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Influence of *Chrysoporthe deuterocubensis* Canker Disease on the Machining Properties of *Eucalyptus urograndis*

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Abstract: This study assessed the machining properties of 11-year-old *Eucalyptus urophylla* × *E. grandis*, known as *E. urograndis* wood, that was infected by stem canker disease, *Chrysoporthe deuterocubensis*. Instead of being discarded directly, the study aimed to explore the possibility of infected trees being used in other applications such as furniture. Sawing, planing, and boring properties as well as the surface roughness of the healthy and infected trees were evaluated. The samples were collected from infected and healthy trees and classified according to the severity of the attack: healthy (class 1), moderately infected (class 2), severely infected (class 3), and very severely infected (class 4). Prior to sawing, planing, and boring, the samples were prepared according to ASTM D 1666-11 Standard Test Methods for Conducting Machining Tests of Wood and Wood-Base Materials. All samples were sawn, planed, and bored and were evaluated for their respective machining quality. The surface roughness of the machined samples was also assessed. Overall, *E. urograndis* of different infection severity has very good machining properties ranging from Grade I to III. Fuzzy grain, chip grain, chip mark, and tear out are the most commonly seen physical defects. As for surface roughness, healthy trees have lower surface roughness compared to that of infected trees, which indicates a better surface quality. The findings of this study suggested that infected *E. urograndis* can still be used in many applications. The results of this study will provide us with better knowledge about the machining performance of disease-infected *E. urograndis* wood and its possibilities to be used as raw material for the wood products industry.

Keywords: *Eucalyptus urograndis*; *Chrysoporthe deuterocubensis*; infection classes; machining properties; sawing; planing; boring and surface roughness

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1. Introduction

Commercial natural wood has excellent physical, mechanical, and aesthetic properties, and it is widely used in markets worldwide. However, the supply of these natural wood species is dwindling, and prices are skyrocketing, indicating a supply–demand imbalance. Plantation forests were established in an effort to reduce reliance on natural round logs from natural forests and as a strategy to address the issue of scarcity [1]. It was expanded after it was discovered that these plantations had the potential to meet the entire world's wood needs [2–4].

In Malaysia, forestry sectors and investors have launched a commercial planting programme of selected fast-growing species to ensure a steady supply of wood. *Neolamarckia cadamba* [5] or kelempayan (laran), *Paraserianthes falcataria* (batai), and *Eucalyptus* spp. were among the native and exotic species planted under this programme [6,7]. Eucalyptus is the most widely planted broad-leaved tree species globally, covering over 20 million ha worldwide [8]. The planting programme was prompted in part by a recent outbreak of *Ceratocystis* spp. wilt disease, which killed 10 to 20% of plantation tree species, particularly Acacias [9]. In response to this situation, planters in Sabah and Sarawak switched to Eucalyptus species such as *E. pellita* F. Muell and Eucalyptus hybrid in areas previously planted with Acacias. Both species have been well accepted as plantation species, with a total of 11,000 ha and 28,090 ha of Eucalyptus hybrid and *E. pellita* plantations established in Sabah and Sarawak by the end of 2015 [9]. The previously introduced E. hybrids from Southern China were successfully trial planted as pilot plantations in various parts of Sabah, with the oldest stands dating back to 2008 in Sabah Softwoods Berhad, Tawau. According to Arnold et al. [10], the hybrid clone created by crossing *E. urophylla* S.T. Blake and *E. grandis* W. Hill ex Maiden and has been widely accepted and planted in plantations due to its stability and other superiorities such as growth, high survival rate, and adaptability [11,12].

Previously, there have been no reports of disease in Malaysian Eucalyptus plantations, indicating a general lack of knowledge about Eucalyptus diseases in the country. However, in mid-2014, stem cankers disease caused by Cryphonectriaceae was reported for the first time. *Chrysoporthe deuterocubensis* Gryzenh. and M. J. Wingf. were found on the bark of *E. grandis* trees in the Sipitang and Tawau plantation regions of Sabah, Malaysia [13]. The findings showed that *C. deuterocubensis* has been identified as a pathogenesis of Eucalyptus species and is a potential threat to plantation forestry in Sabah. Therefore, the aim of this study was to evaluate the machining properties of 11-years old *E. urograndis* coming from the Sabah Softwoods plantation site infected by *C. deuterocubensis*. In order to determine its suitability and potential usage, the effect of the severity of class infection on machining properties was an important matter to be considered. Machining properties describe how wood behaves when planed, shaped, turned, or subjected to any other standard woodworking operation. Machining properties are important for wood and wooden products [14,15]. Equally significant is the machined surface roughness, which serves as one of the primary indicators of the quality of the machined wooden materials [16]. Additionally, the efficacy of glueing and coating, as well as the aesthetic value of timber materials, were strongly influenced by their surface roughness [17].

