Recovery and Grades of *Eucalyptus urograndis* Sawn Timber Infected by *Chrysoporthe deuterocubensis* Stem Canker Disease

Rasdianah Dahali,[a] Lee Seng Hua,[b] Paridah Md Tahir,[a] Adlin Sabrina Muhammad Roseley,[c] Mohd Redzuan Abdul Rauf,[d] Mohammed Abdillah Ahmad Farid,[a] and Mohd Zulkhairi Mohd Yusoff,[a,e,*]

*Corresponding author: mzulkhairi@upm.edu.my

DOI: 10.15376/biores.21.3.7662-7689

GRAPHICAL ABSTRACT

Recovery and Grades of *Eucalyptus urograndis* Sawn Timber Infected by *Chrysoporthe deuterocubensis* Stem Canker Disease

Rasdianah Dahali,[a] Lee Seng Hua,[b] Paridah Md Tahir,[a] Adlin Sabrina Muhammad Roseley,[c] Mohd Redzuan Abdul Rauf,[d] Mohammed Abdillah Ahmad Farid,[a] and Mohd Zulkhairi Mohd Yusoff,[a,e,*]

Global wood demand continues to rise while supply from natural forests declines, increasing the importance of forest plantations as a sustainable timber source. In Malaysia, *Eucalyptus urograndis* has gained attention as a fast-growing plantation species, but stem canker disease caused by *Chrysoporthe deuterocubensis* threatens timber recovery and value. This study evaluated the effect of infection severity on sawn timber recovery, grading, and value in 11-year-old *E. urograndis* trees from Sabah, Malaysia. Twelve trees were classified into four infection-severity classes, felled, and sawn using a back-sawing pattern. A total of 404 boards were assessed for dimensions, recovery, visual grade, and disease-related defects using modified Malaysian Grading Rules. Board size shifted toward smaller dimensions as infection severity increased. However, total recovery remained relatively high across classes, and severely infected logs produced the highest volume recovery. Healthy trees yielded the greatest proportion of SELECT and STANDARD grade boards, whereas infected trees produced more downgraded boards. Infection severity was not significantly correlated with log diameter or board volume recovery. These findings indicate that infected *E. urograndis* logs can still provide commercially usable timber, although with reduced product quality and value.

DOI: 10.15376/biores.21.3.7662-7689

Keywords: Eucalyptus urograndis; Chrysoporthe deuterocubensis; Infection classes; Recovery; Defects; Grades; Values

*Contact information: a: Laboratory of Biopolymer and Derivatives, Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia; b: Department of Wood Industry, Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM) Cawangan Pahang Kampus Jengka, Lintasan Semarak, Bandar Jengka, 26400 Bandar Tun Razak, Pahang, Malaysia; c: Faculty of Forestry and Environment, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia; d: Sabah Softwoods Berhad, Tawau 91019, Sabah, Malaysia; e: Department of Bioprocess Technology, Faculty of Biotechnology and Biomolecular Sciences, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia; *Corresponding author: mzulkhairi@upm.edu.my*

INTRODUCTION

Global demand for wood and wood products continues to exceed the supply that can be sustainably obtained from natural forests. This widening gap has increased interest in forest plantations as an alternative and reliable source of timber. According to the Food and Agriculture Organization (FAO) of the United Nations, the rising demand for wood is driven by population growth, reduced natural forest availability, expanding economies, globalization of the forest products industry, climate change, and the increasing demand for high-quality value-added wood products (FAO 2022). As a result, forest plantations are becoming increasingly important in supplying raw material for both industrial and domestic use (Salleh 1995; Samdin *et al.* 2020). The promotion of non-native species in forest plantations is one strategy to support the timber industry and reduce pressure on natural forests (Samdin *et al*. 2020). Among these species, *Eucalyptus* has attracted considerable attention because of its rapid growth, short rotation, adaptability to a wide range of site conditions, and suitability for both pulp and solid wood production. Plantation grown *Eucalyptus* can be used for a variety of high-value products, including flooring, furniture, veneer, plywood, mouldings, and structural timber. These characteristics make *Eucalyptus* one of the most important fast-growing plantation genera in the tropics and subtropics (Rezende *et al.* 2014; Foroughbakhch *et al.* 2017; McEwan *et al.* 2020; Japarudin *et al*. 2022; Zhang and Jiang 2026).

In Malaysia, forest plantation development has been promoted as part of the strategy to ensure a continuous supply of raw material for the wood-based industry (Bernama 2022; MTIB 2025). *Eucalyptus* plantations have been highlighted as a potential source of wood supply to support the timber industry and downstream processing (Bernama 2022; MTIB 2025). Plantation species are increasingly viewed as an important supplement to timber obtained from natural forests, especially where natural forest production is declining. In particular, *Eucalyptus* plantations have gained importance in several regions of the country because of their potential to supply quality wood for industrial processing. Malaysian forestry sources also list plantation *Eucalyptus* among species used for furniture, mouldings, light construction, and pulp and paper products (Salleh 1995; Khan 2024). Recent studies indicate that *Eucalyptus* plantations have expanded in Malaysia, particularly in Sarawak. One report showed that *Eucalyptus* plantations accounted for 19% of the total forest plantation area in Sarawak. This rapid expansion reflects the growing interest in *Eucalyptus* as a plantation crop, but it also highlights the need to understand production risks that may reduce timber value and recovery (Awing *et al*. 2023; Awing 2023). Several studies have reported increasing disease incidence and severity in *Eucalyptus* plantations, posing significant challenges to plantation productivity, wood quality, and economic returns (Wu and Chen 2019; Suzuki *et al*. 2022).

Eucalyptus species are not highly resistant to disease, and numerous pathogens have been reported in plantation stands including stem canker pathogens (*Chrysoporthe* spp., *Lasiodiplodia theobromae*), wilt pathogens (*Ceratocystis* spp.), leaf pathogens (*Teratosphaeria* spp., *Mycosphaerella* spp.), and root pathogens (*Phytophthora* spp.) (Old *et al.* 2003; Gezahgne 2010; Wu and Chen 2019; Liao *et al.* 2022). Among these, stem canker is one of the most damaging diseases because it affects growth, wood quality, and sawmill recovery. The causal fungus *Chrysoporthe deuterocubensis* has been identified as an important canker pathogen of *Eucalyptus* in tropical and subtropical regions, including Malaysia (Ambrose 2024). In Malaysian plantations, infected trees have shown symptoms such as swelling, bark cracking, kino formation, sunken lesions, and rotten or deformed stems, all of which can reduce the commercial value of the logs (Samdin *et al.* 2018).

Several treatment strategies have been evaluated for canker disease management in trees, although the success of each method depends on the host, pathogen, and timing of intervention. In general, sanitation practices such as pruning infected tissues, removing severely diseased trees, avoiding wounding during wet conditions, and destroying infected material are recommended to reduce inoculum and disease spread. Chemical control has also been tested in plantation systems, and recent work in Malaysia showed that prochloraz manganese chloride, thiram, and copper hydroxide could reduce infection or lesion development caused by *C. deuterocubensis* on *Eucalyptus urograndis* (Ambrose 2024). Biological control and the use of tolerant planting material have also been proposed as longer-term approaches for managing *Eucalyptus* canker diseases (Suzuki *et al.* 2022; Samdin *et al.* 2018).

Despite the importance of canker disease, there is still limited information on how infection severity affects the recovery, grading, and commercial value of sawn timber from plantation-grown *E. urograndis* in Malaysia. Most available studies focus on pathogen identification or disease control rather than the impact of stem canker on wood conversion and board quality. Understanding these effects is important because diseased logs may still enter the processing chain, and their wood value may depend on how much material can be recovered in acceptable grades (Awing 2023). Therefore, the present study aimed to evaluate the effect of *C. deuterocubensis* stem canker severity on the recovery, grading, and value of sawn timber from plantation-grown *E. urograndis*. The specific objectives were to: (i) determine the influence of infection severity on log and board recovery, (ii) assess the effect of disease-related defects on visual grade classification, and (iii) estimate the economic implications of using infected timber for commercial products. The findings are expected to provide useful information for plantation management, disease mitigation, and the efficient utilization of *Eucalyptus* timber from infected stands.

EXPERIMENTAL

The *Eucalyptus* hybrid clone used in this study was *E. urograndis* (*E. urophylla* x *E. grandis*). This hybrid originates from China. The selected plot covers approximately 11.7 hectares and consists of 1,908 *E. urograndis* stands of 11-year-old trees. The sampling area is located in Block 38 C (coordinates: 4°33’16.3” N, 117°42’58.7” E) at Sabah Softwoods Berhad in Tawau, Malaysia. Visual tree inspections were conducted by assessing the physical characteristics and symptoms of stem canker present on the stems (Table 1), which included swelling, bark cracking, gummosis, sunken lesions, and elongated canker areas, as well as the presence of fruiting structures.

The symptoms and locations of each canker on the infected trees were photographed (Fig. 1). The infected trees were examined by forest pathologist Rauf *et al*. (2019), who confirmed the presence of *C. deuterocubensis* based on visual assessment. In addition, the presence of *C. deuterocubensis* was confirmed through DNA extraction, PCR amplification, and molecular phylogenetic analysis, as reported by Awing *et al*. (2023). The symptoms observed on the trees served as indicators of stem canker development and severity, as summarized in Table 1. The physical appearance of infected trees according to severity class is shown in Fig. 2.

Tree Assessment, Selection, Pre-Harvest and Harvesting

The trees were chosen based on a rubric of stem canker symptoms that was created prior to sampling. Before felling, each tree chosen for this study was measured for diameter at breast height over bark (DBHOB) being greater than 25 cm (26.8 to 39.7 cm), total height, and height to the lowest green branch. The overall volume of the stand and the volume between the stands were calculated. The selected trees were harvested manually using chainsaw.

