INFLUENCE OF *Chrysoporthe deuterocubensis* CANKER DISEASE ON THE BASIC PROPERTIES, DURABILITY, AND MACHINING OF INFECTED *Eucalyptus urograndis* LUMBER

By

RASDIANAH BINTI DAHALI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

November 2023

IPTPH 2023 6

DEDICATIONS

To my dedicated supervisory committee members

DR. LEE SENG HUA
PROF. DR. PARIDAH MD TAHIR
&
DR. ADLIN SABRINA MUHAMMAD ROSELEY

To my inspiring mentors

PROF. DR. ZAIDON ASHAARI
&
ASSOC PROF. DR. EDI SUHAIMI BAKAR

To my beloved late father

DAHALI BIRO

To my gorgeous mother

DARIAH SELAMAT

To my lovely family members

HAMZAH, DARWIN, ZAFRI, DAHLAN, MOHD YUSUF, DAHLIA, RASHID, MASRI
&
SITI RAHMAH

and

To my kindest friends and colleagues

KHOO PUI SAN, ELDYJANE, ATIKAH, AHMAD SAFWAN, INTROPIAN
&
FORESTRIAN

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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RASDIANAH BINTI DAHALI

November 2023

Chair : Lee Seng Hua, PhD
Institute : Tropical Forestry and Forest Products

This study investigated the influence of canker disease caused by *Chrysoporthe deuterocubensis* on the basic properties (physical, mechanical, and chemical composition), durability, and machining properties of *Eucalyptus urograndis* (*E. urophylla* x *E. grandis*) trees. Samples were collected from infected and healthy trees and grouped into four different classes, such as healthy (class 1), moderately infected (class 2), severely infected (class 3), and very severely infected (class 4). These classes have been developed according to the severity of the of the infection of *C. deuterocubensis* canker disease based on stem characteristics. The physical and mechanical properties were determined according to the standard test procedures specified by the ISO 13061:2014 and BS 373: 1957. The results showed that the severity of the infection had a significant impact on the physical properties of the wood. Infected wood had low EMC (10.1, 10.2, and 9.7%) and experienced less volumetric (Vol_{sh}), tangential (T_{sh}), and radial (R_{sh}) shrinkage. As a result, hydrophobicity and dimensional stability generally increased. Nevertheless, it had poorer strength compared to healthy wood. Wood from moderately and severely infected trees exhibited reduced mechanical properties, making it suitable for non-structural applications. Further investigation is needed for wood from severely infected trees to determine its suitability for structural purposes, as it obtained a higher MOR (96.4 MPa) and MOE (12.7 GPa). The primary reason for the changes in wood properties was attributed to changes in chemical constituents. The chemical composition of wood was determined according to neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL). These analyses revealed changes in the chemical composition of infected wood, with reductions in both cellulose (53.20 to 45.42%) and hemicellulose (14.13 to 13.91%) content and increased lignin (18.12 to 20.50%) and extractives (14.29 to 19.96%). Fourier transform infrared analysis (FTIR) confirmed the findings. Generally, infected wood behaves better than healthy wood in terms of durability against fungi and termites. Likewise, infected wood showed changes in durability against fungal decay (*P. sanguineus* and *C. puteana*) and termites (*C. curvignathus*) based on a decrease in weight loss (WL). The durability analyses were determined according to procedures outlined in the ASTM D2017 and AWPA E1-09 standard procedure. The results were presented in this study and showed it was shifted from resistance (II) to highly resistance (I) and from very poor (V) to moderately resistance (III), respectively, compared to healthy wood. The machining properties (sawing, planing, and boring) and surface roughness of the machined samples were also assessed. Prior to machining properties, the samples were prepared according to ASTM D 1666-11 standard. Overall, *E. urograndis* of different infection severity classes has very good machining properties, ranging from grade I (very good) to grade II (good) for each machining property tested. Meanwhile, the lowest individual board grade was attained from grade I (very good) to grade IV (poor) in the planing test. Fuzzy grain, chip grain, chip mark, and tear out are the most commonly seen physical defects. As for surface roughness, wood samples from class 1 have lower surface roughness compared to those of infected trees from classes 2, 3, and 4, which indicates a better surface quality (smoother) with only a planing and boring test giving a statistically significant result. Furthermore, *C. deuterocubensis* infection of stem canker had an impact on sawn timber productivity, quality, and processing performance for the logs processed in this study. However, it still has the potential to produce high-recovery and quality timber. The infection classes 2 and 4 managed to gain >40% of timber recovery. Moreover, class 2 could attain a similar grade (SELECT to SERVICEABLE and SERVICEABLE AND BETTER) to class 1. Meanwhile for the value of timber per tonnage, all infected classes 2, 3 and 4 were having a lower value than class 1 (RM 293.01 and 955.74) for SELECT AND BETTER and STANDARD AND BETTER grade. Overall, infected *E. urograndis* showed potential for use in the timber industry, offering durability, machining suitability, productivity, and competitive wood products.

