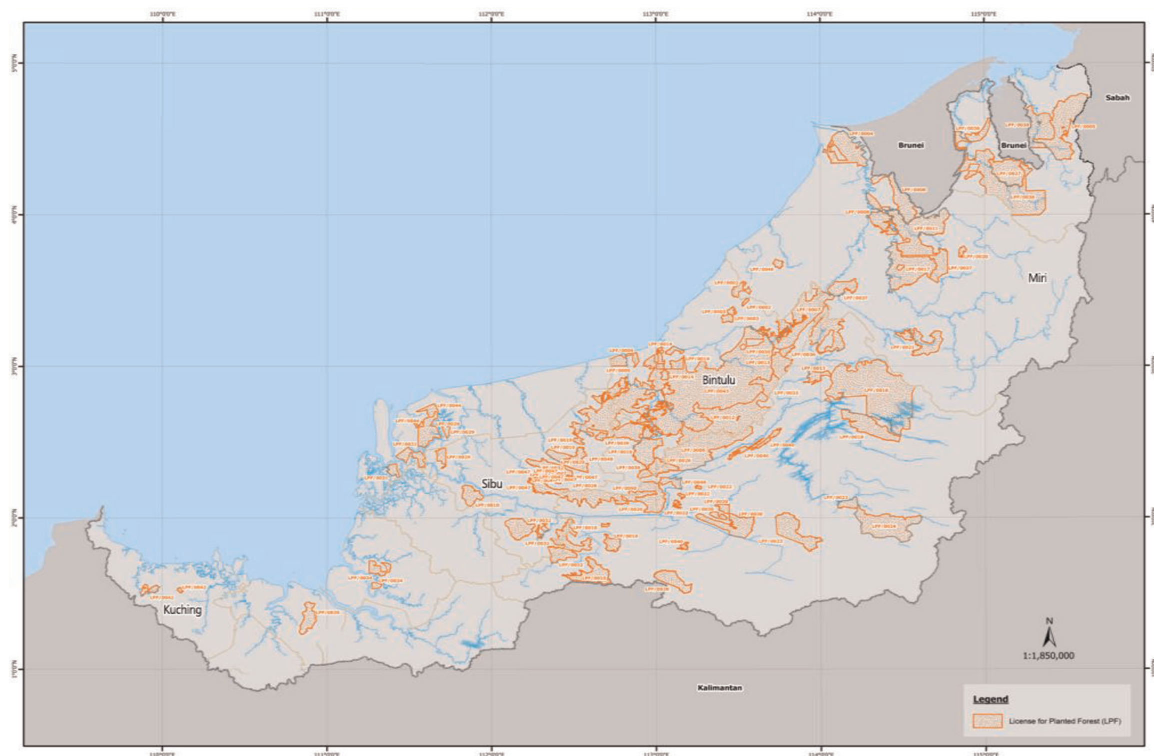

Figure 1.
Map of Sarawak showing the distribution of forest tree plantation which are highlighted areas with red border.

Host	Area in 2021 (ha)	Planting region	Native/ Exotic	Potential end-uses
Acacias	301,653.30	Kuching, Miri, Bintulu, Sibu	Exotic	Veneer, sawn timber, wood chips
Eucalyptus pellita	78,834.51	Kuching, Miri, Bintulu, Sibu	Exotic	Solid timber, sawn timber, timber for furniture
Falcataria molluccana	106,276.20	Kuching, Miri, Bintulu, Sibu	Exotic	Wood chips, veneer

Table 1.
Details of forest plantation species that were surveyed for disease pathogens.

established and marked clearly with a peg. The plots were established at least 20 m from the boundary of plantation, roads or forest gaps. Details of plots are shown in **Table 2**.

2.2 Disease assessment, sampling and disease incidence (DI)

Trees with signs and symptoms such as the presence of any fungal fruiting bodies, swelling and cracking of the stems, branches and canopy appearances (i.e. wilting, yellowing, or defoliations) were observed and thoroughly recorded. Various observations were also taken, including the presence of animal damage, and appearances of insect/pests (i.e. termites' mounds, defoliators, borers or boreholes).

Samples of diseased leaves, branches, stems and roots were taken from diseased trees and collected for laboratory examination. The surface of cankers on stems was examined on the field using hand lenses for dark pycnidia [17] or any signs of fruiting bodies. Trees showing symptoms of branch death, wilting foliage, bark discolouration or sap exudation typical of Ceratocystis as well as showing signed of wood boring insect activities and sweet gaseous smell of pineapple were examined by chopping into the woody xylem at the base of the tree (most infections occur through the root system) or further up the stems for the characteristic xylem discolouration. Longitudinal strips of wood xylem (approximately 0.5 cm thick and around 10 to 15 cm long) were then cut from the discoloured xylem. In some cases, diseased trees were also felled and were cut into several sections measuring between 10 and 20 cm in length. The samples were then placed into paper bags before being transported to the Forest Pathology Laboratory, Industrial Forest Research Centre (IFRC), Kuching. The samples were stored at 4°C prior to fungal isolation.

Below ground variables were recorded for each tree on roots exposed to 20–50 cm from the base of the tree that exhibits symptoms of root rots. Variables recorded included are the presence or absence of any kind of root rot (red, brown, white) as well as the presence or absence of insect pests such as termites' tunnelling activities. Samples of insect pests were also collected for further identification.

The surveys aim to estimate the number of trees with any signs and symptoms of disease infection and thus determine the disease incidences (DI).

The DI were calculated by the following formula:

$$\mathrm{DI} = \left(\frac{n}{N}\right) x \ \mathbf{100}\%.$$

Where:

n = number of infected standing tree

N = total number of standing trees in one plot.

The disease incidences were then evaluated based on the indicator and rating as guided in **Table 3**. Values DI were reported in the results as ranges and are based on the plot data over the years of plot assessment.

2.3 Fungal isolation and identification

2.3.1 Isolation of Ceratocystis wilt disease

The carrot baiting method with minor modification was carried out to isolate Ceratocystis [1]. Pieces of the diseased stem were placed between two slices of fresh

No	Plot ID	Species	Region*	Age (years)	Rotation	Spacing (m)	Types of stand**
1	SGAM1	*A. mangium*	BTU	6	1	3 × 3	CS
2	SGAM 2	*A. mangium*	BTU	6	1	3 × 3	CS
3	SGAM 3	*A. mangium*	BTU	1.5	2	3 × 3	CS
4	SGAM 7	*A. mangiun*	BTU	10	1	3 × 3	CS
5	SGAM 9	*A. mangium*	BTU	1	2	3 × 3	CS
6	PDAM01	*A. mangium*	BTU	3	2	3 × 3	CS
7	PDAM02	*A. mangium*	BTU	3	2	3 × 3	CS
8	GPP-SFC01	*A. mangium*	BTU	<1	2	3 × 3	CS
9	GPP-SFC02	*A. mangium*	BTU	<1	2	3 × 3	CS
10	SFC-DK-001	*A. mangium*	BTU	2	2	3 × 3	CS
11	SFC-DK-002	*A. mangium*	BTU	2	2	3 × 3	CS
12	SFC-DK-003	*A. mangium*	BTU	2	2	3 × 3	CS
13	SFC-DK-004	*A. mangium*	BTU	2	2	3 × 3	CS
14	SFC-DK-005	*A. mangium*	BTU	2	2	3 × 3	CS
15	SFC-DK-006	*A. mangium*	BTU	2	2	3 × 3	CS
16	SFC-DK-007	*A. mangium*	BTU	<1	2	3 × 3	CS
17	SFC-DK-008	*A. mangium*	BTU	<1	2	3 × 3	CS
18	SFC-DK-009	*A. mangium*	BTU	<1	2	3 × 3	CS
19	SFC-DK-010	*A. mangium*	BTU	<1	2	3 × 3	CS
20	BT 1–2016	*A. mangium*	BTU	3	2	3 × 3	CS
21	BT2–2016	*A. mangium*	BTU	2	2	3 × 3	CS
22	SBW 1–2016	*A. mangium*	SBW	2	2	3 × 3	CS
23	BT1–2017	*A. mangium*	BTU	2	2	3 × 3	CS
24	Lws 2-RND	*A. mangium*	MY	1	1	3 × 3	CS
25	Lws-3-RND	*A. mangium*	MY	1	1	4 × 3	CS
26	Lws 4-RND	*A. mangium*	MY	1	1	5 × 3	CS
27	Plot 1AH	*A. hybrid*	SBW	2	2	3 × 3	CS
28	Plot 2AH	*A. hybrid*	SBW	2	2	3 × 3	CS
29	SBW 1-RND	*A. mangium*	SBW	2	1	3 × 3	R&D
30	SBW 2-RND	*A. mangium*	SBW	2	1	3 × 3	R&D
31	SBW 3-RND	*A. mangium*	SBW	2	1	3 × 3	R&D
32	AM4	*A. mangium*	KCH	12	1	3 × 3	CS
33	EP1	*E. pellita*	KCH	11	1	3 × 3	CS
34	EP2	*E. pellita*	KCH	11	1	3 × 3	CS
35	EP3	*E. pellita*	KCH	4	1	3 × 3	CS
36	EP6*	*E. pellita*	KCH	4	1	3 × 3	CS
37	EP5	*E. pellita*	KCH	13	1	3 × 3	CS
38	4	*E. pellita*	BTU	3	2	3 × 3	CS