Table 1. Classes of Severity for *Eucalyptus urograndis* Infected with *Chrysoporthe deuterocubensis* (Dahali *et al.* 2021)

Class	Category	Symptom	Reference in Fig. 1
1	Healthy	Stem appears normal without any symptom of being infected	a
2	Moderate	Swollen bark (callus)	b
		Cracking	c
		Fruiting structure	d
		Fresh kino pocket	e
		Canker	g
3	Severe	Swollen bark (callus)	b
		Cracking	c
		Fruiting structure	d
		Fresh kino pocket and fresh kino/gummosis	e & f
		Canker	g
		Sunken	j
		Rotten	k
4	Very Severe	Swollen bark (callus)	b
		Cracking	c
		Fruiting structure	d
		Dried kino pocket and dried kino/gummosis	h & i
		Canker	g
		Sunken	j
		Rotten	k
		Shoot	i

Due to the logistic constraint during the movement control order (MCO) as Covid-19 and the limited number of man-power/facilities on that time, only three trees from each infection classes were chosen. At a height of 15 cm above ground, twelve trees of *E. urograndis* were felled for an evaluation of sawn timber recovery and quality grades of timber. This study did not cover a complete analysis of the recovery from individual trees. The conversion is based on total sawlogs/billet volumes. Comprising 36 logs in total, 12 trees felled in this study. Three logs (each 2.5 m in length) were obtained from the bottom part of the stem of each felled tree, as it contained the most obvious infected area of stem canker. The remaining logs were excluded because there were very few defects (almost defect-free) present.

Logs Processing, Sawing Pattern, and Measurement of Recovered Timber

Immediately after the logs were cross-cut, they were coded and colored by oil-based painting at the butt and upper parts of each log to minimize released growth stress after tree felling (Blackburn *et al*. 2011), to minimize water or moisture run-off, and for easy tracking during processing. Each log end was painted with one of four colors to uniquely identify the infection classes: healthy (green), moderate (blue), severe (yellow), and very severe (red). Log length, together with the small end diameter over bark (SEDOB) and large end diameter over bark (LEDOB), was recorded for volume estimation.

Fig. 1. Symptoms of *Chrysoporthe deuterocubensis* on *Eucalyptus urograndis* tree plantation at Sabah Softwoods Berhad in Tawau (Dahali *et al*. 2021)

Fig. 2. Physical appearance of infection trees according to severity classes

At the large end (LEDOB), each log was labelled with its corresponding tree number and log section. Log volume was subsequently calculated using metric cylinder volume tables, based on an average centre diameter derived from the mean of the SEDOB and LEDOB. For this reason, 100% green board recovery was assumed from the cutting pattern assigned to each log. Individual log lengths were used to determine green volumes per log. The log volume (m^3) was determined by using Eq. 1,

$$V = \left(\frac{SEDOB+LEDOB}{4}\right)^2 \text{ x } \pi \text{ x } L \tag{1}$$

where V is the individual green log volume (m^3), π is 3.1416, and L is the nominal length of the sawlog (2.5 m)

Then logs were transported to the sawmill at Lotus Region Sdn. Bhd. and stored under a covered sawing shed until conversion commenced. In this study, conversion was carried out approximately three days after felling. In accordance with best-practice recommendations, the logs were processed as soon as operationally practicable following harvesting and transport, as immediate processing or minimizing storage duration is recommended to reduce log degradation and maintain timber quality (Nolan *et al.* 2003a,b). The logs were then sawn into flitches using a vertical band saw into various sizes according to market demand as presented in Table 2. The sawing pattern used in conversion logs into timber was back sawing (Knorr 1996). This pattern is normally applied for smaller diameter trees with a minimum diameter of 25 cm that have high growth stresses, such as *Eucalyptus* sp. (Washusen *et al*. 2009).

Table 2. Sizes of Sawn Timber Produced Based on Current Market Demand

Size of Sawn Timber		
Thickness (m)	Width (m)	Length (m)
0.044 (1 ¾'')	0.0983 (3 ⅞")	
	0.073 (2 ⅞")	
0.022 (⅞'')	0.048 (1 ⅞'')	2.5 (8')
	0.022 (⅞'')	

The back sawn cut, as shown in Fig. 3, was made tangential to the annual growth rings of the log. Once the internal growth stresses were released, these logs required a more balanced cutting pattern to minimize degradation such as end splits and surface checks.

Fig. 3. Back-sawing pattern of the logs

This sawing pattern tended to yield high-grade timber from logs and achieve optimum recovery (Washusen *et al.* 2009; Malik and Hopewell 2011; Cown 2016). Most of the structural timber and many decorative products have been back sawn (Cown 2016). This involved cutting a slab from the side of a log to produce a flat face that was tangential to the tree's growth rings. This flat face was then used as the “reference” face for subsequent sawing (Knorr 1996; Washusen *et al*. 2009). This approach has offered more flexibility, as large boards could be back sawn from the center of the log, with board widths approximating the diameter of the log (Cown 2016).

After sawing, each board was labelled with its corresponding tree/log number and a unique number identifying the individual board. This enabled tracking each board back to the log of origin during and at the conclusion of processing. The nominal length, width and thickness of each board were measured to evaluate the recovery of sawn timber. Each defect on the worst face of each board was identified and mapped diagrammatically. The defects were mapped by measuring the distance from the base of the board to the start and end points of each defect using a measuring tape. The approximate proportion of the board width occupied by each defect was indicated diagrammatically. These defects were evaluated based on those recognized in the Malaysian Grading Rules (MGR) for sawn hardwood timber and rubberwood sawn timber (Malaysian Grading Rules 2009; 2013), together with additional disease-related defects caused by *C. deuterocubensis* and confirmed by a certified forest pathologist (Rauf *et al.* 2019), to categorize boards into ‘reject’ or ‘acceptable’ classes. This grading was carried out at mill operating speed within a restricted workspace; therefore, rejected boards could not be retained for further assessment. The MGR were adapted in this study to reflect the unique defect profile of plantation-grown *E. urograndis*, which differs substantially from native hardwoods for which the original standards were developed. Plantation-grown *Eucalyptus* is more prone to disease-related defects such as kino pockets, gum veins, and localized decay, as well as growth-related issues including end splits, warp, and grain deviation. These features influence both the appearance and structural integrity of the timber, yet they are not fully addressed under standard MGR allowances. The modifications applied in this study ensured that grading outcomes more accurately represented the true commercial value and usability of the timber, particularly for international markets where grading criteria differ. Aligning the adapted MGR with the observed defect patterns allowed for a more accurate and representative evaluation while maintaining consistency with established visual grading principles.

Drying and Visual Grading

After the sawing process was completed, the back-sawn boards were placed in filleted stacks in an open-sided barn and seasoned using a conservative air-drying approach for approximately eight weeks. Care was taken during seasoning; the boards were stacked, covered with plywood, and weighted on top to minimize drying distortion caused by stress release (Washusen 2006) until the visual grading process was completed. Close spacing of stacking strips was important, as back-sawn boards tend to develop checks. The boards were air-dried in the shade at an average temperature of 32 °C and relative humidity (RH) of 82% until they reached a moisture content below 16%, as measured using a moisture meter probe (Exotek instrument MC-410). Once the air-drying period was completed, every acceptable board was measured, and the appearances were graded in accordance with MGR (Malaysian Grading Rules 2009; 2013) to evaluate their quality. Each board’s probable downgrades were noted. The boards were graded by Lotus Region Sdn. Bhd.

grader in consultation with research staff to meet the requirements of MGR. To minimize variation in defect description and measurement and to ensure uniform assessment, the grading process was conducted by a minimum of two experienced graders.

In this grading study, the defect system was used for the Special Market Specification (SMS), (Malaysian Grading Rules 2009). This system is employed when grading timber normally intended for special purposes (furniture) and used in the size at which it is supplied. Permissible defects are defined for each grade. Reject grade was according to severity and defects. If a piece of board contains more defects than are allowed by the rules, then it will be rejected. Normally, the standard in MGR separates into five basic grades from the highest to lowest grades such as PRIME, SELECT, STANDARD, SERVICEABLE, SOUND, and UTILITY. Meanwhile, the grouping of grades is typically employed by producers or consumers who do not want to incur additional costs associated with having each grade in a consignment labelled, tallied, or priced separately.

These grades have been implemented in many sawmill/manufactures in Malaysia. The grades produced were SELECT AND BETTER, STANDARD AND BETTER, SOUND AND BETTER, SERVICEABLE AND BETTER and, UTILITY AND BETTER (MERCHANTABLE) grade, as shown in Table 3. Normally, these MGR rules are designed for grading sawn hardwood timber from natural forest. Although the Malaysian Grading Rules (MGR) were originally developed for sawn hardwood timber from native forests, they were applied in this study because specific grading standards for *Eucalyptus* plantation timber are not yet available. Minor modifications were made to accommodate the board dimensions used in this study (8 feet / 2.5 m), as the current MGR specify standard lengths of 10 to 12 feet (3.048 to 3.658 m) for native hardwoods (MGR 2009) and rubberwood sawn timber (Malaysian Grading Rules 2013). However, these rules were used for the grading of *Eucalyptus* plantation timber for which specific grading rules were not available with some modification in term of length of board which is 8 feet (2.5 m). The current Malaysian grading rules for sawn hardwood timber only for tree from native forest (length =10 to 12 feet/ 3.048 to 3.658 m) (MGR 2009) and for rubberwood sawn timber from plantation (Malaysian Grading Rules 2013).

Table 3. The Modification of Grouping Grades in Malaysian Grading Rules

Grade/Grade Mark	Criteria
SELECT AND BETTER	Normally include sawn timber in SELECT and PRIME grades
STANDARD AND BETTER	Normally include sawn timber in STANDARD, SELECT and PRIME grades
SOUND AND BETTER	Normally include sawn timber in SOUND, STANDARD, SELECT and PRIME grades
SERVICEABLE AND BETTER	Normally include sawn timber in SERVICEABLE, SOUND, STANDARD, SELECT and PRIME grades
MERCHANTABLE	Normally include sawn timber in UTILITY, SERVICEABLE, SOUND, STANDARD, SELECT and PRIME grades

Source: Adapted from Malaysian Grading Rules (2009; 2013)

Each board's potential downgrades were noted. Non-permissible defects were recorded on each air-dried board surface and edge. The volume recovery of each appearance grade was calculated as a percentage using the actual board sizes and docked lengths. In accordance with MGR, board volumes were calculated using nominal dry dimensions. These dimensions were 0.044 and 0.022 m in thickness, and 0.098, 0.073, 0.047, and 0.022 m in width. Board volumes for each grade were totaled for each log to determine grade recoveries and total recovery.