Keywords: *Eucalyptus urograndis*, *Chrysoporthe deuterocubensis*, infection classes, basic properties, durability, machining properties

SDG: GOAL 15: Life On Land

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

PENGARUH PENYAKIT KANKER *Chrysoporthe deuterocubensis* TERHADAP SIFAT-SIFAT ASAS, KETAHANAN DAN PEMESINAN KAYU *Eucalyptus urograndis* YANG DIJANGKITI

Oleh

RASDIANAH BINTI DAHALI

November 2023

Pengerusi : Lee Seng Hua, PhD
Institut : Perhutanan Tropika dan Produk Hutan

Kajian ini menyiasat pengaruh penyakit kanker yang disebabkan oleh *Chrysoporthe deuterocubensis* terhadap sifat asas (fizikal, mekanikal, dan komposisi kimia), ketahanan, dan sifat pemesinan pokok *Eucalyptus urograndis* (*E. urophylla* x *E. grandis*). Sampel dikumpulkan daripada pokok yang dijangkiti dan sihat dan dikelompokkan kepada empat kelas berbeza, seperti sihat (kelas 1), sederhana dijangkiti (kelas 2), dijangkiti teruk (kelas 3), dan dijangkiti sangat teruk (kelas 4). Kelas-kelas ini telah dibangunkan mengikut tahap keterukan jangkitan penyakit kanker *C. deuterocubensis* berdasarkan ciri-ciri yang terdapat pada batang. Sifat fizikal dan mekanikal ditentukan mengikut prosedur ujian standard yang ditentukan oleh ISO 13061:2014 dan BS 373: 1957. Keputusan menunjukkan bahawa keterukan jangkitan mempunyai kesan yang ketara terhadap sifat fizikal kayu. Kayu yang dijangkiti mempunyai EMC rendah (10.1, 10.2, dan 9.7%) dan mengalami pengurangan pengecutan isipadu (Vol_{sh}), tangen (T_{sh}), dan jejari (R_{sh}). Akibatnya, hidrofobisiti dan kestabilan dimensi secara amnya meningkat. Namun begitu, ia mempunyai kekuatan yang lebih lemah berbanding kayu yang sihat. Kayu daripada pokok yang dijangkiti sederhana dan teruk menunjukkan sifat mekanikal yang berkurangan, menjadikannya sesuai untuk aplikasi bukan struktur. Penyiasatan lanjut diperlukan untuk kayu daripada pokok yang dijangkiti teruk untuk menentukan kesesuaiannya bagi tujuan struktur, kerana ia memperoleh MOR (96.4 MPa) dan MOE (12.7 GPa) yang lebih tinggi. Sebab utama perubahan dalam sifat kayu adalah disebabkan oleh perubahan dalam juzuk kimia. Komposisi kimia kayu ditentukan mengikut gentian detergen neutral (NDF), gentian detergen asid (ADF), dan lignin detergen asid (ADL). Analisis ini mendedahkan perubahan dalam komposisi kimia kayu yang dijangkiti, dengan pengurangan dalam kedua-dua selulosa (53.20 hingga 45.42%) dan hemiselulosa (14.13 hingga 13.91%) kandungan dan peningkatan lignin (18.12 hingga 20.50%) dan ekstraktif (14.29 hingga 19.96%). Analisis inframerah transformasi Fourier (FTIR) mengesahkan penemuan itu. Secara amnya, kayu yang dijangkiti bersifat lebih baik daripada kayu yang sihat dari segi ketahanan terhadap kulat dan anai-anai. Begitu juga, kayu yang dijangkiti menunjukkan perubahan dalam ketahanan terhadap pereputan kulat (*P. sanguineus* dan *C. puteana*) dan anai-anai (*C. curvignathus*) berdasarkan penurunan kehilangan berat (WL). Analisis ketahanan ditentukan mengikut prosedur yang digariskan dalam standard prosedur ASTM D2017 dan AWPA E1-09. Keputusan telah dibentangkan dalam kajian ini dan menunjukkan ia telah beralih daripada rintangan (II) kepada rintangan tinggi (I) dan dari sangat lemah (V) kepada rintangan sederhana (III), masing-masing, berbanding kayu yang sihat. Sifat pemesinan (menggergaji, mengetam, dan melubang) dan kekasaran permukaan sampel mesin juga dinilai. Sebelum sifat pemesinan, sampel telah disediakan mengikut Standard ASTM D 1666-11. Secara keseluruhannya, *E. urograndis* dari kelas keterukan jangkitan yang berbeza mempunyai sifat pemesinan yang sangat baik, dari gred I (sangat baik) hingga gred II (baik) untuk setiap sifat pemesinan yang diuji. Sementara itu, gred papan individu terendah diperolehi daripada gred I (sangat baik) hingga gred IV (lemah) dalam ujian pengetaman. Serat bulu halus, serat serpih, tanda serpih dan sobekan adalah kecacatan fizikal yang paling biasa dilihat. Bagi kekasaran permukaan, sampel kayu dari kelas 1 mempunyai kekasaran permukaan yang lebih rendah berbanding dengan pokok yang dijangkiti dari kelas 2, 3, dan 4, yang menunjukkan kualiti permukaan yang lebih baik (lebih licin) dengan hanya ujian mengetam dan melubang memberikan keputusan yang signifikan secara statistik. Tambahan pula, jangkitan *C. deuterocubensis* terhadap kanker batang memberi kesan ke atas produktiviti kayu gergaji, kualiti dan prestasi pemprosesan untuk kayu balak yang diproses dalam kajian ini. Walau bagaimanapun, ia masih berpotensi untuk menghasilkan pulangan kayu yang tinggi dan berkualiti. Kelas jangkitan 2 dan 4 berjaya memperoleh >40% pulangan kayu. Selain itu, kelas 2 boleh mencapai gred yang sama (SELECT hingga SERVICEABLE, dan SERVICEABLE AND BETTER) dengan kelas 1. Manakala bagi nilai kayu setiap tan, kesemua kelas jangkitan 2, 3 dan 4 mempunyai nilai yang lebih rendah daripada kelas 1 (RM 293.01 dan 955.74) bagi gred SELECT AND BETTER dan STANDARD AND BETTER. Secara keseluruhannya, *E. urograndis* yang dijangkiti menunjukkan potensi untuk digunakan dalam industri perkayuan, menawarkan ketahanan, kesesuaian pemesinan, produktiviti dan produk kayu yang kompetitif.