No	Plot ID	Species	Region*	Age (years)	Rotation	Spacing (m)	Types of stand**
39	5	*E. pellita*	BTU	3	2	3 × 3	CS
40	8	*E. pellita*	BTU	8	2	3 × 3	CS
41	10	*E. pellita*	BTU	4	1	3 × 3	CS
42	11	*E. pellita*	BTU	2	2	3 × 3	CS
43	PDEP01	*E. pellita*	BTU	2	2	3 × 3	CS
44	Plot 5 Bt	*E. molluccana*	SBW	2	2	3 × 3	CS
45	Plot 5 Bt	*F. molluccana*	SBW	2	2	3 × 3	CS
46	SFC-WTK003	*F. molluccana*	SBW	<1	2	3 × 3	CS
47	PD-AF-01	*F. molluccana*	BTU	3	2	3 × 3	CS
48	PD-AF-02	*F. molluccana*	BTU	3	2	3 × 3	CS
49	GPP-SFC03	*F. molluccana*	BTU	<1	2	3 × 3	CS
50	GPP-SFC04	*F. molluccana*	BTU	<1	2	3 × 3	CS
51	SFC -Bt-0018	*F. molluccana*	BTU	4	2	3 × 4	R&D
52	SFC-SY-001	*F. molluccana*	MY	2	2	3 × 3	CS
53	SFC-SY-002	*F. molluccana*	MY	2	2	3 × 3	CS
54	SFC-SY-003	*F. molluccana*	MY	2	2	3 × 3	CS
55	SFC-SY-004	*F. molluccana*	MY	2	2	3 × 3	CS
56	SFC-LimbaJ	*F. molluccana*	MY	2	2	3 × 3	R&D

Forestry Region (Figure 1**): BTU, Bintulu; SBW, Sibu; KCH, Kuching; MY, Miri; R&D.*
***Types of stand: R&D, Research and Development; CS, Commercial Stands.*

Table 2.
Details of permanent sampling plots established and evaluated.

Indicator	No	Light	Medium	Serious
Diseases incidence	Affect less than 10% of standing trees	Affect 10–29% of standing trees	Affect 30–59% of standing trees	Affect more than 60% standing trees

Table 3.
Indicator and ratings for evaluating the impact of forest health status in Sarawak [31].

carrot and incubated in plastic containers that served as moisture chambers for 4–6 days. After 5–8 days, a pale orange ascospore mass appeared on the tip of the perithecia was then picked with a sterile syringe needle and transferred into a Petri dish plated with Potato Dextrose Agar medium and incubated at 26°C. All the isolates were identified based on the analyses of morphological characteristics [1, 21, 22] The characteristics and structures of the culture, such as perithecium, ostiolar hyphae, ascospore and conidia (barrel-shaped and cylindrical-shaped) (μm) of all the fungal isolates, were measured and described. Morphological identification for this study was conducted by using a Leica compound microscope ICC50HD with a laptop workstation for data & image acquisition and a stereo microscope of Olympus SZ61 (SZ61TR-2X-DI-TP-118000A-SET) at Forest Pathology Laboratory, IFRC, Kuching.

2.3.2 Isolation of root rot disease

Direct isolation was carried out to isolate the pathogen of root rot disease. Root tissues bearing disease symptoms were cut into several pieces approximately 3 mm × 3 mm in size and were placed on malt extract agar (MEA) and incubated at room temperature for the fungus to grow. The cultures were then transferred to MEA for morphological studies.

2.3.3 Isolation canker disease

Segments of symptomatic plant parts were incubated in moist chambers for 2–3 days to induce the development of fruiting structures. These were then transferred to MEA and incubated at 25°C. Isolation from symptomatic tissue was also made directly onto MEA. Isolations were made onto MEA from fruiting structures occurring on cankered stems [19, 20].

3. Results

3.1 Disease incidence (DI)

In this study, a total of 56 PSPs comprising 32 of *Acacia*, 17 of *Eucalyptus pellita* and 14 of *F. mollucana* have been established and assessed with approximately 5600 trees of the three major species planted have been evaluated, data recorded and analysed. The study showed that DI was varied between tree species.

3.1.1 Acacia

Approximately 3200 *Acacia* stand aged between less than 1-year-old and 12-year-old were assessed in this study with three prominent diseases observed; Ceratocystis wilt disease, root rot disease and pink disease. Based on **Table 4**, Ceratocystis wilt disease was the most devasted and important disease observed. DI was recorded the highest with mortality recorded at 68% in the Bintulu region based on disease indicators rating as depicted in **Table 2**, and the DI rating is categorised at a serious level. The disease was observed in stands less than 1-year-old also in the Bintulu region with DI recorded at 1.9%. The DI is predicted to increase over time with rotation length. The disease was not observed in Miri and Sibu region; however, DI of 3% of the disease was documented in Kuching region in 12 -year-old *A. mangium*.

The disease incidence of root rot was recorded between 0 and 37% in trees aged less than 1 year old to 10 year old. 10 years of plantation of *Acacia mangium* in the Bintulu region recorded the highest incidence of the disease, and no incidences were recorded in the young stand. The disease rating based on the highest DI is light. Root rot disease seems to be the most encountered disease in most of the plots, with 17 out of 32 PSPs observed with the disease.

The pink disease was only observed in Sibu region and had affected 2-year-old taxa seed source trial plot established by Forest Department Sarawak. DI of pink disease was recorded at 5%.

No	Plot ID	Species	Region*	Disease Incidence (DI)			Age (years)	Rotation	Spacing (m)	Types of stand**
				Root rot	Ceratocystis wilt	Pink disease				
1	SGAM1	*A. mangium*	BTU	22	0	0	6	1	3 × 3	CS
2	SGAM 2	*A. mangium*	BTU	22	0	0	6	1	3 × 3	CS
3	SGAM 3	*A. mangium*	BTU	29	0	0	1.5	2	3 × 3	CS
4	SGAM 7	*A. mangiun*	BTU	37	0	0	10	1	3 × 3	CS
5	SGAM 9	*A. mangium*	BTU	6	0	0	1	2	3 × 3	CS
6	PDAM01	*A. mangium*	BTU	17	13	0	3	2	3 × 3	CS
7	PDAM02	*A. mangium*	BTU	0	68	0	3	2	3 × 3	CS
8	GPP-SFC01	*A. mangium*	BTU	0	0	0	<1	2	3 × 3	CS
9	GPP-SFC02	*A. mangium*	BTU	0	0	0	<1	2	3 × 3	CS
10	SFC-DK-001	*A. mangium*	BTU	9.5	0	0	2	2	3 × 3	CS
11	SFC-DK-002	*A. mangium*	BTU	3.6	7.1	0	2	2	3 × 3	CS
12	SFC-DK-003	*A. mangium*	BTU	0	2	0	2	2	3 × 3	CS
13	SFC-DK-004	*A. mangium*	BTU	0	0	0	2	2	3 × 3	CS
14	SFC-DK-005	*A. mangium*	BTU	3.8	10	0	2	2	3 × 3	CS
15	SFC-DK-006	*A. mangium*	BTU	1.4	0	0	2	2	3 × 3	CS
16	SFC-DK-007	*A. mangium*	BTU	0	4	0	<1	2	3 × 3	CS
17	SFC-DK-008	*A. mangium*	BTU	0	15.5	0	<1	2	3 × 3	CS
18	SFC-DK-009	*A. mangium*	BTU	0	12.2	0	<1	2	3 × 3	CS
19	SFC-DK-010	*A. mangium*	BTU	0	1.9	0	<1	2	3 × 3	CS
20	BT 1–2016	*A. mangium*	BTU	8.3	35.2	0	3	2	3 × 3	CS
21	BT2–2016	*A. mangium*	BTU	3	3.5	0	2	2	3 × 3	CS
22	SBW 1–2016	*A. mangium*	SBW	1.2	0	0	2	2	3 × 3	CS

No	Plot ID	Species	Region*	Disease Incidence (DI)			Age (years)	Rotation	Spacing (m)	Types of stand**
				Root rot	Ceratocystis wilt	Pink disease				
23	BT1–2017	*A. mangium*	BTU	7.2	41.2	0	2	2	3 × 3	CS
24	Lws 2-RND	*A. mangium*	MY	0	0	0	1	1	3 × 3	CS
25	Lws-3-RND	*A. mangium*	MY	0	0	0	1	1	4 × 3	CS
26	Lws 4-RND	*A. mangium*	MY	0	0	0	1	1	5 × 3	CS
27	Plot 1AH	*A. hybrid*	SBW	1.2	0	0	2	2	3 × 3	CS
28	Plot 2AH	*A. hybrid*	SBW	1.2	0	0	2	2	3 × 3	CS
29	SBW 1-RND	*A. mangium*	SBW	0	0	5	2	1	3 × 3	R&D
30	SBW 2-RND	*A. mangium*	SBW	0	0	3	2	1	3 × 3	R&D
31	SBW 3-RND	*A. mangium*	SBW	0	0	2	2	1	3 × 3	R&D
32	AM4	*A. mangium*	KCH	3	3	0	12	1	3 × 3	CS

*Forestry Region (see **Figure 1**): BTU, Bintulu; SBW, Sibu; KCH, Kuching; MY, Miri; R&D.*
**Types of stand: R&D, Research and Development; CS, Commercial Stands.*

Table 4.
Details on DI (DI) of observed diseases recorded in Acacia.