In general, wood is simple to cut, shape, and fasten. For some applications, the difference in machinability between woods is negligible; for others, such as furniture and fixtures, the smoothness and ease with which woods can be worked may be the most important of all properties. Unless a wood is machined reasonably well and easily, it is not economically suitable for such uses, regardless of its other qualities. Nevertheless, little information regarding the properties of the Eucalyptus hybrid is currently known, especially its machining properties [18,19]. Wood with good machining properties could be used in industrial applications of high-value-added products [20]. An earlier study by Rasdianah et al. [21] showed that *E. urograndis* wood that was only mildly infected by *C. deuterocubensis* still showed potential for use in furniture and other non-structural applications rather than being rejected immediately. Therefore, instead of being discarded directly, this study aimed to examine the machining properties of *E. urograndis* wood with several infection intensities. The results of this study will provide us with better knowledge about the machining performance of disease-infected *E. urograndis* wood and its possibilities to be used as raw material for the wood products industry.

2. Materials and Methods

The infected Eucalyptus hybrids clone used in this study was identified as *E. urophylla* × *E. grandis*, which is of Chinese origin and is known as *E. urograndis*. The plot used in this study was an 11-year-old *E. urograndis* plantation plot in Block 38 C (4°33′16.3″ N, 117°42′58.7″ E), Sabah Softwoods Berhad, Tawau, Malaysia. Based on the appearing symptom during infection, the trees were divided into four classes of the severity of infection (Table 1) as reported in a previous study [21]. The infected trees were identified by the appearance of canker signs on their stems. The trees were chosen based on a rubric of stem canker symptoms that was created prior to sampling. Table 1 shows how selected trees were visually examined to determine their symptoms and severity, and then classified into severity classes. Due to the limited number of infected trees in the plot, only two trees from each infection class were felled. At a height of 15 cm above ground, eight trees were felled. The remaining logs were not analysed because they had very few to no defects. The logs were then numbered and end coated before being transported to a processing workshop for further analysis. The eight trees felled for this study yielded a total of 40 billets. Using a live sawing technique and a Wood-Mizer twin vertical saw with a bank of four horizontal resaws (Wood-Mizer Europe, Koło, Poland), four to five 28 mm-thick boards were cut from each billet. Prior to air drying, the initial moisture content of the boards was determined. 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 of 20%. Following air drying, the board was planed and ripped to a final dimension (20 mm thick × 102 mm wide × 910 mm long) for sawing, planing, and boring evaluation.

Table 1. Classes of severity for *Eucalyptus urograndis* infected with *Chrysoporthe deuterocubensis* [a].

Class	Category	Symptom
1	Healthy	Stem appears normal without any symptom of being infected
2	Moderate	Swollen bark (callus) Cracking Fruiting structure Fresh kino pocket Canker
3	Severe	Swollen bark (callus) Cracking Fruiting structure Fresh kino pocket and fresh kino/gummosis Canker Sunken Rotten
4	Very severe	Swollen bark (callus) Cracking Fruiting structure Dried kino pocket and dried kino/gummosis Canker Sunken Rotten Shoots

[a] Adapted with permission from Rasdianah et al. [21].

2.1. Evaluation of Machining Properties

The sample preparation and testing procedures were carried out in accordance with the ASTM D 1666-11 standard [22], with some minor modifications. Because of limited wood and resources, the standard has been modified and the dimension has been reduced. The tests were carried out at the Wood Technology Workshop at Universiti Putra Malaysia in Serdang, Selangor. For each severity class and type of machining test, a total of 30 samples were used. Before each machining test, all samples were kept in a conditioning room that was kept at 20 ± 2 °C and relative humidity of 65% ± 2% until they reached an equilibrium moisture content (EMC) of 12%. Following testing, the machining quality of each individual sample was visually examined and graded using the ASTM D 1666-11 standard [22]. The surface qualities were classified into five quality grades based on the degree of defects (%) and the impact of defects, as shown in Table 2. Fuzzy grain, chip grain, chip mark, and tear out were observed as defects in this study. The integral weighted method was used to compare the quality of every sample from four class infections on each machining property: The I, II, III, IV, and V of quality grades received 5, 4, 3, 2, 1, and 1 point, respectively. The surface roughness was tested according to the ISO 4288 standard [23].