Kata Kunci: *Eucalyptus urograndis*, *Chrysoporthe deuterocubensis*, kelas jangkitan, sifat-sifat asas, ketahanan, sifat-sifat pemesinan

MPM: MATLAMAT 15: Hidupan Atas Darat

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

ADF	Acid detergent fiber
AD	Air-dried
ASTM	American Society for Testing and Material
AWPA	American Wood Protection Association
ANOVA	Analysis of Variance
ATR	Attenuated total reflection
BRIS	Beach ridges interspersed with swales soils
BS	British Standard
Merchantable	Contain Prime, Select, Standard, Serviceable, Sound and Utility grade
DMR	Duncan's multiple range
EMC	Equilibrium Moisture Content
E. urograndis	*Eucalyptus urophylla* x *Eucalyptus grandis*
FSP	Fiber saturation point
FRIM	Forest Research Institute Malaysia
FTIR	Fourier Transform Infrared
-OH	Hydroxyyl group
ISO	International Organization for Standardization
LEDOB	Large end diameters over bark
LEDUB	Large end diameters under bark
MIDA	Malaysia Investment Development Authority
MARDI	Malaysian Agricultural Research and Development Institut
MGR	Malaysian Grading Rules
MS	Malaysian Standard

MTC	Malaysian Timber Council
MTIB	Malaysian Timber Industry Board
MPIC	Ministry of Plantation Industry and Commodities Malaysia
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
MC	Moisture Content
NATIP	National Timber Industry Policy
NDF	Neutral detergent fiber
ns	No significance
n.a	Not applicable
OD	Oven-dried
RH	Relative Humidity
rpm	Revolutions per minute
SEDOB	Small diameters over bark
SEDUB	Small diameters under bark
SMS	Special Market Specification
SG	Specific Gravity
SNI	Standar Nasional Indonesia
SS	Sum of squares
TAPPI	Technical Association of Pulp and Paper
H_2O	Water

LIST OF SYMBOLS

R_a	Average roughness of a surface
CO_2	Carbon dioxide
$Com_{//}$	Compression strength parallel to the grain
$Com_{\perp}$	Compression strength perpendicular to the grain
m^3	cubic metre
°	Degree
°C	Degree celcius
Df	Degree of freedom
R_z	Difference between the tallest peak and the deepest valley in the surface
′	Feet
ft	Feet
GPa	Giga Pascal
g	Gram
H_r	Hardness at radial axes
H_t	Hardness at tangential axes
h	Hour/s
″	Inches
kg	Kilogram
kg/m^3	Kilogram per cubic metre
$<$	Less than
$\leq$	Less than or equal to
R_{max}	Maximum roughness depth (Rmax
MPa	Megapascal

m^3	Metre cubic
mm	Milimetre
>	More than
≥	More than or equal to
R^2	Multiple Regression (R-squared)
%	Percentage
±	Plus, and minus
R_{sh}	Radial shrinkage
cm^{-1}	Reciprocal wavelength
s	Second/s
$Shear_{//}$	Shear strength parallel to the grain
$Shear_{\perp}$	Shear strength perpendicular to the grain
T_{sh}	Tangential shrinkage
V_{sh}	Volumetruc shrinkage
WL_{decay}	Weight loss due to fungal decay
$WL_{termite}$	Weight loss due to termite attack