No.	Plot ID	Species	Region*	Disease Incidence (DI)			Age (years)	Rotation	Spacing (m)	Types of stand**
				Root rot	Canker	Bacterial Wilt				
1	EP1	*E. pellita*	KCH		4		11	1	3 × 3	CS
2	EP2	*E. pellita*	KCH		3		11	1	3 × 3	CS
3	EP3	*E. pellita*	KCH		2		4	1	3 × 3	CS
4	EP6*	*E. pellita*	KCH				4	1	3 × 3	CS
5	EP5	*E. pellita*	KCH		2		13	1	3 × 3	CS
6	4	*E. pellita*	BTU				3	2	3 × 3	CS
7	5	*E. pellita*	BTU				3	2	3 × 3	CS
8	8	*E. pellita*	BTU	6			8	2	3 × 3	CS
9	10	*E. pellita*	BTU	6			4	1	3 × 3	CS
10	11	*E. pellita*	BTU		7		2	2	3 × 3	CS
11	PDEP01	*E. pellita*	BTU				2	2	3 × 3	CS
12	PDEP02	*E. pellita*	BTU				2	2	3 × 3	CS
13	Plot 3 EP	*E. pellita*	SBW		1.2		2	2	3 × 3	CS
14	Plot 4 EP	*E. pellita*	SBW				2	2	3 × 3	CS
15	SFC-WTK1	*E. pellita*	SBW				<1	2	3 × 3	CS
16	SFC-WTK2	*E. pellita*	SBW				<1	2	3 × 3	CS
17	SFC-BT	*E. pellita*	BTU			3	2	2	3 × 3	R&D

Forestry Region (see **Figure 1): BTU, Bintulu; SBW, Sibu; KCH, Kuching; MY, Miri; R&D.*
***Types of stand: R&D, Research and Development; CS, Commercial Stands.*

Table 5.
Details on disease incidence (DI) of observed diseases recorded in E.pellita.

3.1.2 E. pellita

Approximately 1700 *E. pellita* stands aged between less than 1-year-old and 13-year-old were assessed in this study with the establishment of 17 PSPs as detailed in **Table 5**. Canker disease was found in 6 PSPs with the highest DI of 7% recorded in 2-year-old stand in Bintulu region. Out of the 6 PSPs, mostly canker incidences were found in Kuching with 11% DI accumulatively. Root rot was observed in the Bintulu region with accumulative DI of 12% in 2 PSPs located within the same area. Bacterial wilt disease with a DI of 3% was encountered in one PSP established within R&D tree breeding plot at Bintulu. No other PSPs recorded such disease.

3.1.3 F. molluccana

A total of 14 PSPs with comprises of approximately 1400 of *F. molluccana* stands of less than 1-year-old and 2- and 3-year-old were established and assessed for DI as

No.	Plot ID	Species	Region*	Disease Incidence (DI) %		Age (years)	Rotation	Spacing (m)	Types of stand*
				Gall Rust	Canker				
1	Plot 5 Bt	*F. mollucana*	SBW			2	2	3 × 3	CS
2	Plot 5 Bt	*F .mollucana*	SBW			2	2	3 × 3	CS
3	SFC-WTK003	*F. mollucana*	SBW			<1	2	3 × 3	CS
4	PD-AF-01	*F. mollucana*	BTU			3	2	3 × 3	CS
6	PD-AF-02	*F. mollucana*	BTU			3	2	3 × 3	CS
7	GPP-SFC03	*F. mollucana*	BTU		1	<1	2	3 × 3	CS
8	GPP-SFC04	*F. mollucana*	BTU			<1	2	3 × 3	CS
9	SFC -Bt-0018	*F. mollucana*	BTU	69.7		4	2	3 × 4	R&D
10	SFC-SY-001	*F. mollucana*	MY			2	2	3 × 3	CS
11	SFC-SY-002	*F .mollucana*	MY			2	2	3 × 3	CS
12	SFC-SY-003	*F. mollucana*	MY			2	2	3 × 3	CS
13	SFC-SY-004	*F. mollucana*	MY			2	2	3 × 3	CS
14	SFC-LimbaJ	*F. mollucana*	MY	1.9		2	2	3 × 3	R&D

Forestry Region (see **Figure 1): BTU, Bintulu; SBW, Sibu; KCH, Kuching; MY, Miri; R&D. Types of stand: R&D, Research and Development; CS, Commercial Stands.*

Table 6.
Details on disease incidence (DI) of observed diseases recorded in F. molluccana.

detailed in **Table 6**. Based on the survey, gall rust disease was the most important prominent disease observed with DI recorded at an alarming 69.7% in an R&D (taxa seed source trials) established at Bintulu. Miri region also recorded gall rust DI of 1.9% in stands less than 1-year-old. Another disease observed affecting *F. molluccana* was canker disease and attacked stands less than 1-year-old also in the Bintulu region with DI recorded at 1.9%. No diseases were observed in the Sibu region.

3.2 Symptoms and signs

3.2.1 Diseases of Acacia

3.2.1.1 Ceratocystis wilt disease of Acacia

Ceratocystis infections observed typically start on the lower stem and move up, causing dark staining of the woody xylem. However, we did observe some symptomatic trees with initial infection starting at the upper stem with dead foliage hanging throughout the tree or on some major branches. The infected blackish gummosis stem upon debarking showed dark brown to black discolouration in the woody xylem, radial pattern in pattern, which is a unique symptom of Ceratocystis wilt disease. Within every plot observed with Ceratocystis, all trees showed these wilt symptoms were noted for Ceratocystis wilt (**Figure 2a–d**). But it was further confirmed upon root excavation to differentiate root rot disease as the latter also exhibits symptoms such as wilting and severe defoliation.

Figure 2.
Ceratocystis wilt disease implicates damages to Acacia mangium *plantation in Sarawak (a–i); (a) blackish lower stem with foamy exudate at the upper stem and wilting and dying 2-year-old tree; (b) blackish streak-like inner bark due to Ceratocystis infection; (c) foamy exudates and slime typical of Ceratocystis infection on stem of the tree; (d) initial infection starting at the upper stem with dead foliage hanging throughout the tree; (e) dead tree with severe bark damage caused by squirrels with wood discolouration; (f) severe bark damage but tree observed free from Ceratocystis infection (g) traces of wood-boring insect holes on the stem;(h) Ambrosia beetle found under bark and the wood appeared with blackish lesion; (i) side view image of wood-boring insect identified as* Immanus desectus *(eggers) collected from the infested tree.*

Some symptomatic and dead trees as young as 6-month-old that were adjacent to the conservation or buffer area were observed with wound damage on the stem of juvenile trees inflicted by squirrels grazing (**Figure 2e**). These wounds would act as the point of entry for Ceratocystis pathogen to infect the trees. However, we did observe that some trees inflicted with these wounds but did not show any Ceratocystis symptoms (**Figure 2f**).

Wood-boring insects were also found present in infected trees, with wood infested exhibited blackish lesions typical of *Ceratocystis* pathogen (**Figure 2g–i**). The wood-boring insects collected from the tree were identified as those of ambrosia beetle species.

Culture characteristics and morphology of Ceratocystis isolates from *A. mangium* were observed and analysed based on morphological characteristics, such as colony form, mycelium colour and reverse media colour [1, 21, 22], were further identified as *C. fimbriata sensu stricto (s.s) complex*, having the characteristic of olive-green colonies with the underside of the cultures was light grey at the margin and became darker towards the centre and typical pineapple-fruit odour. The isolates of *C. fimbriata* showed superficial or submerged in the substrate perithecia, with colours ranging from brown to black both at the base and neck of the perithecium (**Figure 3c**). They had globose to sub-globose ascomata with long necks and typical divergent ostiolar hyphae at their tips (**Figure 2**). Teleomorph and anamorph structures were produced within 2 weeks on MEA cultures (**Figure 3d**).

3.2.1.2 Root rot disease of Acacia

The trees showed symptoms typical of red root rot including dying trees at the periphery of rot centres that had wilting leaves. Most of the affected trees were dead stands that exhibited chlorotic/yellowing foliage and loss of foliage.