Value of *Eucalyptus urograndis* Board

The estimated value was based on the prevailing market price of Malaysian rubberwood sawn timber, which was used as a reference because rubberwood is the first plantation species in Malaysia to have an established grading system. The value of *E. urograndis* sawn timber was determined in accordance with the Malaysian Grading Rules (2013). Price data were obtained from indicative prices provided by selected sawmills in several regions of Malaysia that process rubberwood sawn timber, and these values were used as a benchmark in this study.

The limited market availability of *E. urograndis* lumber may be attributed to its status as a minor plantation species and the absence of a well-established commercial supply chain. In addition, its market acceptance may be influenced by wood properties, including density and mechanical performance, which vary with grade and intended end use. *E. urograndis* has a density of 400 to 750 kg/m^3 and is classified as a medium hardwood, whereas rubberwood has a density of 560 to 640 kg/m^3 and is classified as a light hardwood (Boland *et al.* 1991; Wan Mohd Nazri *et al.* 2020; Malaysian Timber Industrial Board 2010). The prices quoted by sawmill or factory operators may vary depending on specifications, dimensions, and grades (Table 4).

Table 4. The Value of Rubberwood Sawn Timber in Malaysia

Size of Sawn Timber	Value (USD/1000 kg)	
	SELECT AND BETTER	STANDARD AND BETTER
1” x 1” x 6’	379.0	343.5
1” x 2” x 6’	450.1	414.5
2” x 3”x 6’	544.8	509.3
2” x 4” x 6’	615.9	580.4

Source: Adapted from Impressive Transform Sdn. Bhd. (August 2023)

Statistical Analysis

The purpose of this study was to see how different *C. deuterocubensis* stem canker diseases severity classes affected the volume recovery and grade of *E. urograndis* wood. The data were analyzed and interpreted using a one-way analysis of variance (ANOVA). Using Duncan's multiple range (DMR) test at $P<0.05$, the discrepancies between the mean values of each severity class were investigated further. The data was subjected to regression analysis to determine the relationship between the diameter of the logs and the volume recovered. SPSS version 22.0 was used for all statistical analyses. (IBM, Armonk, New York, USA).

RESULTS AND DISCUSSION

Size, Quantity, Volume, and Visual Defects of Sawn Timber

Back-sawn logs with small diameters (26.8 to 39.7 cm) yielded approximately 8-11 lumber pieces per log from classes 1 and 2, and 6 to 16 pieces from classes 3 and 4. Table 5 presents the sizes and quantities of boards produced by each infection class. Logs were grouped into four size categories. As shown in Fig. 4, logs from Classes 1 (healthy) and 2 (moderately infected) yielded a greater volume of larger sized (0.044 × 0.098 x 25 m and 0.044 x 0.073 × 25 m) boards. In contrast, Classes 3 (severe) and 4 (very severe) primarily yielded smaller (0.022 × 0.048 x 25 m and 0.022 x 0.022 × 25 m) boards. A total of 404 boards were obtained, with classes 1 and 2 contributing 99 and 77 pieces (0.603 m^3 and 0.466 m^3), while classes 3 and 4 yielded 113 and 115 boards (0.517 m^3 and 0.602 m^3), respectively.

Table 5. The Sizes, Quantities and Volumes of Healthy and Infected *Eucalyptus urograndis* Sawn Boards

Description (Boards/Volume)	**Infection Classes**				
	Class 1	**Class 2**	**Class 3**	**Class 4**	**Total**
0.044 x 0.098 x 2.5 m	38	33	32	28	131
Total volume (m^3)	0.403	0.313	0.295	0.283	1.293
0.044 x 0.073 x 2.5 m	13	11	14	28	66
Total volume (m^3)	0.100	0.085	0.095	0.212	0.492
0.022 m x 0.047 x 2.5 m	32	21	46	39	138
Total volume (m^3)	0.081	0.053	0.103	0.084	0.321
0.022 m x 0.022 x 2.5 m	16	12	21	20	69
Total volume (m^3)	0.019	0.014	0.024	0.023	0.081
Total Boards (Pieces)	**99**	**77**	**113**	**115**	**404**
Total Volume (m^3)	**0.603**	**0.466**	**0.517**	**0.602**	**2.188**

The results listed in Table 5 demonstrated that the ability of 11-year-old *E. urograndis* to produce a high proportion of larger-sized boards declined as infection severity increased. This reduction in size yield was due to the presence of more unacceptable defects, which required the boards to be re-sawn into smaller dimensions for defect removal. This observation is consistent with Jones *et al*. (2010), who also reported reduced grade recovery when defects reduced the yield of larger boards. The defects identified in the sawn timber were associated with several factors, including natural forces, seasoning, conversion processes, pest infestation, and stem canker disease caused by *C. deuterocubensis* (Appendix A). Except for timbers from class 1, these defects were observed in most sawn boards, particularly those obtained from the first and second cuts. Class 4 exhibited larger and deeper defects compared with classes 2 and 3, which is also in agreement with Dahali *et al*. (2021), who reported more severe defects in heavily infected.

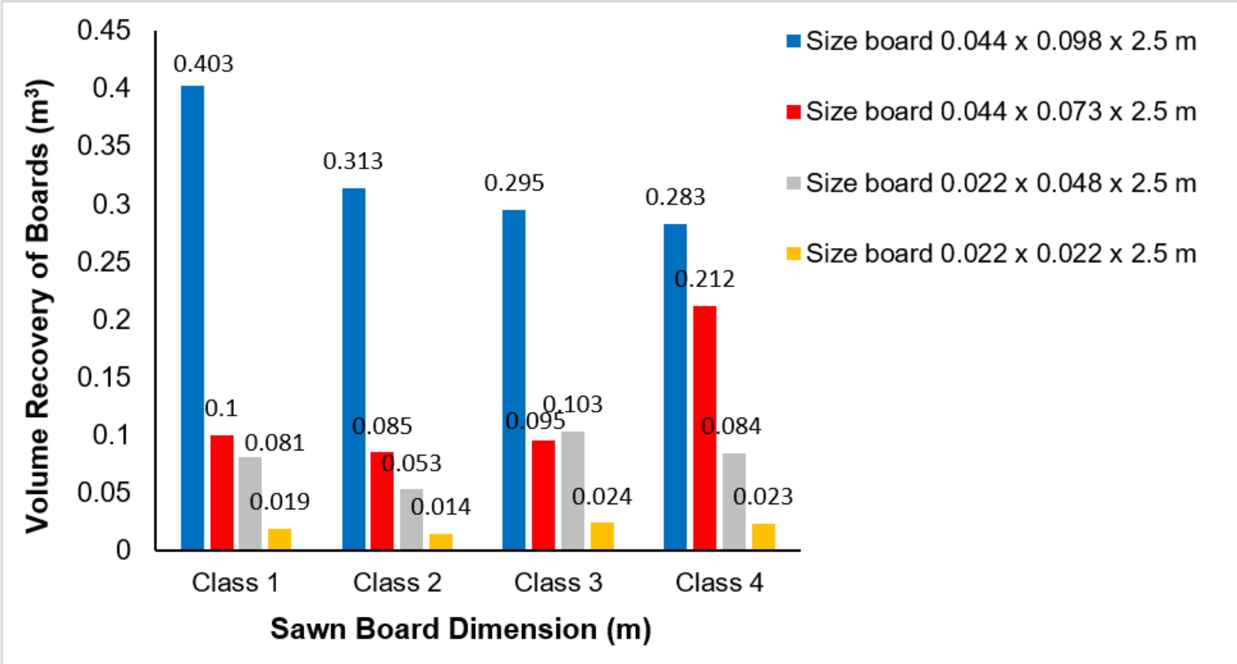


Fig. 4. Volume recovery of *Eucalyptus urograndis* sawn boards for each class (Classes 1-4) across four board dimensions (0.044 × 0.098 × 2.5 m; 0.044 × 0.073 × 2.5 m; 0.022 × 0.048 × 2.5 m; and 0.022 × 0.022 × 2.5 m).

In general, knots were the leading cause of board downgrades, accounting for approximately 12.2% to 27.8% of all severity classes. These knots included unsound/encased, hollow, and checked. Knots had the greatest impact on healthy (class 1) sawn boards, followed by end checks, star shakes, end splits, and pin/shot holes. Meanwhile, knots, kino, canker, and kino pockets were the most common defects in boards from infected classes. The most significant grade-limiting defects were kino and canker, which were more prevalent in infected boards (classes 2, 3, and 4) and were the primary causes of differences in select and standard grade recoveries between the four infection classes, affecting 7% to 13.3% and 8.8% to 11% of boards, respectively. Most defects on infected board surfaces were caused by *C. deuterocubensis* infection (Dahali *et al*. 2021). According to Beadle *et al*. (2008), defects such as kino, canker, rotten, and insect borers are potential sources of loss of recoveries and values in *Eucalyptus* plantations managed for solid wood. The kino defect was caused by kino veins found in *Eucalyptus* sp. These were frequently quite large and contained viscous resin. Kino pockets were found in all infected groups.

These types of defects demonstrated the obvious difficulties in recovering sawn boards from small-diameter hardwood trees that were infected by the disease. For example, the presence of bumps (callus) and cankers resulted in irregularly shaped logs. These defects had to be removed to obtain the desired boards (flitches) for processing, which in turn generated numerous small or short boards (slabs) and increased the amount of sawdust due to the many saw kerfs (Afrifah and Mensah 2014). These findings suggest that disease may have an impact on product conversion efficiency as well as product quality, quantity, and value in this study, primarily through a decrease in the size and grade of boards gained. This is consistent with study by Ratnasingam *et al*. (2013), which found that log quality had a significant impact on sawmilling yield.