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Because of its superior material properties, wood has been used by humans throughout history. Although the use of timber in some markets has decreased, overall consumption of timber has increased. Thus, the global demand for wood and forest products from natural forests has increased year after year, and this trend is expected to continue in the foreseeable future (Elias & Boucher 2014; Hasyim et al., 2015). Nonetheless, the Malaysian wood industry has been experiencing a decline in wood supply since 1995. (Abdul Rahim & Mohd Shahwahid, 2009). The increase in demand and supply of commercial hardwood from natural forests is insufficient to meet the needs of the industry (Zaidon, 2017). Furthermore, the growth rate of native trees from natural forests is slower, and these species are scarce (Chua et al., 2023). Another reason for this is uncontrolled logging, which has resulted in a significant reduction in natural forest area, which has an impact on future supply (Ellisa et al., 2019; Pearson et al., 2017).

Due to the limited supply of wood, manufacturers and industry players have shifted their focus to developing non-native species plantations in a variety of locations around the world, particularly in the tropics and subtropics (Foroughbakhch et al., 2017; Malan, 2005). National and international markets are increasingly demanding greater quantities and higher quality primary forest products (Botman, 2010). As a result, there is a need to supplement the current system of using natural forests with commercial forest plantations managed according to sustainable criteria. This method of production would provide primary materials to the forest industry from more suitable terrain, relieving the current pressure caused by the use and exploitation of rapidly dwindling and degrading natural forests (Foroughbakhch et al., 2017).

Forest plantations in Malaysia started with planted a selected commercial timber tree such as Nyatoh taban (*Palaquium gutta*), Rambung (*Ficus elastica*), Teak (*Tectona grandis*) and Mahogany (*Swietenia macrophylla*) plantations at several locations in Selangor, Malacca, Perak and Kedah before the turn of 20th century (Appanah & Weinland, 1993; Krishnapillay, 1998). Then follow by exotic forest tree species including *Acacia mangium*, *Gmelina arborea*, *Maesopsis eminii* and *Paraserianthes falcataria*. Due to better site adaptability and growth performance, *Acacia mangium* is the main plantation species being planted in Malaysia with a total area of 300,000 ha. *A. mangium* was planted for the manufacture of pulp logs and chips on a 5 to 7-year rotation (Midgley et al., 2002; Harwood and Nambiar, 2014).

Unfortunately, as disease threats emerged, interest in forest plantations waned. Several diseases, including gall rust, heart rot, and red root rot disease (associated with *Ganoderma philippii*), caused high mortality in mature *Acacia mangium* plantations (Ratnasingam et al., 2021; Glen et al., 2009; Lee, 2003). In this scenario, the forest plantation programme fell short of expectations, resulting in the suspension of planting activities and significant financial losses. The most recent was for *Ceratocystis* spp. caused fast-spreading stem wilt-canker (Maid and Ratnam, 2014; Lee et al., 2018). The disease was first discovered in the Indonesian province of Riau on the island of Sumatra. Ceratocystis emerged as a new disease threat to Acacia plantations in 2010, killing many young trees (Lee, 2018).

In Sarawak, *Ceratocystis* wilt was first observed in one *A. mangium* plantation in late 2011, infecting a small group of about ten trees in one stand. The disease has not recurred in that particular stand after removal of the infected trees. *Ceratocystis fimbriata* is also known to cause moldy rot on rubber in Peninsular Malaysia (Thompson and Johnston, 1953; Lee et al., 2018). Meanwhile in Sabah, about 30,000 ha of Acacia plantations was destroyed by this disease which cost the country dearly. After 25 years of operation, it has been confirmed that *A. mangium* and its hybrids are severely harmed by the fungus Ceratocystis in Sabah, Sarawak, and Peninsular Malaysia (Japarudin et al., 2020; Ambrose et al., 2022; Lee, 2003).