The diseased trees were observed to be clustered in patches that were roughly circular. The trees with symptoms of root rots were adjacent to one another. Fruit bodies were only observed on the stem of some of the trees. Types of root disease were distinguished by the colour of infected roots, red root rot, brown root rot and white root rot.

Underground symptoms observed include the presence of red-coloured rhizomorphs with blackish exudates (**Figure 4c**) on the surface of the roots and white mycelium (denote as *My* in **Figure 4d).** Yellow mottles of the foliage with patches in the majority of the infected *A. mangium* trees were easy to recognise as typical of red root rot and further identified as *G. philippii*. Trees discovered to be infected with brown root rot were observed with soft, fibrous and totally rotten roots and sandy particles adhering to the rhizomorph (**Figure 4e**). The causal pathogens identified were *G. philippii* and *Phellinus noxius.*

3.2.1.3 Pink disease of Acacia

Pink disease in *A. mangium* was observed both in the base of the main stem and branches and twigs. Trees observed with pink disease (**Figure 5**) initially exhibited silky-like whitish mycelium on the surface of the bark, known as the 'cobweb' stage, infecting the branch and stem. Pinkish to salmon cobweb-like structures were observed soon after known as the pustule stage, and subsidiaries symptoms of wilting of the branch's foliage and subsequently turned brown and branches that extending to all parts of the plant until dieback observed by death in the canopy. Infected branches and stems showed sign of bark crack and scaled bark. Where infection was observed centralised in certain areas of the stem or bark, cankers and wounds developed. In this

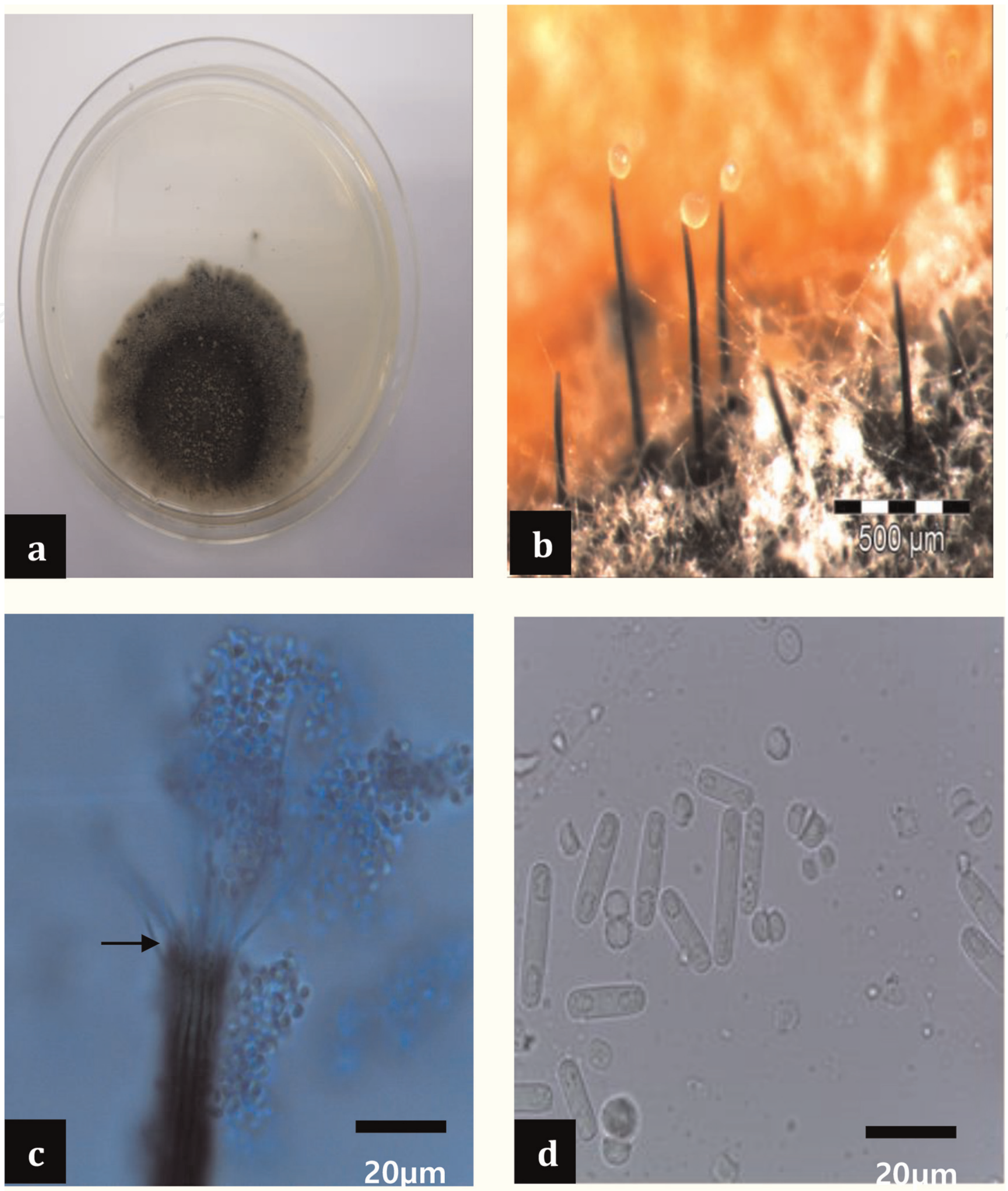

Figure 3.
Microscopic structures of identified Ceratocystis fimbriata *obtained from* Acacia mangium *plantations in Sarawak* ***(a–d);*** *(a) culture of* C. fimbriata *grown on MEA appeared cotton-like, sparse, initially white, later turning to olive grey with white to grey at the margin after 5–7 days with banana-like aroma and salmon-like shiny globose spores; (b) Salmon-like colour ascospores mass extruded at the tips of the long-necked black fruiting bodies (perithecia); (c) long, divergent ostiolar hyphae (arrow); (d) spores of* C. fimbriata., Thelaviopsis *sp.- elongated, cylindrical condia of* Thelaviopsis *sp. (imperfect state) and hat-shaped ascoscopres of* C. fimbriata *(teleomorph or perfect state).*

survey, we observed severe infection in one PSP in Sibu region and inflicted mortality of the tree stands. The symptoms described above showed similarity with the symptoms described [24] and thus, the pathogen of pink disease was identified as *Erythricium salmonicolor.*

3.2.2 Diseases of E. pellita

3.2.2.1 Root rot disease of E. pellita

Root rot disease infecting *E. pellita* in this study was observed to be very detrimental and trees dying in patches. The first signs typical of root rot disease attacked