Table 2. Grading quality of wood machining properties [24–26].

Quality Grade	Machining Quality	Defect Free Area (%)
I	Very good (no defects)	81–100
II	Good (few slight defects which can be eliminated by light sanding)	61–80
III	Fair (lots of slight defects, some obvious defects which can be eliminated by sanding)	41–60
IV	Poor (serious defects (deep and big) which are hard to eliminate)	21–40
V	Very poor (very serious defects and prohibited to use)	0–20

2.1.1. Sawing Quality Assessment

The samples were cut using a panel saw machine (Altendorf F45, Remscheid, German) (Figure 1) fitted with a tungsten carbide tipped (TCT) circular saw. The TCT circular saw has a 300 mm diameter, a bore size of 30 mm, a cutting width of 3.2 mm, and the number of teeth was 72 with alternate tooth bevel to prevent snatching in crosscut applications for exceptionally clean cutting results. The cutting direction was across the grain at 4000 rpm, and the feeding speed was about 2.4 m/s. Samples from each infection class were cut using a new circular saw blade. The samples were then compared and graded visually for qualitative qualities. A visual examination for each testing sample was performed and expressed in a percentage based on the defect-free surface and graded based on five visual examinations as shown in Table 3. For the sawing test, the cuts of wood were graded visually based on the roughness of the edge surface such as the occurrence of fuzzy grain and tear out.

Figure 1. Panel saw machine.

Table 3. Specification of stylus tracing.

Tracing Direction	Across the Grain
Tracing speed	0.1 mm/s
Cut off length	0.8 mm (sawing and boring), and 2.5 mm (planing)
Stylus tip radius	2 µm
Stylus tip angle	90°
Tracing length	4 mm (sawing and boring), and 12.5 mm (planing)

2.1.2. Planing Quality Assessment

All the samples were tested using a thickness planer to assess their planing performance. The planing test was carried out using a standard single-faced planing machine (Sanjui SA16, Taichung, Taiwan) equipped with a 40 cm long cutterhead with four knives at a 27° cutting angle attached (Figure 2). The rotational speed of the cutterhead was 5500 revolutions per minute (RPM). All samples were planed twice with a 2 mm depth of cut at a feed rate of 18 m/min. Only the second planing was utilised for observation, with the first planing being excluded. This was to ensure that all the samples were in the same condition. The planed samples were marked to identify their planed surface. New knives were used for these tests and knives were freshly sharpened every time to start planed samples from other class of severity to minimize the knife blunting effects. The samples were planed along the grain and run butt to butt to eliminate the possibility of a defect, such as a burn mark caused by overheating of the knife edge. The samples were then assessed visually for defects. The defect types and defectives-free area were recorded. Samples were graded based on the presence of fuzzy grain, chip grain and chip mark. The defective areas of the planed sample were assessed using the planimeter and graded based on percentages of the defect-free area. The percentages of the defected areas were obtained using Equation (1):

$$\text{Defected area, (\%)} = 100\ (W_i - W_f)/W_i \tag{1}$$

where, W_i is the total area of the surface (mm), and W_f is the defective area (mm) for each sample.

Figure 2. Thickness planer machine used for planing testing.

2.1.3. Boring Quality Assessment

A single-spindle electric boring machine (JK-BD-25, Gujarat, India) as shown in Figure 3 was used for this test. The machine was fitted with a TCT Forstner type bit, and the bits are all new. Two holes were bored across the grain in the same sample with a brad point bit with a diameter of 25 mm. The spindle rotation was set at 900 RPM as bigger diameter holes required less speed and a feed rate of 0.6 m/min. Four holes were bored across the grain for each sample. A smooth board was set under the samples to ensure that they were closely touching. The boring properties of different infection classes were evaluated based on the examination of the holes. Transverse and lateral faces of each hole were visually examined for the smoothness of the cut and the defect that was present during the bore is recorded. Surfaces were evaluated for fuzzy grain and tear out and were rated on a grade scale of I to V. The results of the boring properties were expressed as a percentage.