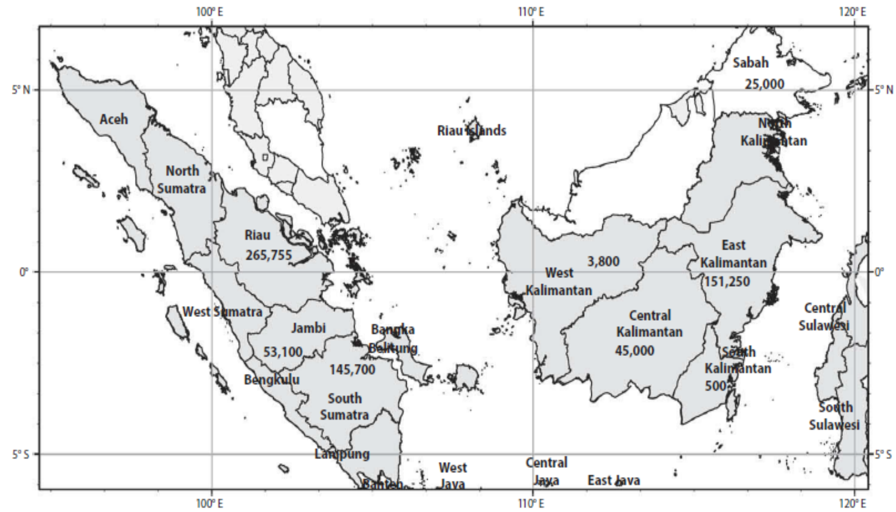

Figure 1.1 : Distribution of plantations area in ha, where *A. mangium* has been replaced with *E. pellita* and Eucalyptus hybrids in regions of Sumatra, Kalimantan and Sabah from 2012 to mid-2017
(Sources: Hardiyanto, 2017)

As a result, the planters in Sabah and Sarawak, where Ceratocystis caused significant damage, shifted from growing *A. mangium* to Eucalyptus species (Lee, 2018). This is due to the widespread presence of Ceratocystis disease, which killed 10 to 20% of Acacia trees in plantations (Wong et al., 2015). The same experienced was also happened in Sumatra and Kalimantan, Indonesia plantation those switched from planting *A. mangium* to *Eucalyptus* spp. as reported (Tarigan et al., 2011; Hardiyanto 2017; Nambiar et al., 2018; Lee et al. 2018) (Figure 1.1).

The fact that *A mangium* has very low variability and few genes for resistance to *Ceratocystis* sp. is one of its drawbacks (Brawner et al. 2015). In comparison to *Eucalyptus* spp., there are more than 1,000 species of Acacia (Brune, 2022; Boland et al. 2006), but only a few have commercial growth potential, whereas the genus Eucalyptus has over 700 species, at least 25 of which are grown in tropical and subtropical regions around the world, with numerous possibilities for hybridization and cloning. This implies that, under ideal circumstances, selection progress for resistance will be very slow through tree generations (Brune, 2022).

Most Eucalyptus grow naturally in low-nutrient soils, although they can adapt to more fertile circumstances (particularly greater levels of nitrogen and phosphorus) with faster growth rates. The reaction to increased soil fertility differs per species. Soil depth is a crucial factor for tree growth since it affects moisture storage and root penetration. A few Eucalyptus species thrive in relatively shallow soils, while some can use fractures in the underlying rock to maintain stability and obtain moisture. Only a few species thrive in heavy clays, sandy soils, and loams. Waterlogged and poorly drained soils are generally unfavorable for growing Eucalyptus, however some species, such as *E. camaldulensis, E. robusta*, *E. rudis*, and, to a lesser extent, *E. grandis*, may endure frequent floods. Some Eucalyptus species have responded positively to flood irrigation, particularly in locations with high temperatures and limited rainfall (Zaiton et al., 2018).

Extraordinary progress with Eucalyptus productivity has been achieved in many parts of the world (Brune, 2023; Zhang and Wang., 2021). In Brazil, pure species with unknown hybrids were planted, with a maximum productivity of 15 m^3 ha^{-1} $year^{-1}$ at 6-7 years of age and high individual variability (Assis 2006; Brune, 2023). Meanwhile in Malaysia, productivity managed *Eucalyptus pellita* plantations have been shown highly productive with an average yearly increment of 35 m^3 ha^{-1} $year^{-1}$ after three years and could supply the sawn timber and veneer on a 10 to 12-year rotation (Japarudin et al.,2020). Compared to other fast-growing species like *Falcataria molluccana* (formerly *Albizia falcataria*), *Gmelina arborea*, and *Neolamarckia cadamba,* they have been managed on 10- to 15-year rotations to produce veneer and sawn timber (Ahmad et al., 2012; Ahmad, 2015). (Ahmad et al., 2012; Ahmad, 2015).