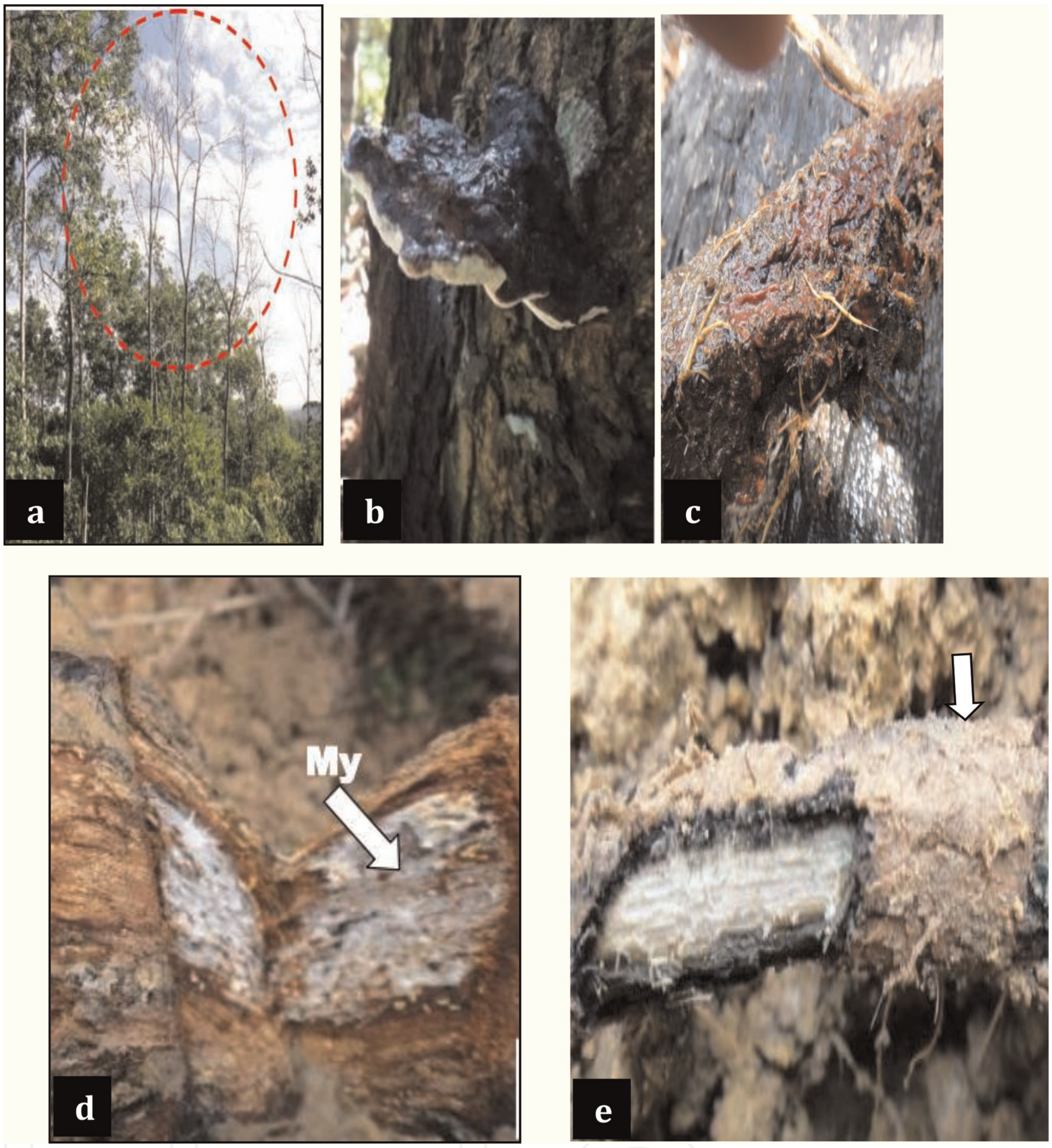

Figure 4.
Root rot disease of Acacia mangium*; (a) 10-year-old trees with severe defoliation and open gaps are the most advanced symptoms of the disease; (b) Ganoderma fruiting body on infected trees; (c) red-coloured leathery rhizomorphs with blackish exudates on infected roots; (d)whitish mycelium on the under bark; (e) Brown root rot caused by the pathogen* P. noxious *with soft roots, fibrous and totally rotten and sand like soil (arrow adhering to the rhizomorphs).*

were yellowing of the foliar, and falling with twigs and branches die. The whole crown seems to be burnt-like (**Figure 6a**) and subsequently, the tree died with the tree became bare. The base of the stem and roots appeared rotten, and discolouration of bark stem was observed with fine white threads typical mottled pattern of mycelia growth below the bark (**Figure 6b**). Fruit body body's shape is like a fan, semicircular, hard and woody and the bottom surface is white; the upper middle is dark brown and measured around 50 cm was seen growing on the stem's base. The roots were then uprooted revealing red leathery rhizomorph covering the root system. Following the symptoms observed especially the characteristic of the fruiting found on the tree, the pathogen was identified as *G. philippii [25]*.

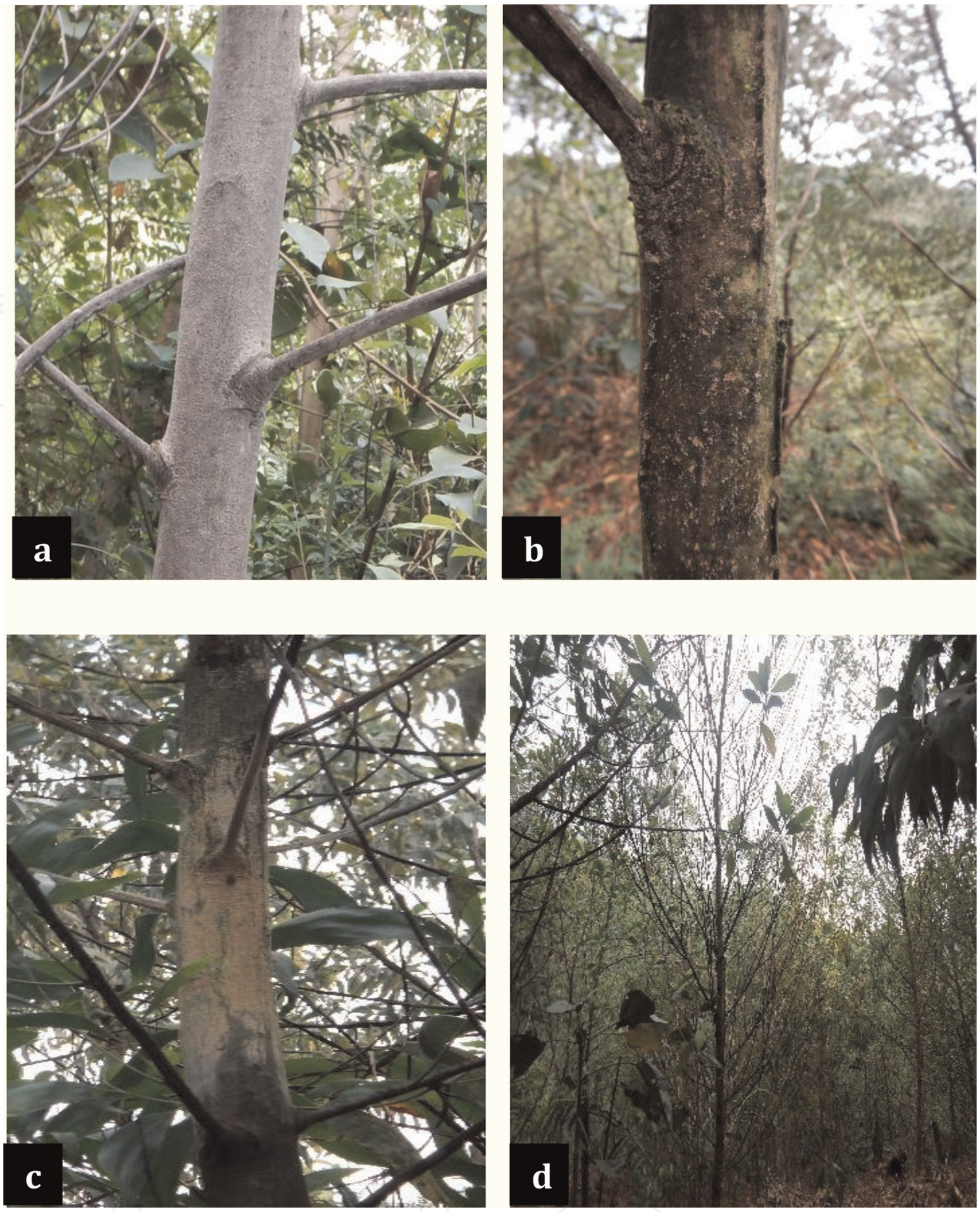

Figure 5.
Erythricium salmonicolor *pink disease in* a.mangium. *(a)* E. salmonicolor *'cobweb' stage of infection.; (b)* E. salmonicolor *'pustule stage; (c) incrustation pink cobweb-like colonies on upper stems; (d) patches of tree death caused by the pink disease pathogen* E. salmonicolor.

3.2.2.2 Canker disease of E. pellita

Symptoms of canker disease of *E. pellita* varied in each region where it was detected. Canker found in 13- to 11-year-olds (**Figure 7a–e**) in Kuching was found some at the base of the stem and others slightly higher up the stem (**Figure 7b**). The cankered stem characteristics are swollen and misshapen and the bark fissured with traces of drying blackish gummosis, but all trees were still alive without any sign of dying. The canker found in 2-year-old PSP trees stand in Bintulu showed characteristic of the whole bark cracking with stems blackened and leaves yellowing and wilting with mortality recorded. Based on the different symptoms observed in PSPs assessed, there were possibilities that more than 1 pathogen caused this disease. A small portion of the bark of one tree in 2-year-old stand in Bintulu region was collected for