The surface of infected boards was rougher due to defects that adversely affect machining properties (Gunduz *et al*. 2016; Dahali *et al*. 2022). Grain irregularities and localized density variations caused by *C. deuterocubensis* infection led to tear-out, fuzzy grain, chip marks, and increased surface roughness, impairing coating adhesion, glue bonding, and finishing quality, reducing the suitability of the boards for precision manufacturing and high-end applications (Dahali *et al*. 2022). These machining difficulties are consistent with the broader challenges reported for many *Eucalyptus* species, which commonly exhibit poor dimensional stability, high shrinkage, splitting, warp, and brittle heart during processing (Wessels *et al*. 2020). Such inherent defects are often exacerbated by the release of growth stresses during logging and milling, resulting in severe splitting, deformation, and rougher surfaces (Lee *et al*. 2022). In infected boards, disruption of fiber alignment caused by grain deviation and pith misalignment may affect mechanical performance, including modulus of rupture (MOR), modulus of elasticity (MOE), compression strength, and shear strength. Dahali *et al*. (2021) reported that *E. urograndis* infected by *C. deuterocubensis* showed reduced physical and mechanical properties, with the severity of reduction increasing with infection class. Japarudin *et al*. (2021) similarly reported that wood defects and anatomical irregularities in plantation-grown *E. pellita* reduced flexural and compression properties.

Localized growth stresses also contribute to internal checking and microcracks, further weakening structural integrity (Dahali *et al*. 2021). The uneven growth pattern associated with infection promotes differential shrinkage during drying, increasing the likelihood of warp, bow, twist, and end splits. These processing challenges are consistent with widely documented issues in plantation-grown *Eucalyptus*, which commonly exhibit high shrinkage, growth stress related deformation, and poor dimensional stability even in the absence of disease (Mohd Ghani and Lee 2021). These combined effects limit the final usable dimensions of the boards and often necessitate trimming, and removal of defective portions during processing, resulting in smaller cross-sections and greater material loss.

In terms of appearance, kino pockets and gummosis exudation result in staining and discoloration, which lower visual grades under the Malaysian Grading Rules (MGR) and reduce the suitability of the timber for high-value appearance grade products (Dahali et al., 2021). From a chemical perspective, infection reduces cellulose and hemicellulose content while increasing lignin and extractives (Dahali *et al*. 2023). Cellulose decreased from 53.2% in healthy wood to as low as 45.4% in very severely infected samples, while lignin and extractives increased to 20.5% and 20.2%, respectively. These chemical changes are linked to the degradation of polysaccharides by the pathogen and the activation of the tree's defense mechanisms, which lead to the accumulation of lignin, phenolic compounds, gums, and tyloses (Dahali *et al*. 2023).

Regarding durability, infected *E. urograndis* demonstrated improved resistance to fungal decay and termite attack compared with healthy wood, as previously reported by Dahali *et al.* (2023). The durability classification improved from resistant to highly resistant against white rot (*Pycnoporus sanguineus*) and brown rot (*Coniophora puteana*) fungi, and from very poor to moderately resistant against subterranean termites (*Coptotermes curvignathus*) (Dahali *et al*. 2023). This enhanced durability was attributed to increased lignin and extractive contents, vessel obstruction, and the presence of natural toxic compounds such as phenolics and volatile oils (Dahali *et al*. 2023). In addition, the authors' earlier studies showed that *C. deuterocubensis* infection adversely affected machining properties (Dahali *et al*. 2022) and physical and mechanical properties (Dahali *et al.* 2021). Taken together, these previously reported changes indicate that *C. deuterocubensis* infestation can reduce the recovery of higher-grade boards and lower market classification. Severely infected logs are therefore often downgraded to low-value applications such as pallets, packaging, or woodchips rather than structural or premium-grade uses (Dahali *et al*. 2021, 2022).

Volume of Board and Recovery

The average log diameter, total volume, and percentage of usable boards obtained after conversion from a log for each infection class are presented in Table 7. As infection severity increased, the average log diameter decreased slightly from 0.286 to 0.268 m. Similarly, log volume declined from 1.339 m^3 1.159 m^3, while board volume ranged from 0.603 m^3 to 0.466 m^3. The volume of boards in infection classes 2, 3, and 4 were lower than in the healthy class. Because healthy (class 1) sawn timber had a larger log volume (billet) than infection samples, its total volume was greater (class 2, 3, and 4). These low board recoveries may be attributed to quality losses caused by severe canker disease. Class 3 yielded only 39.5% air-dried board recovery relative to log volume, with losses amounting to approximately 60.5%. Despite the fact that the billet volume of the healthy sample was greater than that of the other infection classes, the timber recovered from the most severe (class 4) infection classes had a higher recovery value (51.2%) than class 1 (45.0%).

Table 7. The Recovery of Healthy and Infected *E. urograndis* Sawn Timber

Infection Classes	Average Diameter of Log (m)	Total Volume of Log/Billet with Bark (m^3)	Total Volume of Board (m^3)	Recovery (%)	Loss (%)
1 (Healthy)	0.286	1.339	0.603	45.0	55.0
2 (Moderate)	0.273	1.159	0.466	40.2	59.8
3 (Severe)	0.272	1.309	0.517	39.5	60.5
4 (Very severe)	0.268	1.177	0.602	51.2	48.8
Total	**-**	**4.985**	**2.188**	**43.9**	**56.11**

The percentage of loss was mostly caused by *C. deuterocubensis* stem canker disease. Biologically, the pathogen infects and colonizes the cambial region, resulting in necrosis that inhibits normal cell division and xylem production. In reaction, the tree produces kino (resinous exudate) and callus tissue as defense mechanisms, which disrupt the uniform development of wood fibers and result in defects such as cankers, kino pockets, and rotten areas (Beadle *et al*. 2008; Dahali *et al*. 2021, 2022). These defense related growth interruptions cause irregular grain orientation (Stewart 1980; Cruickshank 2010: Afrifah and Mensah 2014) and density changes, resulting in a coarser texture that is more difficult to saw and process (Gunduz *et al.* 2016; Dahali *et al*. 2022).

The impact of pathogen infection on timber recovery will vary depending on the type of pathogen, infection period, fungus aggressiveness, and severity of the infection (Mafia *et al*. 2013; Terhem *et al*. 2021). The disease's symptoms and characteristics, as well as the shape and size of infected logs, varied depending on the severity of infection, placement on the stem, and the tree's physiological response. Collectively, these biological and anatomical changes lower the amount of usable timber, impair processing efficiency, and have a negative impact on the ultimate quality of sawn boards. Similar reductions in sawn timber recovery have been reported in other *Eucalyptus* species, such as *E. regnans*, where internal defects, log form irregularities, and end splitting significantly decreased usable lumber yield (Rozas *et al*. 2023). For example, a board with extensive decay may need to be cut shorter to remove the defected area, resulting in smaller or shorter board dimensions or parts of boards that were smaller or shorter than the final target size. However, in other cases, the impact can be significant, and the recovery may be reduced to the point where the log is no longer economically viable for processing because the board contained unacceptable defects and was rejected. Higher growth stress in smaller diameter trees is frequently associated with a higher proportion of juvenile wood with immature cell wall structure and uneven internal tensile and compressive forces, which contributes to recovery issues and potential economic value loss. As a result, the release of these stresses during sawing and drying can cause warp, checks, splits, and distortion that degrade board quality (Cassens and Serrano 2004; Kojima *et al*. 2012; Lee *et al*. 2022). Many studies have linked growth stress to increased severity of end split in logs (Franca *et al*. 2020; Espey *et al*. 2021; Naghizadeh and Wessels 2021).

In the context of *C. deuterocubensis* stem canker disease, infection can exacerbate longitudinal growth stresses in *Eucalyptus* spp., similar to the relationships reported by Beltrame *et al*. (2015) between longitudinal residual strain (DRL), longitudinal growth stress (TCL), and the extent of log end-splitting. The pathogen damages the cambium and disrupts normal xylem formation, leading to uneven radial and tangential growth, fiber misalignment, and localized density variations. These anatomical abnormalities create imbalances in internal tensile and compressive forces, thereby increasing growth stress levels. In this study, infected logs exhibited a higher frequency of end splits than healthy logs, indicating that disease-induced growth irregularities contribute to stress release during felling and drying. Elevated longitudinal growth stress has a pronounced effect on the recovery and processing of high-quality timber, as it can lead to shake, checks, and brittle heart in standing trees; end-splitting in logs shortly after harvest and severe splitting, twisting, and cracking in timber during drying (Yang 2005; Malan 2009; Beltrame *et al.* 2015). Although all trees experience longitudinal growth stresses, their magnitude varies both between and within species. These findings highlight the need for disease management strategies that also incorporate growth stress mitigation to minimize processing losses and maintain timber quality.

Another characteristic that may have a detrimental impact on the recovery of *Eucalyptus* wood for timber production is interlocking grain, which is associated with stem canker, and caused by *C. deuterocubensis*. Grain that is interlocked, which is defined by alternate fiber orientation in successive growth layers, may be more prone to distortions and cracks during machining and drying. Although some *Eucalyptus* species may naturally possess this anatomical trait, diseased trees that have it might worsen drying faults, impair product quality, and decrease processing efficiency as their structural integrity is already weakened (Franca *et al*. 2020). Thus, in addition to disease management measures, ways to maximize timber recovery should also consider the selection and processing of logs with the least amount of interlocked grain. Comparable difficulties have been documented during the sawing of plantation-grown *E. pellita*, where internal defects, grain deviation, and growth stresses required frequent log turning, increased handling time, and resulted in substantial off-cuts and sawdust generation, ultimately reducing sawn board recovery (Ghaffariyan *et al*. 2021). Aside from that, defects during the sawing process necessitate skill and require more handling time, such as turning the logs (Malik and Hopewell 2011). Because recovering square sections from circular logs inevitably causes some loss, the logs were processed using a back-sawing technique after debarking, which generated more off-cuts and sawdust.

Effect of Log Diameter on Board Volume Recovery

Figure 5 shows the volume recovery (m^3) *versus* diameter distribution for the healthy and infected classes. This study found no significant relationship between volume recovery and diameter for either the healthy or infected classes for each log in each tree. However, the recovery of infected board was lower and the average diameter of log was reducing gradually as the class infection became very severe as shown in Table 7 (0.286, 0.273, 0.272, and 0.268 m). Cruickshank *et al.* (2009) discovered that disease causes a reduction in the number of boards in infected trees in a study using healthy and infected Douglas-fir trees of the same diameter.