Therefore, planting Eucalyptus provides an alternative wood supply to meet the high demand for logs caused by reduced harvesting of mixed tropical hardwood species and the pressure on the endangered wood species from native forests. Eucalyptus plantations are needed to sustain Malaysia's timber industry. In 2019, a total of 70,200 ha of Eucalyptus species have been planted in Malaysia by a number of plantation-owned industries to supplement *A. mangium* (MTIB, 2019). Such reports of widespread mortality in young plantations, as well as the fear of future failure of Acacia plantations, have alarmed plantation managers and growers, prompting some to advocate for a switch in tree species for Eucalyptus fast-growing plantations. Among the Eucalyptus species planted are mostly Eucalyptus hybrid (E. *urophylla* x *E. grandis*) is known for their rapid growth and yield, excellent survival rates, greater range of adaptability with locations, and favourable stem morphology for timber production (Ahmad, 2020; Zhang and Wang., 2021). *E. pellita* is also a promising candidate for hybridization with other Eucalyptus species other than *E. urophylla* and *E. grandis* to produce hybrids better suited to Malaysia's hot and humid climate.

1.2 Problem Statement

Tactically, transitioning from *A. mangium* to Eucalyptus plantation is challenging as the pest and disease management, are critical components of growing Eucalyptus. Eucalypt trees were usually largely free of pest and disease issues in the early years of plantation growth. However, due to the global movement of plant materials to every part of the world caused diseases and pests have steadily emerged throughout time (Dahlsjo, 2023). Disease have been identified as a major issue for nearly as long as plantation forestry has been practised with these exotic trees that are introduced to a new environment, exposing them to new pests and diseases. According to Old et al. (2003), a greater number of pests and diseases that were brought into plantations of non-native Eucalyptus species seem to have moved with the germplasm of Eucalyptus. These harmful substances are either unintentionally introduced or native and have developed the ability to infect or infest Eucalyptus (Wingfield et al., 2012; Old et al., 2003). The establishment of non-native Eucalyptus plantations in South Africa and parts of South America would have confirmed this as well (Wingfield et al., 2008).

A similar experience was encountered during the cultivation of *A. mangium*. According to Lee. (2014), *A. mangium* had minimal disease concerns when it was first introduced as a plantation species in Malaysia, and it was even promoted as robust and easy to grow. However, as time passed, difficulties began to arise. Heart rot disease in *A. mangium* was detected in Sabah (Gibson, 1981) and spread to plantations in the 1980s, reducing timber quality and yield (Hashim et al., 1990, Lee et al., 1988, Zakaria et al., 1994). A decade later, the appearance of red root rot (related with *Ganoderma philippii*) resulted in high mortality rates among mature *A. mangium* plantings in Peninsular Malaysia. Followed by vascular wilt disease (*Ceratocystis* sp.) fungus and was initially discovered in Indonesia in 2005, is the most recent threat to *Acacia* spp. It currently affects a sizable portion of plantations in Sabah and portions of plantations in Johor and Pahang in Peninsular Malaysia (Lee, 2017). Due to that, many corporations were forced to forgo *A. mangium* in favor of other fast-growing species like *Eucalyptus* spp. (Lee, 2017).

The cultivation of Eucalyptus species program in peninsular Malaysia, Sabah and Sarawak began in 1893, 1974, and 1979 respectively (Salleh et al., 1995). However, all of the forest plantation programs met with failure when the *E. deglupta*, *E. camaldulensis*, and *E. tereticornis* is vulnerable to insect attacks and demonstrated no ability to survive the 15-year rotation (Ahmad, 2017; Salleh, 1995). Moreover, in Sabah plantation, particularly at the Sabah Softwoods Berhad, the planting of *E. deglupta* was halted in 1982 due to the species' significantly slower growth rate when compared to other tree species such as *Gmelina arborea*, *Paraserianthes falcataria*, and *A. mangium* (Salleh, 1995).

Followed by *E. grandis* found pathogenic to *Chrysoporthe deuterocubensis* (Rauf et al., 2019). As a result of its poor growth characteristics and lower economic value, these species were quickly replaced by other Eucalyptus superior species such as *E. pellita* and Eucalyptus hybrid (Zaiton et al., 2020). From studies by Arnold et al. (2017) and Ahmad et al. (2020) reported the hybrid clone, crossing between *E. urophylla*, and *E. grandis* has been extensively approved and planted in plantations due to its stability and other superiorities such as growth and high rate of survival.

Despite the negative experience, the area of Eucalyptus plantation in the world has been increasing year after year, most notably in South and East Asia (Del Lungo et al., 2006; Wingfield et al., 2008; Ambrose et al., 2023). *Eucalyptus* spp. is one of the four primary fast-growing tree species worldwide include Pinus, Populus and Acacia (Zhang and Wang., 2021). *Eucalyptus* spp. has been extensively used for large-scale afforestation in many nations include Malaysia (Megat Najib et al., 2021; Ambrose et al., 2022). Given its advantageous properties, which include greater resistance to pest and disease attacks, exceptional rooting ability, excellent pulp and wood quality, rapid growth and recovery that can exceed an average of >40 m^3 ha^{-1} $year^{-1}$. Another advantage of Eucalyptus over other forest species is its ability to coppicing after the tree has been felled (Silva et al., 2020) and can be utilized up to five times without needing to be replanted (Berita Harian, 2023). *Eucalyptus* spp. is ideal for a variety of end-product utilisations, including solid wood, veneer, charcoal, pulp, paper and energy production purposes, honey, essential oil, and ornamental (Ambrose et al., 2022; Zhang and Wang., 2021).