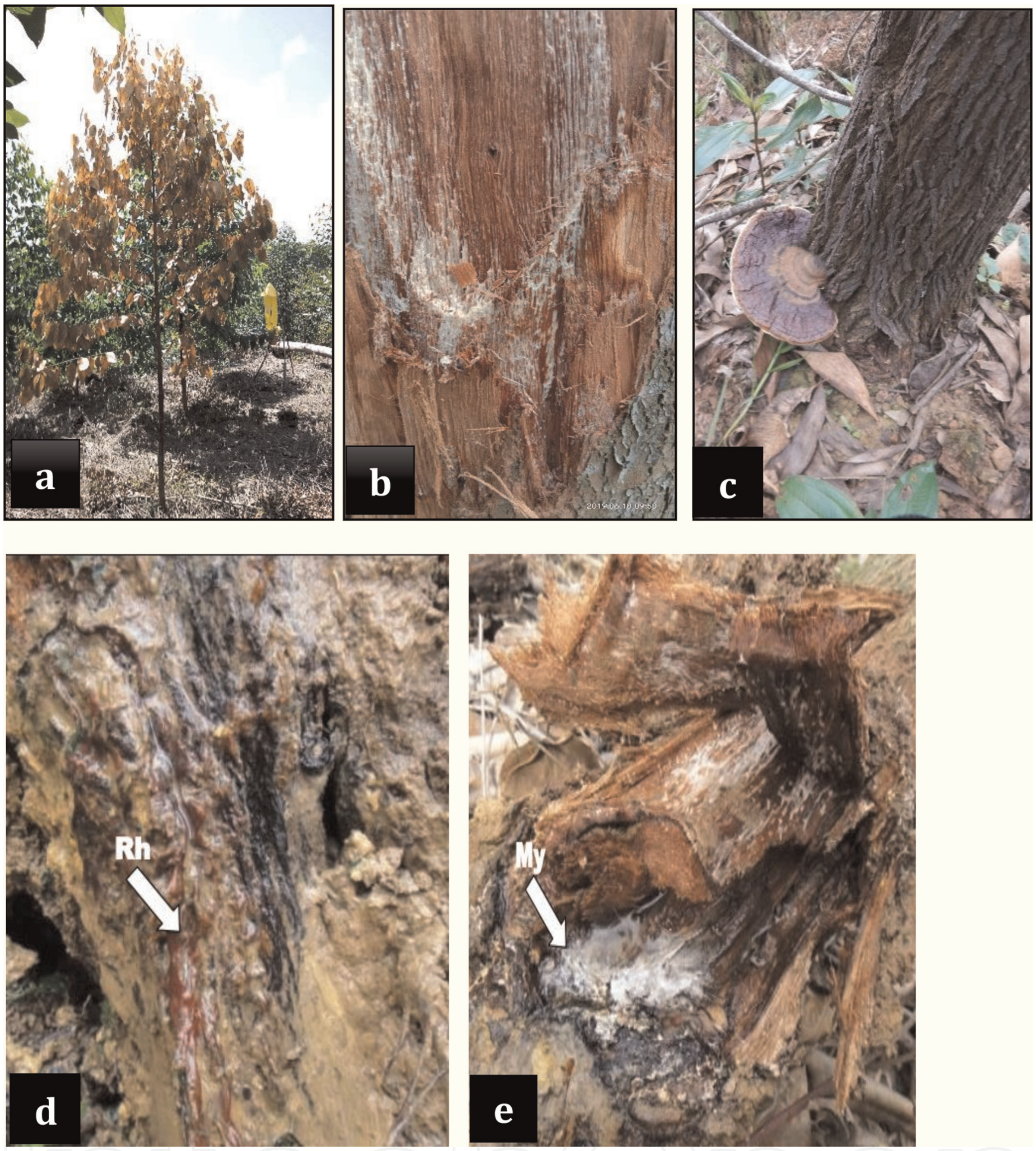

Figure 6.
Root rot disease of Eucalyptus pellita*; (a) 6-month-old tree with burned like foliar and blackish stem; (b) mycelium on under the bark of the basal stem; (c) Ganoderma root rot fruiting body; (d) red-coloured leathery rhizomorphs with blackish exudates on* E. pellita *root; (e) rotting and fibrous root system.*

examination in the laboratory. We managed to identify the pathogen as Botryosphaeriaceae based on the conidia and the culture characteristic grown on MEA as guided (**Figure 8**) [26, 28].

Based on silviculture regimes were not recorded by the management of the plantation. It was observed weeding was not incorporated into the silviculture regime.

3.2.2.3 Ralstonia solanacearum*—bacterial wilt of Eucalyptus*

The symptoms started with foliar exhibiting chlorotic, yellowish to reddish and gradually spreading to the branches started to wilt and trees will succumb to mortality. The inner stem exhibits vascular discolouration of blackish to brownish and bacterial ooze from the wood when observed using a hand lens (**Figure 9**). The

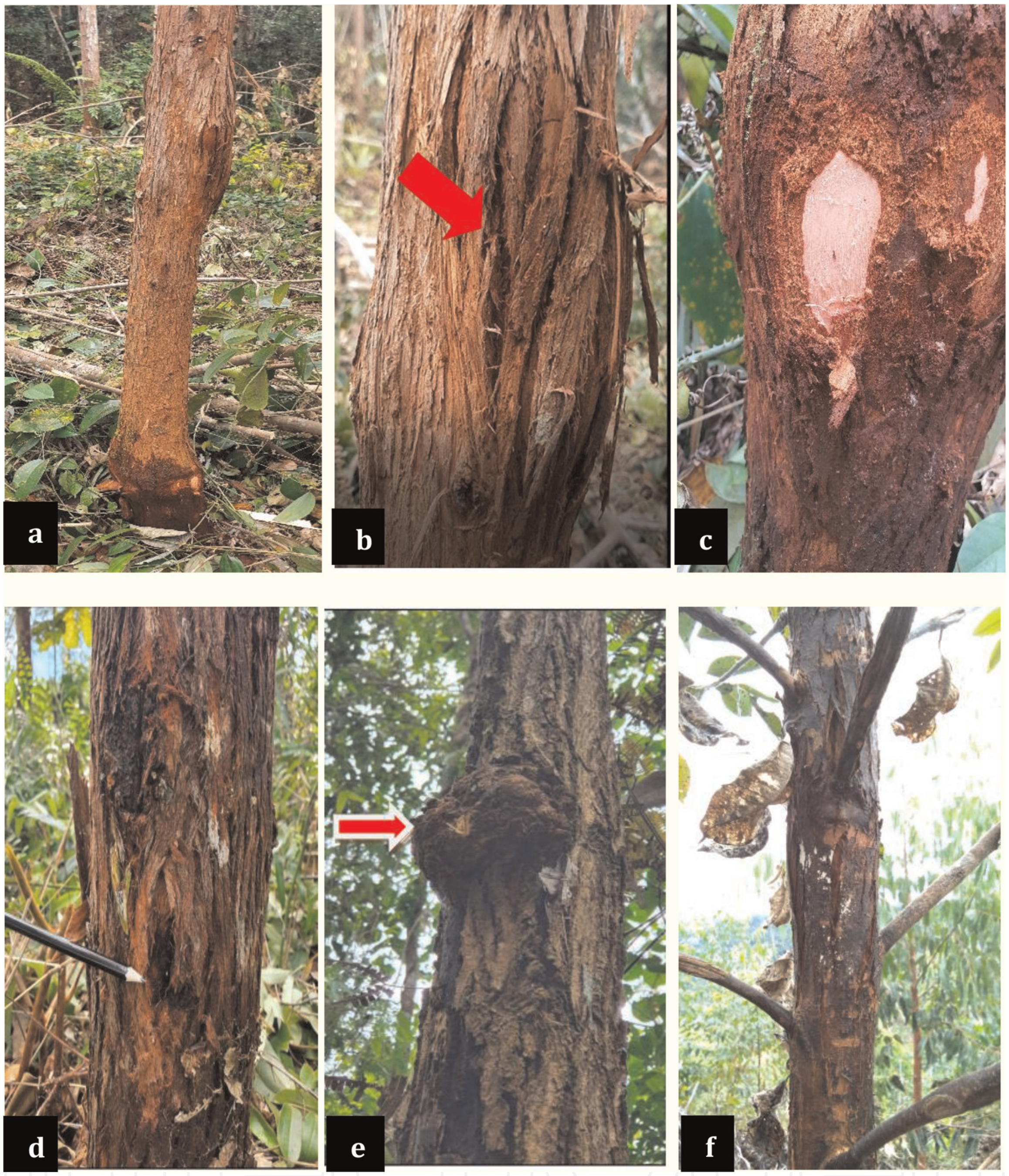

Figure 7.
Canker disease symptoms of Eucalyptus pellita*; **(a–e)** stem cankers on 11-year-old* E. pellita *(a) double' canker at basal and middle stem on 11-year-old; (b) close-up showed cracked and fissured bark on 11-year-old; (c) wood under bark seems to be healthy on 11-year-old; (d) canker developed from injury because of self-pruning and on 11-year-old (e) upper stem canker with swollen bark on 11-year-old; (f) huge canker swelling on 2-year-old* E. pellita *at Bintulu region.*

infected trees were chopped and burned. The possible pathogen would be *R. solanacearum* Smith based on disease symptom described [29, 38].