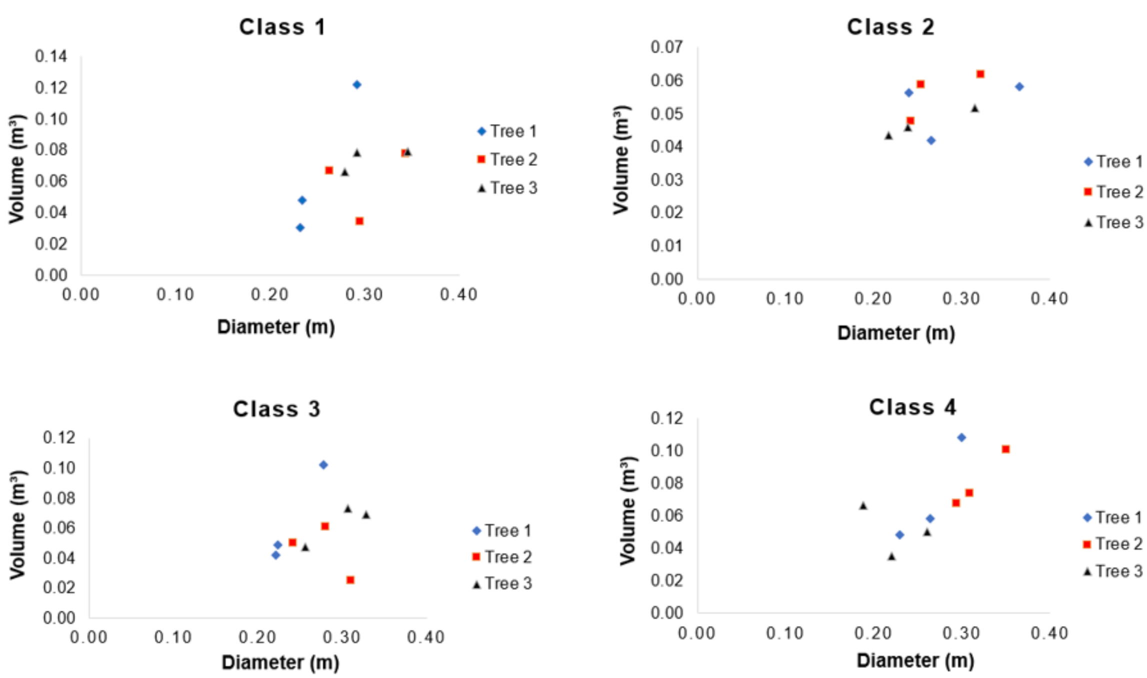


Fig. 5. Distribution of volume recovery (m^3) of board *versus* diameter of log for healthy and infected classes

Infection of a tree resulted in a volume reduction of up to 50% (Lockman 2004), lowering the density of wood indirectly. Mafia *et al*. (2013) and Fernandes *et al*. (2014) discovered that wood from both *E. grandis* hybrid and *E. urophylla* clones infected with *Ceratocystis* has lower density than wood from healthy trees. Furthermore, Cown *et al*. (2013) demonstrated that timber grade and recovery are strongly influenced by stem defects and form irregularities, which reduce the proportion of recoverable sawn boards. This supports the need to minimize infection incidence, as disease-induced deformities can significantly lower timber quality and usable yield.

These results suggest that pathogen infection affects trees by reducing their stem diameter. In the absence of published data on the effects of *C. deuterocubensis* on stem taper in *E. urograndis*, the observed reduction in diameter provides an indication that the disease may alter stem taper and diminish product conversion efficiency. Evidence from related studies supports this possibility. For example, Kallio and Tamminen (1974) reported that spruce trees infected with butt rot exhibited greater stem taper than healthy trees, which reduced the volume of recoverable timber. Additional support comes from studies on other *Eucalyptus* stem canker diseases. *Botryosphaeria* stem canker has been shown to distort wood anatomical structure including vessel deformation and irregular radial growth (Syofuna *et al*. 2025). Such disruption to cambial activity demonstrates that stem canker pathogens can alter stem form and radial increment, supporting the likelihood that *C. deuterocubensis* infection may similarly affect stem taper and product conversion efficiency in *E. urograndis*. Given that this study compared trees of the same age (11 years) but with differing levels of infection severity, it is plausible that stem canker infection influenced radial growth, resulting in smaller stem diameters and reduced product recovery.

Table 8 shows the Pearson's correlation between infected classes and log diameter and volume recovery (m^3). Pearson's correlation analysis revealed weak and not significant correlations between infection severity and both log diameter (r = -0.140, P = 0.416) and board volume recovery (r = 0.030, P = 0.864), suggesting that disease severity did not strongly influence these metrics. This implies that as the infection progressed, the volume recovery decreased but not significantly. The lower correlation coefficient may be due to the unusual behavior of infected class 4, which has a slightly lower volume recovery than class 1 (0.602 $m^3$and 0.603 m^3) but with higher percentages of recovery (51.2% and 45.0%).

Table 8. Correlation between Infected Classes with Diameter of Log and Volume of Sawn Board

		Correlations		
		Class	**Log Diameter (m)**	**Volume (m^3)**
Class	Pearson Correlation	1	-0.140	0.030
	Sig. (2-tailed)		0.416^{ns}	0.864^{ns}
	N	36	36	36

^{ns} Not significant (*P* > 0.05)

Board Grades, Quality and Values

Boards from healthy and infected tree pairs were compared in terms of the number of boards for each grading standard (PRIME, SELECT, STANDARD, SOUND, SERVICEABLE, and UTILITY). Table 9 depicts the visual appearances of board grades for the four infected classes with no board in PRIME grade. Classes 1 and 2 produced boards ranging from SELECT to SERVICEABLE, while classes 3 and 4 produced boards ranging from SELECT to UTILITY. Classes 1 and 2 demonstrated the ability to produce a greater volume of higher-quality timber. In class 1, surface and end checks, knots, and pin/shot holes were the most common defects, whereas in class 2, timber quality was reduced due to additional defects such as callus, kino pockets, cankers, and knots. Classes 3 and 4 produced lower-quality timber as the number and severity of defects increased. The results revealed that the healthy (class 1) tree was of higher quality. This was primarily due to more boards from higher grades (SELECT and STANDARD) and fewer overall downgrades (Table 9). The infected tree class 2 (moderate) gained a better grade than the classes 3 (severe) and 4 (very severe). This was mainly due to a greater number of boards in the STANDARD grade and a slightly lower number of boards in the SERVICEABLE grade.

Table 9. Grades of Healthy and Infected *Eucalyptus urograndis* Sawn Timbers

Infected Classes	Description	PRIME	SELECT	STANDARD	SOUND	SERVICE-ABLE	UTILITY	Total
1	Pieces	0	13	57	26	3	0	99
	Volume	0	0.130	0.333	0.135	0.005	0.000	0.603
2	Pieces	0	6	42	23	6	0	77
	Volume	0	0.064	0.265	0.125	0.011	0.000	0.466
3	Pieces	0	4	49	50	7	3	113
	Volume	0	0.043	0.229	0.226	0.014	0.005	0.517
4	Pieces	0	9	46	48	7	5	115
	Volume	0	0.091	0.285	0.204	0.016	0.006	0.602
Total	Pieces	0	32	194	147	23	8	404
	Volume	0	0.328	1.112	0.690	0.047	0.011	2.188

Meanwhile, the infected trees from classes 3 and 4 had comparable quality to the STANDARD, SOUND, SERVICEABLE, and UTILITY grades. Yet, class 4 had the advantage of having a slightly higher number of boards and volume for grade SELECT than class 3. Overall, the higher recoveries obtained for classes 1, 2, 3, and 4 were standard grades 0.333, 0.265, 0.229, and 0.285 m^3. Disease infection significantly affected timber grade by introducing defects such as decay, kino pockets, insect borers, and cracks. These defects limit the usability and aesthetic qualities of boards from classes 2 to 4. While class 1 produced more SELECT and STANDARD grade boards, classes 3 and 4 were largely graded as MERCHANTABLE because of visible defects on machined surfaces. This finding is consistent with the study by McGavin and Laggate (2019), which reported defects contributing to the downgrade of *Corymbia citriodora* and *Callitris glaucophylla* veneers.

According to our prior research (Dahali *et al*. 2022), wood samples from class 1 had a cleaner and smoother surface than infected samples from classes 2, 3, and 4. However, the severity of class infection did not provide significantly different results in terms of machining properties (sawing, planing, and boring quality). According to Beadle *et al.* (2008), stem defects such as canker, decay, kino and insect borer (pin, short, and large holes borer), and stain fungi, are potential sources of value loss and downgrade in plantations managed for solid wood. As a result, silviculture treatments such as thinning and pruning are critical to minimizing this potential defect (White and Kile 1991). Knots, decay, cracks, and checks are examples of defects that can reduce the strength and structural integrity of wood. Furthermore, disease infection can cause discoloration and other visual defects (Dahali *et al*. 2021) reducing the aesthetic appeal of the wood.

Lower grade boards were most likely downgraded due to the severity of the infection and the presence of rotten/decay in their boards. Sawn timber with large knots, for example, may be graded as lower quality and sold at a lower price. Similarly, rotten/decayed timber caused by disease may be downgraded to the point where it is no longer suitable for use in high-grade applications. These findings were consistent with the study of Yang *et al.* (2002), where the degree of downgrade is determined by the type and severity of defects and can be quantified by the final grade of the sawn boards. The relative yield of sawn boards in various grades is addressed by grade recovery. The lower acceptable quality grade of sawn timber results in lower value (prices) and decreased demand.

Table 10 shows the back sawn board grouping grades from each infection class. Classes 1 and 2 received a similar grade, which is SERVICEABLE AND BETTER, because of the quantity and log volume for each grade. Classes 3 and 4, on the other hand, were of MERCHANTABLE quality. The presentability of rotten/decayed and surface checks boards on three and five boards, respectively, were the downgrade causes for MERCHANTABLE grade boards. These defects are significant value-limiting defects in current markets when exposed to the board surface *via* machining on graded surfaces.