With the current global interest in *Eucalyptus* spp. for plantations, Eucalyptus has piqued the interest of several parties, including planters and the timber industries (Zaiton et al., 2018; Ambrose et al., 2022). Eucalyptus has been planted commercially by private investors and agency in Sarawak, Sabah, and Peninsular Malaysia including Rimbunan Hijau Group, Samling Sarawak, Sabah Softwoods Berhad, Sabah Forest Industries, Pei Cheong Plywood & Timber Sdn Bhd (Zaiton et al., 2020), Landasan Era Jaya Sdn Bhd, Aramijaya Sdn Bhd, J Biotech Johomuo Sdn Bhd, Getah Upaya Sdn Bhd, Hasil Sekitar Sdn Bhd, Souncern Timber Sdn Bhd, Cosmo Hectars Sdn Bhd, Peninsular Forest Management Sdn Bhd, and Forest Research Institute Malaysia (FRIM). Although Eucalyptus is a promising substitute plantation tree, concerns have been raised about its susceptibility and vulnerability to various diseases. The disease Cryphonectria canker is among the more significant ones (Rauf et al., 2019; Wingfield 2003), leaf diseases caused by Mycosphaerella and Teratosphaeria species (Silva and Asiegbu, 2023), Ceratocystis wilt disease caused by Ceratocystis species (Roux et al., 2020), Myrtle rust disease caused by *Austropuccinia psidii* (Yong et al., 2021), and stem canker disease caused by Botryosphaericeae (Li et al., 2022).

Stem canker caused by Cryphonectriaceae is one of the most feared threats to plantation-grown Eucalyptus trees. Species of Chrysoporthe have a wide distribution in tropical and subtropical areas of the world (Vermeulen et al., 2011; Gryzenhout et al., 2009) and it has started to spread to new places in recent years. The family includes *Chrysoporthe cubensis*, *C. austroafricana* (Gryzenhout et al., 2009), *C. deuterocubensis* Gryzenh. & M.J.Wingf. (Vermeulen et al., 2011) *C. syzygiicola* Chungu, Gryzenh. & Jol. Roux and *C. zambiensis* Chungu, Gryzenh. & Jol. Roux (Chungu et al. 2010).

This study has discovered that a species of *Chrysoporthe deuterocubensis* Gryzenh. & M.J.Wingf. were identified on Sabah plantation. *C. deuterocubensis* is the causal pathogen for stem canker disease in *E. urogandis* (*E. urophylla* x *E. grandis*) tree (Dahali et al., 2020). This pathogenic disease was first reported to infect an *E. grandis* tree in mid-2014 on the same plantation by Rauf et al. (2019). Before being replaced by *E. pellita* and *E. urograndis*. Stem canker diseases caused by *Chrysoporthe* sp. are the most important pathogens causing severe infection and tree mortality of young *Eucalyptus* spp. in the tropics and subtropics (Gryzenhout et al., 2009). The extent of the impact of canker disease on Eucalyptus plantations may vary compared to other regions where the disease is already known to occur. Meanwhile, the severity of infection can vary depending on the duration of the infection and the fungus's aggressiveness (Md Tahir et al., 2023), species of Eucalyptus, environmental conditions, and management practices.

Outbreaks of canker disease can have significant repercussions, where Eucalyptus plantation are commercially significant for timber production and other purposes. Disease infection had a negative impact on the Eucalyptus plantation, such as disrupting the tree's growth rate performance, reduced timber output, cracks, splits in wood along the stem and branches, reduced coppicing, increased tree mortality, and lowering the tree's quality and productivity (Ambrose et al., 2023; Gezahgne, 2010; Old and Davison, 2000). Aside from that, the widespread of a disease like *C. deuterocubensis* in Eucalyptus plantations could gave a significant economic loss. These may include possible ecological effects as a result of shifting forest dynamics and higher management expenses due to disease control measures. For example, infected trees are either left to die on site or are extracted and discarded before they reach maturity, resulting in an RM 200/m^3 economic loss (Wen et al., 2018). Furthermore, any disease outbreak in Eucalyptus plantations has the potential to endanger Malaysia's forest industry, which aims to produce 75 million m^3 of timber per year to meet the raw material requirement of the Malaysian timber industry (Megat Najib et al., 2021). As a result, other sustainable development goals, such as poverty reduction and economic growth may suffer. The loss of Eucalyptus trees may also have negative environmental consequences, such as a decrease in biodiversity and carbon sequestration. As a result, the Malaysian government and other relevant parties must take action to prevent disease spread in Eucalyptus plantations and ensure their long-term viability. This can include promoting sustainable farming methods, deploying efficient pest and disease management systems, improving breeding strategies such as superior hybrid and clone species, assisting impacted farmers and industries, and utilizing infected trees into value-added products.