3.2.3 Disease of Falcataria molluccana

3.2.3.1 Uromycladium falcatarium*—gall rust of* F. molluccana

The disease was observed to cause severe damages and mortality to young trees of *F. mollucana*, especially in the Miri region. The disease causes severe damage to all

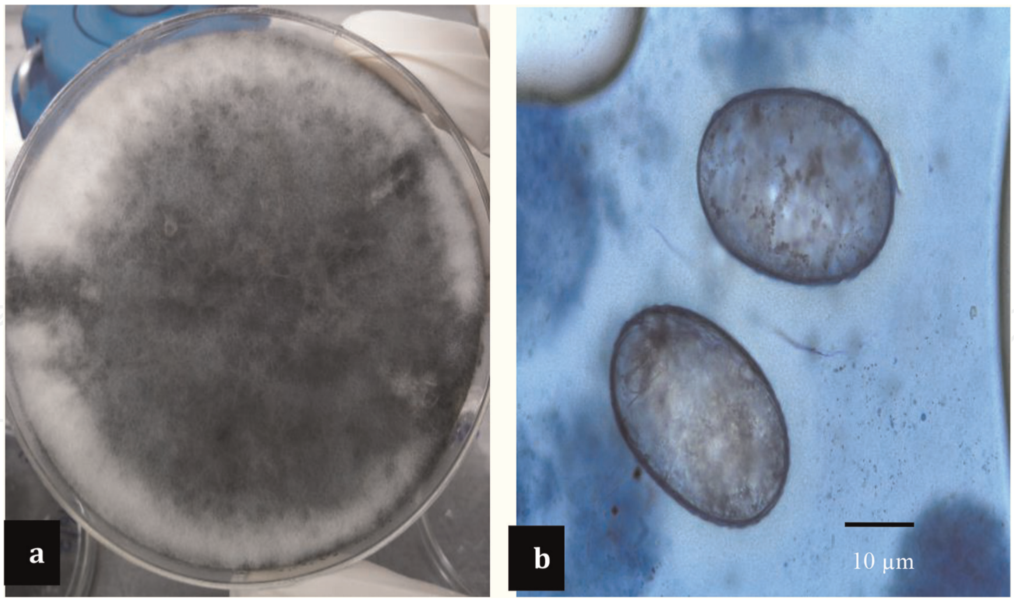

Figure 8.
Botryosphaeriaceae pathogen of canker disease of Eucalyptus pellita*. (a) Culture morphology on MEA; (b) conidia of* Botryosphaeria.

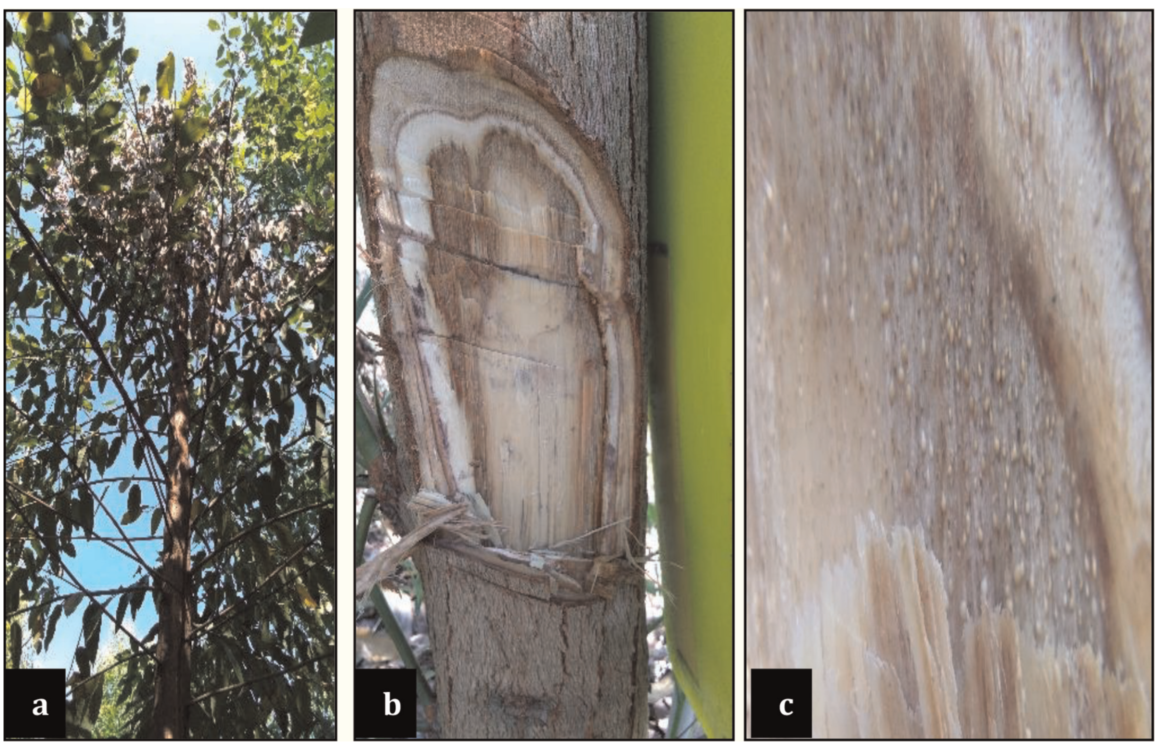

Figure 9.
Bacterial wilt sign and symptoms in Eucalyptus pellita*. (a) Wilting and drying branches symptom on 1-year-old eucalyptus; (b) colour changes turning blackish-brown on eucalyptus 1-year -old stem further symptoms (c) bacterial exudates (ooze) on wood.*

developmental stages of the plant, from seedlings in the nursery to mature trees in the field. Early symptom of infected trees observed was rigid, crooked bending stems, branches or shoot and greenish to reddish necrotic lesion (**Figure 10b**). The symptoms then developed to the development of large chocolate-brown, irregularly shaped, broccoli-like or whip-like galls on the stem and branches (**Figure 10c**).

Figure 10.
Gall rust of F. mollucana*. (a) Whole crown dieback and tree died in 2-year -old tree stands at Miri region; (b; c) the shape of gall in the twig; (d) spores with ridged longitudinal striations typical of* Uromycladium falcatarium *pathogen.*

The disease pathogen was identified as *U. falcatarium* based on the symptoms observed in this study as well as referred [30]

4. Discussion

This is the first baseline data of disease incidence (DI) of the current as well as emerging pathogen threats to plantation forests in Sarawak. It comprised about 5 years of field surveys as well as monitoring the health on a yearly basis. PSPs were established randomly across all the four regions of Sarawak and were representative of the 521702.27 ha of exotic tree species. Overall, seven species of plant pathogens were recognised as either current or emerging threats to the forestry sector. *Ceratocystis fimbriata* is of the greatest concern due to its significant increase in geographical range, the successive rotation and fear of spread or 'jumping host' from Acacia to other species such as *Eucalyptus*.

4.1 Diseases of Acacia

4.1.1 Root rot disease

This disease is considered one of the most important diseases of *A. mangium* plantations in Indonesia and Malaysia [2, 5, 15]. The pathogen builds up in every successive rotation and caused tree mortality in trees as young as 3-month-old in particular in the 2nd and 3rd rotation trees based on observation. Tree death can exceed 50% in some areas within less than 20 years of establishing the first rotation [6]. The trees with symptoms of root rots were adjacent to one another. It is a known fact that the root systems of trees are entangled with one another, and thus, one infected root will have higher possibility of infecting the roots of the tree next adjacent. As such, the trees infected with root rot appeared to be centralised and clustered in patches that were roughly circular. The nearer the planting distance, the probability spread of infection will increase exponentially.

Currently, the spread of root rot diseases is control by excavating and destroying the infecting trees as well as construction of drainage trenches filled then with fungicides, which will probably minimise the roots contact of infected trees to healthy trees adjacent. However, mostly all plantation owners commented that such practices is not economically viable and opted to just leaving the infected trees as it are. From general overview, root rot disease will always be a menace as the pathogen fungi, which are present in native forest left in infected stumps and roots when native forest is cleared for plantations, and these then act as inoculum sources and it will definitely increase with successive rotation [5]. Land preparation and silviculture management are the only way to minimise the inoculum build up as the wood debris left after planting will act as the food source of the fungi.

4.1.2 C. fimbriata complex-*Ceratocystis wilt disease*

The pathogen emerged as a force to be reckoned with, as with the concerns about the vitality and survival of Acacia plantations in Indonesia, Vietnam and Sabah since 2010. It had created havoc on the tree plantation industries in Indonesia and resulted in the replacement of approximately 600, 000 ha of *A. mangium* plantation with *E. pellita* and its hybrid [1, 3, 4]. The disease was first observed in Sarawak in early 2010 in the Bintulu region, infected not more than 10 trees adjacent to the roadsides and trees in the vicinity of the conservation area and buffer zone. Over the years, based on observation and feedback from plantation company personnel who worked on the ground, the number of infected trees is increasing and spreading to the region of Sibu, Miri and Kuching as well. Compared to root rot pathogen modes of spread through root contact, the spread of Ceratocystis pathogens through air and water could be considered rapid especially when the trees were inflicted with wounds made by pruning, animal damages such as squirrel observed in the Bintulu region. However, one most important discovery in some of the surveyed plots in Bintulu region was some infected trees showing sign of recovery from the infection with new sprouts growing out from the trees.

This could indicate resistance and/or tolerance of some of the individual trees. It was later found out that the plantation company has planted improved clones in their area. This justifies that breeding of disease should be actively pursued as a tool to help with the growing problem of invasive pests and pathogens that threaten our forests. However, resistance breeding is sometimes viewed as being too long term (5 years) and too expensive to be practical as lack of scientific understanding between planters and scientists in the matter concerned [16].

There are some assumptions that wood-boring insects could have the possibilities of harbouring the pathogen in their gut and acting as a vector of the disease; however, no concrete studies have been able to prove this theory. The attempted isolation of Ceratocystis from the carcass of the ambrosia beetle collected during the survey using the carrot bait method but none bore any traces of the pathogens, thus concluding that it did not harbour the fungus and thus not the vector in this specific study. Therefore, we presume the wood-boring beetle found is most probably due to secondary infestation caused by abiotic tree stress.