Figure 3. Single-spindle electric boring machine used in this trial.

2.1.4. Surface Roughness Test

Surface roughness testing (Figure 4) was conducted on all the samples after the machining test (sawing, planing, and boring). The test is carried out by using the portable contact stylus tracing method (Profilometer TR-220, Shandong, China). This device was operated for obtaining the roughness data according to the ISO 4288 standard [23] and a study by Redzuan et al. [27] with the specifications specified in Table 3. The tool had a measurement speed of 0.1 mm/s, a pin diameter of 2 m, and a pin top angle of 90°, respectively. The parameters measured were maximum roughness depth (Rmax), mean peak-to-valley height (Rz), and average surface roughness (Ra). For sawing, planing, and boring, readings were taken perpendicular to the direction of the grain using tracing lengths of 4 mm, 4 mm, and 12.5 mm, respectively. Each sample underwent five random measurements.

Figure 4. Surface roughness tester.

2.2. Statistical Analysis

The data were analysed and interpreted using a one-way analysis of variance (ANOVA) in order to assess the impact of infection classes on the machining characteristics of the wood. The difference between the mean values of each severity class was tested using Duncan's multiple range (DMR) test at $p < 0.05$. All statistical evaluations were performed using SPSS version 22.0. (IBM, Armonk, NY, USA).

3. Results and Discussion

3.1. Sawing Properties

Sawing is the first step in the machining process in the woodworking industry. Defect-free surfaces are commonly used to assess the quality of wood surfaces produced during the sawing process [28,29]. Tables 4 and 5 summarises the effects of infection classes (healthy, moderate, severe, and very severe) on the sawing properties of the 11-year-old *E. urograndis*. In the sawing test of *E. urograndis*, the most noticeable defects were fuzzy grain and tear out, with the fuzzy grain being more dominant. The presence of a group of standing fibres causes fuzzy grain (not cut perfectly). This is due to the presence of reaction wood [30]. Meanwhile, tear out occurs most frequently when the blade exits the stock and breaks rather than cuts the wood fibres [31]. As a result of this breakage, the majority of the tear out occurs only at the underside, back edge, and corners of the wood (Figure 5). The sawing quality of the class 1 sample (84.04% defect-free area) is slightly better. The defective area did not differ significantly between classes 1, 2, and 3. However, when compared to other classes, the defective area of class 4 wood was significantly higher (23.33% defective area). Therefore, classes 1, 2, and 3 of wood were classified as grade I, while class 4 was classified as grade II.

3.2. Planing Properties

Table 6 and Figure 6 summarises the obtained defect-free values and quality classes based on the planing process. The samples defect-free surface area is related to the machining defects that appear during the planing process. The proportion of defects for each severity classes was not obvious, as class 1 is 83.60% defect-free. Meanwhile, the infected class 2, 3, and 4, respectively, has 78.90, 76.93, and 71.71% defect-free area. In all wood classes, the largest defect is chip mark followed by chip grain. Fuzzy grains also existed but to a much lesser extent. Another plausible reason for this observation is because classes 2, 3, and 4 contain kino pockets and gummosis [32], causing the wood to withstand the force from the blade during blade exit. The defects also could be caused by feed speed, which plays an important role in processing. High feed speed can cause a poor surface, especially for hardwood [33].

Table 4. Sawing performance of healthy and infected samples of *Eucalyptus urograndis*.

Defect Types	Value	Infection Classes				*p*-Value
		1 (Healthy)	2 (Moderate)	3 (Severe)	4 (Very Severe)	
Defect-free area (%)	Mean [1] SD	84.04 [b] 5.85	81.35 [b] 6.68	83.88 [b] 8.29	76.67 [a] 10.01	0.001 ***
Defective area (%)	Mean SD	15.96 [a] 5.85	18.65 [a] 6.68	16.11 [a] 8.29	23.33 [b] 10.01	0.001 ***
Fuzzy grain (%)	Mean SD	8.57 [a] 4.97	10.11 [ab] 6.28	9.60 [ab] 6.97	12.77 [b] 6.46	0.064
Tearout (%)	Mean SD	7.39 [a] 2.69	8.54 [ab] 3.33	6.51 [a] 3.32	10.57 [b] 6.17	0.002 **

Notes: Defect types according to ASTM D 1666-11 standard [16]. [1] Means followed by the same letter a, b in the same column is not significantly different at $p < 0.05$ according to Duncan multiple range test. ** high significance ($p < 0.01$); *** very high significance ($p < 0.001$).