Table 10. Grades of Healthy and Infected *Eucalyptus urograndis* Sawn Timber According to Grouping of Grades

Infected Classes	Description	SELECT AND BETTER	STANDARD AND BETTER	SOUND AND BETTER	SERVICEABLE AND BETTER	MERCHANTABLE
1	Pieces	13	70	96	99	0
	Volume	0.130	0.463	0.598	0.603	0.000
2	Pieces	6	48	71	77	0
	Volume	0.064	0.329	0.454	0.466	0.000
3	Pieces	4	53	103	110	113
	Volume	0.043	0.272	0.498	0.512	0.517
4	Pieces	9	55	103	110	115
	Volume	0.091	0.376	0.580	0.596	0.602
Total	Pieces	32	226	373	396	228
	Volume	0.328	1.440	2.130	2.177	1.119

Furthermore, Washusen *et al*. (2009) discovered that many mills in Australia require SELECT and STANDARD (SELECT AND BETTER, and STANDARD AND BETTER) grade surfaces to be free of surface checks in their study. Surface checking severity and prevalence were influenced by processing methods such as felling, sawing, and drying because of growth stress release. As a result, the affected boards were demoted to the UTILITY (MERCHANTABLE) grade. The Malaysian Timber Industrial Board (MTIB, 2009) defines MERCHANTABLE (UTILITY AND BETTER) as a category of all grades that provides higher quality timber than typical “run of the mill” since the worst pieces are eliminated during grading. However, the pricing information is unavailable for other classes, including SOUND AND BETTER, SERVICEABLE AND BETTER, and MERCHANTABLE. The value of sawn timber was calculated by multiplying the volume of grade for only SELECT AND BETTER and STANDARD AND BETTER by the market price shown in Table 11. Price per cubic meter was converted from price per tonnage. According to the results in Table 11, the value of sawn timber from all infected classes 2, 3, and 4 were lower than class 1. The higher price of *E. urograndis* board in SELECT AND BETTER and STANDARD AND BETTER grade was from class 1 (USD 69.3 and 225.9), followed by class 4 (USD 48.1 and 181.0), class 2 (USD 34.7 and 184.0), and class 3 (USD 23.1 and 129.9). According to Cruickshank (2010), timber value was correlated to log volume and grade of sawn timber obtained.

Table 11. Value of Healthy and Infected *Eucalyptus urograndis* Sawn Timber

Infection Classes	Value (USD)/Tonnage	
	SELECT AND BETTER	STANDARD AND BETTER
1	69.3	225.9
2	34.7	184.0
3	23.1	129.9
4	48.1	181.0
Total	**175.2**	**720.8**

Source: Adapted from Impressive Transform Sdn. Bhd. (August 2023)

The main constraints in utilizing timber from canker-infected trees are the physical defects caused by the disease and the limitations of conventional processing methods, which can exacerbate end-checking, splitting, and diamonding. Improving sawing and drying techniques, along with advanced machinery, could help reduce these defects and optimize yield. Furthermore, since managing hardwood plantations for solid wood involves longer rotations and higher costs, the industry faces added risks related to market stability and processing challenges. Therefore, further research is needed to develop more effective processing techniques suited for plantation-grown *E. urograndis* with small end diameters.

Despite these challenges, the study demonstrates that infected *E. urograndis* timber retains sufficient quality and recovery to remain viable for the timber market. Plantation-grown *Eucalyptus* wood can fulfill a range of applications, including appearance-grade products, providing a sustainable alternative to native hardwoods. For *Eucalyptus* to compete successfully in the hardwood market, the focus should shift toward ensuring a reliable supply of plantation wood that meets both industry standards and market demands over the next 25 to 30 years. This will require targeted improvements in both silvicultural practices and processing technologies to fully realize the potential of *E. urograndis* as a robust resource for the timber industry. A key limitation of this study is the small sample size of only three trees per infection class, which restricts the generalizability of the findings. Therefore, future studies should replicate the work with larger samples to validate these results.

Selective harvesting of Classes 1 and 2 may improve board recovery from less-infected logs, but it does not necessarily increase the proportion of infected trees remaining in the plantation. Any potential effect on residual stand infection will depend on the epidemiology of *C. deuterocubensis*, harvest hygiene, and the handling of infected residues. Therefore, sanitation measures and monitoring of the remaining stand are recommended to minimize the risk of secondary infection.

CONCLUSIONS

1. The findings of this study underscore the complex impact of *Chrysoporthe deuterocubensis* stem canker on *Eucalyptus urograndis* plantations. Although the disease negatively affects timber productivity, quality, and market value, the study revealed that moderately infected trees (class 2) retain potential for commercial use.
2. Class 2 logs achieved recovery rates above 40% and included boards that met SELECT and SERVICEABLE grades, comparable to those from healthy trees (class 1). However, as infection severity increased, timber value decreased significantly due to visual and structural defects such as kino pockets, decay, and cracks, and decay impacting the overall grading and marketability.

RECOMMENDATIONS

Several recommendations are suggested to improve the future profitability and productivity of *Eucalyptus urograndis* plantations infected by *Chrysoporthe deuterocubensis* stem canker disease such as:

a) Disease Management: Silvicultural practices, including early detection, pruning, and sanitation, should be intensified to reduce the incidence and spread of canker disease in *Eucalyptus* plantations.
b) Utilization Strategy: Moderately infected logs should not be discarded prematurely, as they can yield MERCHANTABLE and SERVICEABLE timber with appropriate processing.
c) Grading Standards: Specific grading rules for plantation-grown *Eucalyptus* timber should be developed to reflect its unique defect profile and optimize its commercial potential.

ACKNOWLEDGMENTS

This research was funded by the Trans-disciplinary Research Grant Scheme (TRGS 2018-1), Reference code: TRGS/1/2018/UPM/01/2/3 (vote number: 5535800) by Ministry of Higher Education (MOHE), Malaysia. The authors express their sincere gratitude to the management and staff of Sabah Softwoods Berhad (SSB) for providing the wood materials and to the Eco-friendly Alternatives (materials such as biopolymers and bio composites for food processing, construction, and building applications) Research Program under the Institute of Tropical Forestry and Forest Products (INTROP) and the Faculty of Forestry and Environment, Universiti Putra Malaysia, for their facilities and assistance.

REFERENCES CITED

Afrifah, K. A., and Mensah, K. F. (2014). “Assessment of the effect of log diameter and inherent characteristics of four timber species on the yield of sliced veneer,” *Global Advanced Research Journal of Physical and Applied Sciences* 3(2), 17-24.

Ambrose, A. (2024). "Evaluation of fungicides as protective and curative treatments against canker disease of *Eucalyptus urograndis* caused by *Chrysoporthe deuterocubensis* in Malaysia," *Forests* 14(12), 2337-2356. https://www.mdpi.com/1999-4907/14/12/2337

Awing, N. H., Ambrose, A., Abdu, A., Hassan, A., and Terhem, R. (2023). "Characterisation of *Chrysoporthe cubensis* and *Chrysoporthe deuterocubensis*, the stem canker diseases of *Eucalyptus* spp. in a forest plantation in Malaysia," *Forests* 14(8), article 1660. https://doi.org/10.3390/f14081660

Awing, N. H. (2023). "Characterization, biological control of *Chrysoporthe cubensis* and *Chrysoporthe deuterocubensis* and fungal diversity in *Eucalyptus* plantations in Malaysia (Doctoral dissertation, Universiti Putra Malaysia, Serdang, Malaysia). UPM Institutional Repository. https://doi.org/10.3390/f14081660

Beadle, C., Volker, P., Bird, T., Mohammed, C., Barry, K., Pinkard, L., Wiseman, D., Harwood, D., Washusen, R., Wardlaw, T., and Nolan, G. (2008). "Solid-wood production from temperate eucalypt plantations: A Tasmanian case study," *Southern Forests* 70(1), 45-57. https://doi.org/10.2989/SOUTH.FOR.2008.70.1.6.516

Beltrame, R., De Peres, M. L., Lazarotto, M., Gatto, D. A., Schneid, E., and Haselein, C. R. (2015). "Growth stress and its relationship with end splits in logs of *Eucalyptus* spp.," *Ciência Florestal* 43, 63-74.

Bernama. (2022). "Community eucalyptus plantations will boost timber industry," Bernama. https://bernama.com/en/news.php?id=2118809

Blackburn, D., Hamilton, M., Harwood, C., Innes, T., and Potts, B. (2011). "Genetic variation in traits affecting sawn timber recovery in plantation-grown *Eucalyptus nitens*," *Annals of Forest Science* 68(7), 1187-1195. https://doi.org/10.1007/s13595-011-0130-y

Boland, D. J., Brophy, J. J., and House, A. P. N. (1991). *Eucalyptus Leaf Oils: Use, Chemistry, Distillation and Marketing*, Inkata Press, Melbourne.

Cassens, D. L., and Serrano, J. R. (2004). "Growth stress in hardwood timber," in: *Proceedings of the 14th Central Hardwoods Forest Conference*, GTR-NE-316, pp. 106-115.

Cown, D. (2016). "Review of eucalypt wood processing issues," *Special Wood Product Technical Report SWP-T016*, Scion Research Partnership, Forest Product Innovation, pp. 1-46.