1.3 Justification

A general trend in all areas where Eucalyptus are being grown in plantations is that pathogen problems are increasing (Wingfield et al., 2008; Wingfield et al., 2012). This is certainly a major worry for plantation growers. The increasing number of disease concerns clearly raises the cost of forestry, and some argue that plantation forestry based on these trees may eventually fail to generate fair returns on investment. This is certainly a significant matter that needs careful consideration. As threats might come unexpectedly or be difficult to detect before causing irreversible damage, such as those caused by microbial diseases.

Therefore, executing disease mitigation in a timely manner to safeguard tree populations is a complex endeavour. Expectedly, resources are directed toward diseases that offer the greatest economic and environmental damage (Dahlsjo, 2023). Researchers and managers will undoubtedly need to look for a new way to address pathogen issues as they pose a growing threat to Eucalyptus plantation forestry. Although the vegetative propagation of hybrid clones has been a driving force to address health issues (van Heerden and Wingfield, 2002; Wingfield, 2003; Wingfield et al., 2008), the strategy is expensive, response times to new threats can be protracted, and long-term success depends on maximizing natural resistance, which might not be sufficient to combat all diseases. It is noteworthy that resistance may ultimately have to be traded off with growth, particularly when dealing with challenges from various disease species (Potts and Dungey, 2004).

Currently, the management control for mitigating Chrysoporthe stem canker include excising the canker, chopping down and burning the trees, or leaving it alone, depending on the severity of the infection (Ambrose et al., 2023). Thus, growers of Eucalyptus will have to use other alternative strategies to cut losses. There may be new way to disease management that have not been studied. As of yet, there is no effective way to control this disease and plantations that are completely disease-free are difficult to maintain. Furthermore, plantation of *Eucalyptus* spp. in Malaysia is still relatively new and diseases affecting have not been widely reported.

Thus, there is limited information on the disease issues and effects of disease infection on the properties of *Eucalyptus* spp. Due to a lack of supporting research data on the earlier infection, quality, and changes in wood properties of infected wood. A study was conducted on Eucalyptus *urograndis* (*E. urophylla* x *E. grandis*) from Sabah plantation that were found to be infected with stem canker disease (*Chrysoporthe deuterocubensis*). Therefore, the influence of the infection on this wood are worth investigating in order to determine the utilization potential of these infected trees, minimize wood wastage and losses. It is necessary to ensure that the wood properties are commercially suitable and meet industry standards.

1.4 Objectives of the Study

The main objectives of this study are including the sub-objectives as follows:

I. To develop the severity classes of disease infection *Eucalyptus urograndis* (*E. urophylla* x *E. grandis*) based on stem characteristics.

II. To determine the effects of disease infection on the basic properties (physical, and mechanical) of *E. urograndis.*

III. To determine the effects of disease infection on the chemical composition and durability of *E. urograndis* against wood rotting fungi and termite infestation

IV. To establish the machining properties and grade of infected and healthy of *E. urograndis* lumber.

V. To evaluate the sawing recovery and grade of infected and healthy *E. urograndis* lumber.

1.5 Significance of the Study

This study would be able to quantify the extent of stem canker disease and its influence on wood properties. This study provides information on the strength, durability, bonding, and machining properties of *E. urograndis* that can be used as a reference for end-use selection. As a result of this study, the wood can be fully utilized and developed into value-added products. Thus, it can overcome the dwindling supply of timber. As for the plantation owners and policymakers, the findings of this study would serve as referral data for mitigating stem canker threats, as the plantation and uses of *Eucalyptus* spp. in Malaysia are still new and limited. They can assess the properties of the infected tree based on the type of severe infection. Furthermore, the findings and new discoveries will provide more reference sources for future research, particularly in the field of improving wood quality.

1.6 Limitations of the Study

The limitations of the study are as follows:

- Ages: The ages of the sampled trees were 11 years old. There is no information or evidence on when the disease first occurred.

- Species: The characterization in this study was based on *E. urograndis* (*E. urophylla* x *E. grandis*) only.

- Sample coverage: Initially, there were 5 classes in development of severity classes, such as healthy, slight, moderate, severe, and very severe (Md Tahir et al., 2023). However, owing to the absence of tree samples from class 2 ‘slight’ in the sampling area,it is assumed that no new infection took place for some time. Therefore, in this study, 'slight' infection was omitted and replaced by 'moderate'.

- Sampling location: Sampling was only conducted in Brumas,Tawau and Sabah.

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