Table 5. Machining grade of healthy and infected samples of *Eucalyptus urograndis* in sawing test.

Infection Classes	Grade I (Very Good)	Grade II (Good)	Grade III (Fair)	Grade IV (Poor)	Grade V (Very Poor)
1 (Healthy)	22	8	0	0	0
2 (Moderate)	19	10	1	0	0
3 (Severe)	22	6	2	0	0
4 (Very severe)	15	11	4	0	0

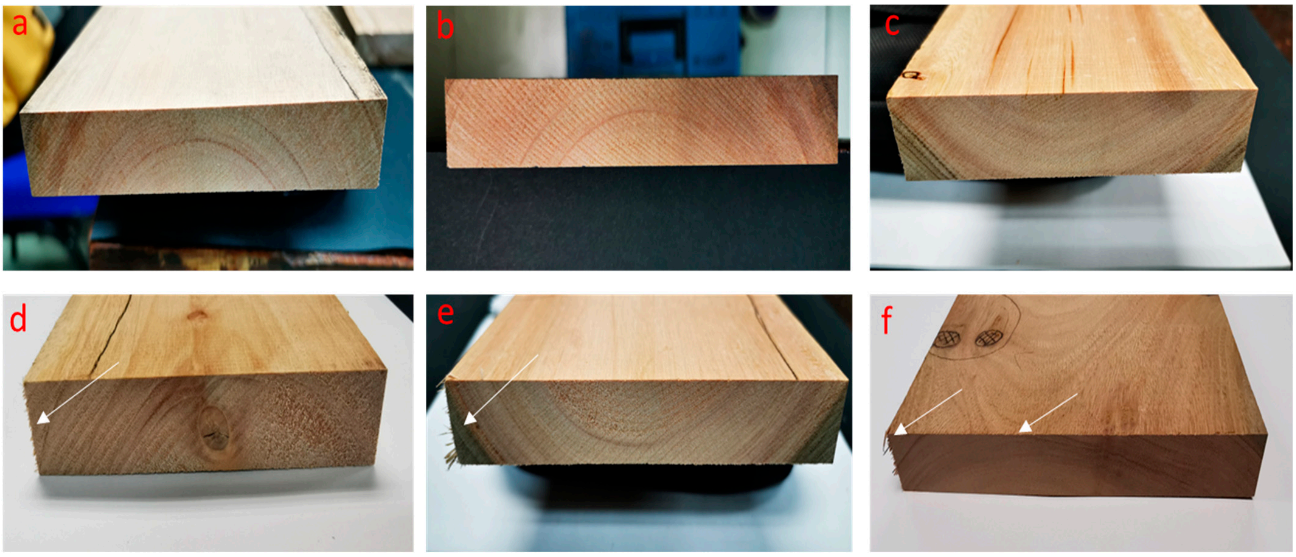

Figure 5. Surface quality of healthy and infected *E. urograndis* wood samples after sawing test; (**a**–**c**); clean surface cut signifies acceptable quality (upper) while unclean (**d**) fuzzy grain and (**e**,**f**); tear out signifies low quality (lower).

Table 6. Planing performance of healthy and infected samples of *Eucalyptus urograndis*.

Defect Types	Value	Infection Classes				p-Value
		1 (Healthy)	2 (Moderate)	3 (Severe)	4 (Very Severe)	
Defect-free area (%)	Mean [1] SD	83.60 [b] 10.42	78.90 [ab] 14.75	76.93 [ab] 13.39	71.71 [a] 15.81	0.011 **
Defective area (%)	Mean SD	16.40 [a] 10.42	21.00 [ab] 14.75	23.07 [ab] 13.39	28.29 [b] 15.81	0.011 **
Fuzzy grain (%)	Mean SD	1.20 [a] 1.93	1.12 [a] 1.92	1.30 [a] 1.83	2.05 [a] 2.53	0.286
Chip grain (%)	Mean SD	4.91 [a] 5.34	8.00 [ab] 9.32	8.22 [ab] 7.50	10.42 [c] 10.44	0.093
Chip mark (%)	Mean SD	10.29 [a] 8.05	11.98 [a] 12.99	13.56 [a] 11.21	15.82 [a] 12.41	0.279

Notes: Defect types according to ASTM D 1666-11 standard [16]. [1] Means followed by the same letter a, b, c in the same column is not significantly different at $p < 0.05$ according to Duncan multiple range test. ** high significance ($p < 0.01$).