Cown, D., Marshall, H., Silcock, P., and Meason, D. (2013). "Sawn timber grade recovery from a planted coast redwood stand growing in New Zealand," *New Zealand Journal of Forestry Science* 43, article 8. https://doi.org/10.1186/1179-5395-43-8

Cruickshank, M. G. (2010). "Effect of Armillaria root disease on quality and value of green Douglas-fir lumber," *The Forestry Chronicle* 86, 263-266. https://doi.org/10.5558/tfc86263-2

Cruickshank, M. G., Morrison, D. J., and Lalumiere, A. (2009). "The interaction between competition in interior Douglas-fir plantations and disease caused by *Armillaria ostoyae* in British Columbia," *Forest Ecology and Management* 257, 443-452. https://doi.org/10.1016/j.foreco.2008.09.013

Dahali, R., Lee, S. H., Md Tahir, P., Bakar, E. S., Muhammad Roseley, A. S., Ibrahim, S. A., Mohd Yusof, N., and Mohammad Suffian James, R. (2022). "Influence of *Chrysoporthe deuterocubensis* canker disease on the machining properties of *Eucalyptus urograndis*," *Forests* 13(9), article 1366. https://doi.org/10.3390/f13091366

Dahali, R., Lee, S. H., Md Tahir, P., Salim, S., Hishamuddin, M. S., Che Ismail, A., Khoo, P. S., Krystofiak, T., and Antov, P. (2023). "Influence of *Chrysoporthe deuterocubensis* canker disease on the chemical properties and durability of *Eucalyptus urograndis* against wood rotting fungi and termite infestation," *Forests* 14(2), article 350. https://doi.org/10.3390/f14020350

Dahali, R., Md Tahir, P., Roseley, A. S. M., Hua, L. S., Bakar, E. S., Ashaari, Z., Abdul Rauf, M. R., Zainuddin, N. A., and Mansoor, N. S. (2021). "Influence of *Chrysoporthe deuterocubensis* canker disease on the physical and mechanical properties of *Eucalyptus urograndis*," *Forests* 12(5), 639. https://doi.org/10.3390/f12050639

Espey, M., Paridah, M. T., Lee, S. H., Muhammad Roseley, A. S., and Meder, R. (2021). "Incidence and severity of end-splitting in plantation-grown *Eucalyptus pellita* F. Muell. in North Borneo," *Forests* 12, article 266. https://doi.org/10.3390/f12030266.

FAO (2022). "Global forest sector outlook 2050: Assessing future demand and sources of timber for a sustainable economy," *Food and Agricultural Organization of the United Nations*, Italy.

Fernandes, B. V., Zanuncio, A. J. V., Furtado, E. L., and Andrade, H. B. (2014). "Damage and loss due to *Ceratocystis fimbriata* in eucalyptus wood for charcoal production," *BioResources* 9, 5473-5479. https://doi.org/10.15376/biores.9.3.5473-5479

Foroughbakhch, R., Carrillo-Parra, A., Hernandez-Pinero, J. L., and Guzman-Lucio, M. A. (2017). "Growth and yield of a eucalyptus subtropical plantation in a northeastern Mexico degraded land soil," *Madera y Bosques* 23(3), 71-85. https://doi.org/10.21829/myb.2017.2331130

Franca, F. J. N., Suely, T., Franca, F. A., and Vidaurre, G. B. (2020). "Effect of growth stress and interlocked grain on splitting of seven different hybrid clones of *Eucalyptus grandis* × *Eucalyptus urophylla* wood," *Holzforschung* 74(10), 917-926. https://doi.org/10.1515/hf-2019-0209

Gezahgne, A. (2010). "Main diseases of eucalyptus species in Ethiopia," in: *Eucalyptus Species Management, History, Status and Trends in Ethiopia*, G. Wubalem, and T. Lopez (eds.), Technical University of Madrid, Madrid, Spain, pp. 351-369.

Ghaffariyan, M. R., Japarudin, Y., Lapammu, M., Alwi, A., and Chiu, K. C. (2021). "Veneering and sawing performance of plantation-grown *Eucalyptus pellita*, aged 7-23 years, in Borneo, Malaysia," *International Wood Products Journal* 12(2), 116-127. https://doi.org/10.1080/20426445.2020.1871275

Gunduz, G., Oral, M. A., Akyuz, M., Aydemir, D., Yaman, B., Asik, N., Bulbul, A. S., and Allahverdiyev, S. (2016). "Physical and morphological properties and Raman spectroscopy of chestnut blight diseased *Castanea sativa* Mill. wood," *Cerne* 22, 43-58. https://doi.org/10.1590/01047760201622012101

Impressive Transform Sdn. Bhd. (2023). Lots 1 and 2, Jalan PBR 33, Kawasan Perindustrian Bukit Rambai, 75250 Melaka, Malaysia. https://www.ifwat.com/

Japarudin, Y., Meder, R., Lapammu, M., Waburton, P., Paul-Macdonell, P., Brown, M., and Brawner, J. (2022). "Developing *Eucalyptus pellita* breeding populations for the solid wood industry of Eastern Malaysia," *Journal of Tropical Forest Science* 34(3), 347-358. https://doi.org/10.26525/jtfs2022.34.3.347

Japarudin, Y., Meder, R., Lapammu, M., Alwi, A., Ghaffariyan, M., and Brown, M. (2021). "Compression and flexural properties of plantation-grown *Eucalyptus pellita* in Borneo, Malaysia: Potential for structural timber end use," *Australian Forestry* 84, 139-151. https://doi.org/10.1080/00049158.2021.1962628

Jones, T. G., McConnochie, R. M., Shelbourne, T., and Low, C. B. (2010). "Sawing and grade recovery of 25-year-old *Eucalyptus fastigata*, *E. globoidea*, *E. muelleriana* and *E. pilularis*," *New Zealand Journal of Forestry Science* 40, 19-31.

Kallio, T., and Tamminen, P. (1974). "Decay of spruce (*Picea abies* (L.) Karst.) in the Åland Islands," *Acta Forestalia Fennica*, 41 pp. https://doi.org/10.14214/aff.7572

Khan, R. (2024). "Current status, challenges & opportunities of forest plantations," paper presented at the Malaysian Forestry Conference (MFC) 2024, Forest Department Peninsular Malaysia, Malaysia, Jawala Plantation Industries Sdn. Bhd.

Knorr. (1996). *Backsawn Timber Production from Radially Sawn Wedges*, U.S. Patent No. 5,560,409, October 1, 1996.

Kojima, M., Nakai, T., Saegusa, K., Yamaji, F. M., Yamamoto, H., and Yamashita, S. (2012). "Anatomical and chemical factors affecting tensile growth stress in *Eucalyptus grandis* plantations at different latitudes in Brazil," *Canadian Journal of Forest Research* 42(1), 134-142. https://doi.org/10.1139/x11-161

Lee, S. H., Lum, W. C., Antov, P., Kristak, L., and Md Tahir, P. (2022). "Engineering wood products from *Eucalyptus* spp.: A review," *Advances in Materials Science and Engineering*, article 8000780, 14 pages. https://doi.org/10.1155/2022/8000780.

Liao, K., Yang, F., Dang, H., Wu, Y., Luo, K., and Li, G. (2022). "Detection of eucalyptus leaf disease with UAV multispectral imagery," *Forests* 13, article 1322. https://doi.org/10.3390/f13081322

Lockman, B. (2004). "Management guide for *Atropellis* canker," in: *Forest Insect and Disease Management Guide for the Northern and Central Rocky Mountain Region*, USDA Forest Service, Northern and Intermountain Region, State and Private Forestry, Forest Health Protection, Boise, ID, and Missoula, MT (Non-standard pagination).

Mafia, R. G., Ferreira, M. A., Zauza, A. V., Silva, J. F., Colodette, J. L., and Alfenas, A. C. (2013). "Impact of *Ceratocystis* wilt on eucalyptus tree growth and cellulose pulp yield," *Forest Pathology* 43, 379-385. https://doi.org/10.1111/efp.12041

Malan, F. S. (2009). "Clonal differences in log end splitting in *Eucalyptus grandis* in relation to age, parent performance, growth rate and wood density in two even-aged trials in Mpumalanga, South Africa," *Southern Forests* 70, 37-43. https://doi.org/10.2989/SOUTH.FOR.2008.70.1.7.517

Malaysian Timber Industry Board (MTIB). (2009). *The Malaysian Grading Rules for Sawn Hardwood Timber*, 2009 Edition, Malaysian Timber Industry Board.

Malaysian Timber Industry Board (MTIB). (2010). "Medium hardwood: Eucalyptus," in: *100 Malaysian Timbers-2010 Edition*, Malaysian Timber Industry Board, Kuala Lumpur, Malaysia, pp. 132-133.

Malaysian Timber Industry Board (MTIB). (2013). *Malaysian Grading Rules for Rubberwood Sawn Timber*, Third Edition, Malaysian Timber Industry Board, ISBN 978-967-5384-41-7.

Malaysian Timber Industry Board (MTIB). (2025). "Development of forest plantation," Malaysian Timber Industry Board. https://www.mtib.gov.my/en/services/forest-plantation/development-of-forest-plantation.html

Malik, J., and Hopewell, G. P. (2011). "Sawing recovery of several sawmills in Jepara," *Jurnal Penelitian Hasil Hutan* 29(4), 331-342. https://doi.org/10.20886/jphh.2011.29.4.331-342

McEwan, A., Marchi, E., Spinelli, R., and Brink, M. (2020). "Past, present and future of industrial plantation forestry and implication on future timber harvesting technology," *Journal of Forestry Research* 31(2), 339-351. https://doi.org/10.1007/s11676-019-01019-3

McGavin, R., and Leggate, W. (2019). "Comparison of processing methods for small-diameter logs: Sawing versus rotary peeling," *BioResources* 14(1), 1545-1563. https://doi.org/10.15376/biores.14.1.1545-1563

Mohd Ghani, R. S., and Lee, M. D. (2021). "Challenges of wood modification process for plantation eucalyptus: A review of Australian setting," *Journal of the Korean Wood Science and Technology* 49(2), 191-209. https://doi.org/10.5658/WOOD.2021.49.2.191

Naghizadeh, Z., and Wessels, C. B. (2021). "The effect of water availability on growth strain in *Eucalyptus grandis* × *Eucalyptus urophylla* trees," *Forest Ecology and Management* 483, article 118926. https://doi.org/10.1016/j.foreco.2021.118926

Nolan, G., Innes, T., Redman, A., and McGavin, R. L. (2003a). *Australian Drying Best Practice Manual, Part 1*, FWPRDC Report No. PN01.1307, 180 pp.

Nolan, G., Innes, T., Redman, A., and McGavin, R. L. (2003b). *Australian Drying Best Practice Manual, Part 2*, FWPRDC Report No. PN01.1307, 324 pp.