4.1.3 Pink disease

Currently, the pink disease caused by the pathogen *U. salmonicolor* was never been considered a major threat to Acacia plantations as compared to root rot and *Ceratocystis* wilt [23] disease as the reports of the pink disease were very few and it assumed that Acacia species particularly *A. crassicarpa* seems to be resistant to the fungal pathogen of *U. salmonicolor* [24, 33]. In Sarawak, the earliest occurrence of pink disease on *A. mangium* was recorded in 1979 and it reached epidemic proportion in 1987 [34]. The mortality inflicted by this pathogen observed in 2-year-old *A. mangium* indicated that this disease should be taken seriously. As the spores could travel by wind and water, it will be a threat to nurseries and early establishment of seedlings planted.

4.2 Disease of Eucalyptus

4.2.1 Canker disease

Several fungi are known to cause stem cankers in eucalyptus, among them *Botryosphaeria* spp., *Chrysoporthe deuterocubensis* and *Teratospaeria zuluense* (syn. *Coniothyrium zuluense*) [18]. *Chrysoporthe deuterocubensis* is a widespread and important pathogen of plantation eucalypts in the tropics. Basal cankers caused by *C. deuterocubensis* can extend several meters up the stem and have the ability to kill young trees. Where stems have been girdled, young trees may wilt and die suddenly during hot and dry weather [8, 9, 39]

Older trees of 11 to 12 years in the Bintulu region at the first rotation that exhibit symptoms of canker in this assessment are growing well and without any concern for mortality. The wood under bark seems to be healthy without any signs of lesion or discolouration although gummosis is present on the canker stem. This might be that trees normally could have survived the initial infection and only will develop basal swellings and severe bark cracking over brown necrotic sapwood [7]. However, younger trees of 2-year-old in this study recorded mortality. The trees are currently in 2nd rotation planting; thus, it could be concluded that DI and severity, as well as tree mortality in especially young *E. pellita* plantations, can thus only be expected to increase after the species has been grown for several rotations on the same site [5].

4.2.2 R. solanacearum*—bacterial wilt of Eucalyptus*

Bacterial wilt disease of Eucalyptus will pose a difficulty to contain as *R. solanacearum* sensu lato is known to be a destructive bacterial phytopathogen that is able to cause bacterial wilt in over 50 plant families growing in tropical, subtropical and some temperate areas globally [35]. Bacterial wilt arises from the blockage of the xylem tissue by bacterial growth, thereby resulting in wilt symptoms in the aerial parts of infected plants that ultimately die. The symptoms are very much similar to Ceratocystis wilt disease with the inner stem exhibiting blackish-brown. However, to distinguish between the latter and bacterial wilt disease, examination of the plant stem using a hand lens will be required to observe bacterial oozing (**Figure 7**). As with many pests and diseases, the technology of breeding and selection of disease and insect cultivars should be the key to minimising damage and ensuring the productivity of tree plantation industry [35, 36]. However, the process requires scientist to weigh many factors that include pathogen diversity, prevailing environmental conditions and the availability of material for breeding as well to make the management level understand that process is lengthy that requires at least 1 cycle rotation (8–9 years) planting and costly to begin with.

4.3 Disease of *F. mollucana*

Gall rust was found as the predominant disease of *F. mollucana* in part of Miri and Bintulu regions. It was first reported by some plantation owners back in 2012; however, the disease only affected the seedlings in the nursery. The source of infection was deduced from the seeds imported from the island of Jawa Indonesia. This could be related that Indonesia had experienced the major outbreak of the disease, which affected much of *F. molluccana* plantation estate in Java in 2010 [12].

The plantations affected were those of higher elevation of more than 152 m asl with spacing of 3 m^2 that could be considered to be a close gap between trees. The pathogens thrive in an environment with elevations ranging from 152 m asl to 975 m asl, in trees ages 1-year-old to 9-year-old, and spacing between 6 m^2 to 16 m^2 [14] and require fog or mist as well as high relative humidity to ensure infection [13] (m)

4.4 General overview

The loss of yield due implicated by insect pests and pathogens attacks could hamper the overall maximum production yield of the plantation forest. Sarawak, in recent years, has observed the dramatic losses of *A. mangium* plantation in its neighbouring country Sabah due to the incidence of a serious canker and wilt disease caused by *Ceratocystis acaciivora* [3], the conversion of 1 million hectares of the *A. mangium* plantation estate in Indonesia to *E. pellita* Muell. and related hybrids over the past 5 to 10 years as detailed by [4]. These critical developments have since propelled the forest plantation industry players in Sarawak to be more cautious and attentive to any signs of threats especially caused by fungal pathogens.

Insect pests have not been associated with widespread mortality or failure of any acacia plantations in Sarawak so far. However, an investigation survey conducted in early 2022 to determine the cause of mortality in one of *A. mangium* superbulk plantations in the Bintulu region revealed that termite's infestation further identified as *Coptotermes travians* appeared to be the most prevalent pest that had inflicted tree mortality in the area, which accounted for 24.1% in mortality of trees.

The tree plantations in Sarawak are currently in the second rotation planting but will soon enter the third rotation of planting, and the concerns of increasing pests and diseases attack will definitely be inevitable [10, 11]. There is growing concern that *A. mangium* may no longer be capable of producing commercial yields after three rotations [32]. Significant reductions in productivity have been reported with each successive rotation and reductions have frequently been associated with mortality caused by fungal pathogens [17].

Thus, Sarawak is looking for other alternative tree species to compliment or maybe even replace *A. mangium*. *E. pellita* and its hybrid are seen to be the next species of choice as Eucalyptus species are easy to hybridise as compared to Acacia species, which is due to the long time and the low productivity in multiplication due to the ageing effects [37]. By theory, hybrid clones combine fast growth, increased tolerance to pests and diseases, excellent rooting ability, as well as wood quality suitable for different uses [27].

Other tree species such as *F. mollucana* seem to be at a lower risk of pathogen attack; however, through observation and communication with planters, insect pests such as defoliators moth and borers will contribute to lower quality of the woods produced although mortality caused by these pests are expected of less concern. New exotic species of that Paulownia are slowly making a wave in Malaysia, and some planters in Sarawak are experimenting in planting this tree on a small scale.

The diagnosis and determination of the cause of any damage or disease on a tree can only be made when the trees are still alive. Once the tree is dead, it is very difficult if not impossible to determine the cause of the problem. Therefore, it is very important that tree health inspections and pest and disease surveys are carried out at regular intervals to enable recognition of early signs and/or symptoms of pests and disease infection.

Once recognised, the initial stages and the development of symptoms can be followed until the death of the tree. This would go a long way towards better identifying the causes of tree mortality in the plantations. By so doing, instead of just encountering a dead tree during a random inspection, one would have detailed information about when the symptoms first appeared, their pattern of development and spread, mode and rate of spread, and thus a better idea of the agent(s) involved. It is, therefore, very encouraging that the management has decided to set up pest and disease monitoring transects in the young plantations.

As such, different strategies should be employed in better managing the threats of pests and disease, such as good silviculture, increasing the knowledge of proper identification of pathogens and pests threats among the planters, sharing of knowledge and more transparent in R&D data and information between different companies in Sarawak particularly, management consideration in acknowledging that R&D especially tree pest and disease surveillance, as basis it seems but the information gain is invaluable to predict the next outbreaks and to better contain the damages.

5. Conclusion

In view of the survey done in the period of 5 years through FHS, Ceratocystis wilt disease of *A. mangium* emerged as a major disease in hampering the progress of the

Sarawak forest plantation industry. Research effort must be intensified in making sure *A. mangium* could make it to the subsequent rotation. Although *E. pellita* and its hybrid are making a hype to replace *A. mangium* as the main species planted, diseases such as bacterial wilt and canker disease will be a major problem to planters later on if no countermeasure is readily in place.

Acknowledgements

This study was financed in part by the Sarawak State Government under the Ministry of Natural Resources and Urban Development (Rancangan Malaysia Ke-11) under the project titled 'Centre of Excellence for Planted Forest'. We acknowledge the support received from Datu Hamden Bin Haji Mohammad, Director of Forest Sarawak, and as well the assistance rendered by members of the Forest Health Unit (Erica Hadari, Lily Encharang, Jonnidi Suib and Jaies Chankul) throughout this study, and especially, the surveys and collection of diseased samples are highly appreciated.

Author details

Annya Ambrose[1,2], Jack Liam[2] and Razak Terhem[1*]

1 Laboratory of Forest Pathology and Tree Health, Department of Forestry Science, Faculty of Forestry and Environment, Universiti Putra Malaysia, Selangor, Malaysia

2 Laboratory of Forest Pathology, Industrial Forest Research Centre, Forest Department Sarawak, KM20 Jalan Puncak Borneo, Sarawak, Malaysia

*Address all correspondence to: razakterhem@upm.edu.my

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