The test results show that the test samples from class 1 are significantly better than class 4 samples, with class 4 recording a higher degree of defect (28.29%). Wood class 4 had a higher defect rate, with three samples in grade III and four samples in grade V out of 30 samples tested as depicted in Table 7. Overall, 10 of the 30 samples were in grade I, while 13 were in grade II. From Tables 6 and 7, the overall planing quality of class 1 wood falls into grade I—very good quality. Meanwhile, all infected wood classes 2, 3, and 4 fell in grade II. This shows the planing surface of the infected classes 2, 3, and 4 wood has a low magnitude of defect. According to MTIB [34], Eucalyptus wood is relatively easy to plan and produce a smooth surface where, less vibration and noise is emitted by the planer during the cut, but the quality of planing is very much dependent on its density [35,36] and how severe the wood was infected. According to [21], the densities of classes 1, 2, 3, and 4 are 670.8 kg/m^3, 618.9 kg/m^3, 706.8 kg/m^3, and 542.3 kg/m^3, respectively; those with higher densities (Classes 1, 2 and 3) perform better than those with lower densities (Class 4).

Figure 6. Surface quality of healthy and infected *E. urograndis* wood samples after planing test; (**a**,**b**); clean surface cut signifies acceptable quality (upper) while unclean (**c**) fuzzy grain, (**d**,**e**); chipped grain and (**f**); chip mark surface cut signifies low quality (lower).

Table 7. Machining grade of healthy and infected samples of *Eucalyptus urograndis* in planing test.

Infection Classes	Grade I (Very Good)	Grade II (Good)	Grade III (Fair)	Grade IV (Poor)	Grade V (Very Poor)
1 (Healthy)	25	3	2	0	0
2 (Moderate)	13	14	2	1	0
3 (Severe)	18	9	1	2	0
4 (Very severe)	10	13	3	4	0

Note. Grade I = 81%–100%; Grade II = 61%–80%; Grade III = 41%–60%; Grade IV = 21%–40%; Grade V = 0%–20%.

3.3. Boring Properties

Fuzzy grain and tear cut are the defects that appear in the boring test shown in Table 8 and Figure 7. Meanwhile, the total number of samples in each grade of healthy and infection classes are summarized in Table 9.

Table 8. Boring performance of healthy and infected samples of *Eucalyptus urograndis*.

Defect Types	Value	Infection Classes				*p*-Value
		1 (Healthy)	2 (Moderate)	3 (Severe)	4 (Very Severe)	
Defect-free area (%)	Mean [1]	82.82 ^{c}	81.30 ^{bc}	77.26 ^{ab}	74.81 ^{a}	0.001 ***
	SD	6.58	8.65	9.47	8.25	
Defective area (%)	Mean	17.80 ^{a}	18.70 ^{ab}	22.74 ^{bc}	25.19 ^{c}	0.001 ***
	SD	6.58	8.65	9.47	8.25	
Fuzzy grain (%)	Mean	7.43 ^{a}	8.90 ^{ab}	10.58 ^{b}	11.75 ^{b}	0.027 **
	SD	2.97	6.51	7.64	5.08	
Tearout (%)	Mean	9.75 ^{a}	9.80 ^{a}	12.17 ^{b}	13.44 ^{b}	0.001 ***
	SD	4.49	3.40	3.30	4.94	

Notes. Defect types according to ASTM D 1666-11 standard [16]. [1] Means followed by the same letter a, b, c in the same column is not significantly different at $p < 0.05$ according to Dun- can multiple range test. ** high significance ($p < 0.01$); *** very high significance ($p < 0.001$).