Old, K. M., Wingfield, M. J., and Yuan, Z. Q. (2003). *A Manual of Diseases of Eucalypts in South-East Asia*, Centre for International Forestry Research (CIFOR), Jakarta, Indonesia. https://doi.org/10.17528/cifor/001428

Ratnasingam, J., Aznor, M. A., Ramasamy, G., and Seng, C. Y. (2013). "A review of different sawing and drying techniques used in processing small-diameter logs," *Journal of Applied Sciences* 13(3), 341-347. https://doi.org/10.3923/jas.2013.341-347

Rauf, M. R. B. A., McTaggart, A. R., Marincowitz, S., Barnes, I., Japarudin, Y., and Wingfield, M. J. (2019). "Pathogenicity of *Chrysoporthe deuterocubensis* and *Myrtoporthe bodenii* gen. et sp. nov. on eucalyptus in Sabah, Malaysia," *Australasian Plant Pathology* 49, 53-64. https://doi.org/10.1007/s13313-019-00676-6

Rezende, G. D. S., de Resende, M. D. V., and de Assis, T. F. (2014). "Eucalyptus breeding for clonal forestry," in: *Challenges and Opportunities for the World's Forests in the 21st Century*, *Springer*, Dordrecht, The Netherlands, pp. 393-424. https://doi.org/10.1007/978-94-007-7076-8_16

Rozas, C., Zapata, B., Muñoz, F., Ortiz-Araya, V., and Erazo, O. (2023). "Characterization and yield of *Eucalyptus regnans* F. Muell logs for lumber production," *Forests* 14(12), article 2359. https://doi.org/10.3390/f14122359

Salleh, S. (1995). "*Eucalyptus* plantations: The Malaysian experience," in: Reports Submitted to the Regional Expert Consultation on Eucalyptus, FAO, Bangkok, Thailand. https://www.fao.org/4/AC772E/ac772e0d.htm#bm13

Samdin, Z., Md. Tahir, P., Abdul Hamid, H., and Azim, R. A. R. A. (2018). "Potential of eucalyptus plantation in Malaysia," *The Malaysian Forester* 81(1), 64-72.

Samdin, Z., Mohd Razali, S., Rosman, A., Khaw, A., and Kamaruddin, N. (2020). "*Eucalyptus* in Malaysia: Review on environmental impacts," *Journal of Landscape Ecology* 13(3), 1-15.

Stewart, H. A. (1980). "Some surfacing defects and problems related to wood moisture content," *Wood and Fiber* 12(3), 175-182.

Suzuki, H., Marincowitz, S., Wingfield, B. D., and Wingfield, M. J. (2022). "Genetic diversity and population structure of *Chrysoporthe deuterocubensis* isolates from

Melastoma and *Eucalyptus* in Malaysia and Indonesia," *Forest Pathology* 52, article e12762. https://doi.org/10.1111/efp.12762

Syofuna, A., Banana, A., Nakabonge, G., and Ndawula, J. (2025). "Effect of *Botryosphaeria* stem canker disease on the anatomical structure of *Eucalyptus* wood," *Forest Science and Technology* 22(1), 231-238. https://doi.org/10.1080/21580103.2025.2571225

Terhem, R., Alias, N. I. M., and Kamarudzaman, K. (2021). "Preliminary study of canker disease for development of urban tree health standard in Malaysia," in: IOP Conference Series: *Earth and Environmental Science* 918, article 012037. https://doi.org/10.1088/1755-1315/918/1/012037

Wan Mohd Nazri, W. A. R., Muhammad, F. S., Suffian, M., Nur Nazihan, S., and Nor Yuziah, M. Y. (2020). "Wood and veneer properties of fast-growing species from Batai, Eucalyptus and Kelampayan," *International Journal of Management and Humanities* 4(8).

Washusen, R. (2006). *Comparison of Sawn Recovery and Efficiencies of Radial and Linear Multi-Sawing Systems*, Ensis Client Report No. 1633, 29 pp.

Washusen, R., Harwood, C., Morrow, A., Northway, R., Valencia, J. C., Volker, P., Wood, M., and Farrell, R. (2009). "Pruned plantation-grown *Eucalyptus nitens*: Effect of thinning and conventional processing practices on sawn board quality and recovery," *New Zealand Journal of Forestry Science* 39, 39-55.

Wessels, C. B., Nocetti, M., Brunetti, M., Crafford, P. L., Pröller, M., Dugmore, M., Calvin Pagel, Lenner, R., and Naghizadeh, Z. (2020). "Green-glued engineered products from fast-growing *Eucalyptus* trees: A review," *European Journal of Wood and Wood Products* 78(5), 933-940. https://doi.org/10.1007/s00107-020-01553-6

White, D. A., and Kile, G. A. (1991). "Thinning damage and defect in regrowth eucalypts," in: *The Young Eucalypt Report*, Kerruish, C. M., and Rawlins, W. H. M. (eds.), CSIRO, Canberra.

Wu, W., and Chen, S. (2019). "Distribution and damage of *Calonectria* in eucalyptus in China," *Eucalypt Science and Technology* 36, 43-49. (In Chinese).

Yang, J. L. (2005). "The impact of log-end splits and spring on sawn recovery of 32-year-old plantation *Eucalyptus globulus* Labill.," *Holz als Roh- und Werkstoff* 63, 442-448. https://doi.org/10.1007/s00107-005-0035-2

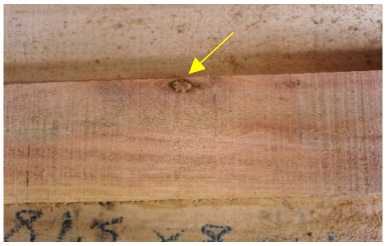
Yang, J. L., Fife, D., Waugh, G., Downes, G., and Blackwell, P. (2002). "The effect of growth strain and other defects on the sawn timber quality of 10-year-old *Eucalyptus globulus* Labill.," *Australian Forestry* 65, 31-37. https://doi.org/10.1080/00049158.2002.10674850

Zhang, X., and Jiang, G. (2026). "Impact of silvicultural practices on the growth of *Eucalyptus* plantations: A meta-analysis," *Journal of Tropical Forest Science* 38(1), 22-39. https://doi.org/10.26525/jtfs2026.38.1.22

Article submitted: March 3, 2026; Peer review completed: May 24, 2026; Revised version received: June 17, 2026; Accepted: June 21, 2026; Published: July 2, 2026.
DOI: 10.15376/biores.21.3.7662-7689

Appendix. Description of Non-Permissible Defects Found on *E. urograndis* Boards

Defects	Description
	a) End check ➢ A small separation of the wood fibers at the end of the longitudinal direction.
	b) Surface check ➢ A small fracture or separation of wood fibers on a surface in the longitudinal direction, usually occurring in the annual rings. ➢ It does not extend as deep as the opposite or adjacent piece of sawn timber on the side (shake and split). ➢ Checks typically occur as a result of strain developing during seasoning. These negatively impact the durability of wood because they easily admit moisture and air.
	c) End split ➢ Also known as a shake. Is a longitudinal separation of the fibers in a piece of sawn timber that extends to the opposing face or joining edge.
	d) Star shake ➢ A term used for a split, crack, or deep check that occurs as a result of heartwood shrinking. ➢ This type of defect is called a star shake when it completely encircles the pith (heart) and runs outward toward the sapwood.
	e) Diamonding ➢ A piece of lumber that was initially square or rectangular in cross-section may be distorted due to differential shrinkage during drying to become diamond-shaped. ➢ The discrepancy between tangential and radial shrinkage is what causes this flaw, which manifests itself when rays pass through the diagonal corners of a square or rectangle.
	f) Wane ➢ The lack of wood on any face or edge of a piece of sawn timber. ➢ Typically brought on by a portion of a log's original rounded surface still being present on the piece. ➢ Bark may or may not be present.



g) Knot

- A knot is a part of a branch that has become entrenched in the wood as a result of the tree's natural growth.
- The cross-section of a knot is usually circular or oval in form and is calculated by taking the mean of the longest and shortest diameters.
- Knots are classified as follows: unsound/encased, hollow and checked knots.

h) Scorching

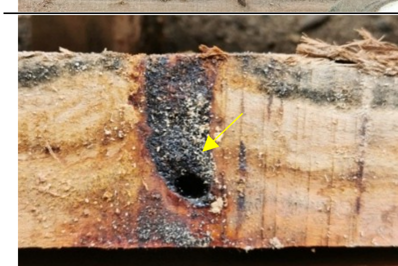
- Darkening of the colour of the timber surface.
- Excessive heat during the sawing operation.

i) Callus

- Callus or swelling near the site of infection, resulting in cambium bulging.
- This callus may eventually form a crack.

j) Kino pocket

- A kino pocket patch that is partially or entirely encased within the wood.
- Kino or gummosis may occasionally be present in the pocket.



k) Kino/Gummosis shakes

- Minute shakes arising from kino veins.

l) Canker

- Area or part of wood that is infected by *C. deuterocubensis* stem canker disease

	m) Decay ➢ Decay is due to the disintegration of wood resulting from the action of *C. deuterocubensis*. Accompanied by discoloration.
	n) Pin/shot holes ➢ Holes made by boring insects or their larvae in living trees such as Ambrosia beetles or after they have fallen or been sawed such as powder post beetles. ➢ Pin holes typically have a diameter not exceeding 1.6 mm, and are usually around 0.8 mm or smaller. The edges of these holes may sometimes exhibit discoloration. ➢ Meanwhile shot holes have a diameter greater than 1.6 mm but less than 3.2 mm.
	o) Emergence holes ➢ Also referred to as a life borer holes. A member of the *Bostrychidae* or *Lyctidae* families, known for its larval borer that attacks partially seasoned wood. The diameter of emergence holes ranges from approximately 1.6 mm to 3.2 mm.
	p) Grub holes ➢ Also known as large borer holes, longhorn beetles cause holes over 3.2 mm in diameter, often averaging about 6.4 mm in diameter.

Source: Adapted from Malaysian Grading Rules (2009; 2013); Dahali *et al*. (2021).