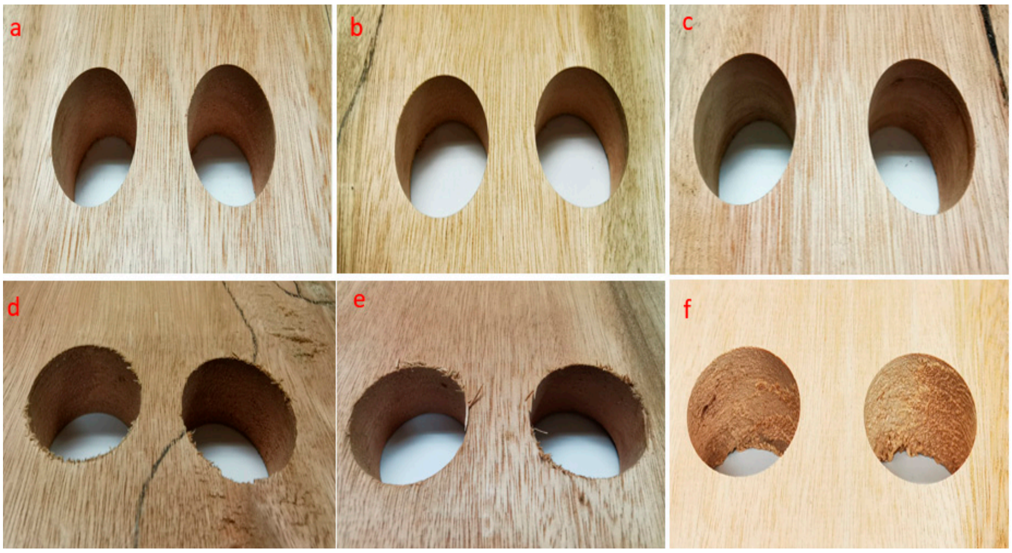

Figure 7. Surface quality of healthy and infected *E. urograndis* wood samples after boring test; (**a**–**c**); clean surface cut signifies acceptable quality (upper) while unclean (**d**) fuzzy grain, (**e**); tear out and (**f**); smoothness signifies low quality (lower).

Table 9. Machining grade of healthy and infected samples of *Eucalyptus urograndis* in boring test.

Infection Classes	Grade I (Very Good)	Grade II (Good)	Grade III (Fair)	Grade IV (Poor)	Grade V (Very Poor)
1 (Healthy)	18	11	1	0	0
2 (Moderate)	12	12	6	0	0
3 (Severe)	16	11	3	0	0
4 (Very severe)	4	22	4	0	0

Note. Grade I = 81%–100%; Grade II = 61%–80%; Grade III = 41%–60%; Grade IV = 21%–40%; Grade V = 0%–20%.

The most common defect was tear cut, which ranged from 9.75 to 13.44%, followed by fuzzy grain, which ranged from 7.43 to 11.75%. Based on Abdurrachman criteria [24], which classify the grade of the machined surface based on the percentage of defective areas, it can be seen that *E. urograndis* wood shows very good and good boring quality as it falls into grade I to grade II with a defect-free surface percentage range of 82.82%–74.81%. Belleville et al. [37] and Gupta et al. [38] observed that the denser species of eucalyptus showed better boring performances than lighter timbers. This result is in the line with finding by MTIB [34], as the boring process of *Eucalyptus* sp was easy to handle and produce a fairly smooth surface. Sitinjak [36] added that the presence of broken fibers occurs during the machining process as the surface of the wood sample is forcibly removed. This happens presumably because the drill bit is blunt. In contrast to the process of sawing and planing, the condition of the wood before boring also greatly affects the final result. This is thought to be because the mechanism and direction of the cut in the boring process are slightly different from the two processes. Boring is commonly used in the manufacture of chairs, furniture, and other hardwood products that use dowels, spindles, rungs, and screws for the wood structure joint. The bored hole should be round without any noticeable distortion and the inner surface should be smooth for good glue bonding.

Stem canker diseases are common in trees under stress. Damage occurs when opportunistic, living (biotic), infectious pathogens (fungi or bacteria) enter a wound during a time of tree stress, such as transplant shock, drought, or winter injury. Other stress agents that provide opportunities for canker diseases include prolonged exposure to extremely high or low temperatures, flooding, summer or winter sunscald, hail, high winds, nutritional imbalances, soil compaction, mechanical injuries (lawn mower, vehicles), animal damage, pruning wounds, root rot, insect borers, and improper planting. Most cankers are caused by fungi, which invade bark tissue on current season wood. Plants do not have immune systems like animals. Instead, they have evolved an entirely different way of dealing with infections. In trees, this process is known as the compartmentalization of decay in trees or "CODIT" [39]. Trees have an amazing ability to generate new cells. However, they do not have the ability to repair the damage. Instead, trees respond to disease and injury by walling it off from their living tissues. This involves three distinct processes. The first of these has to do with minimizing the spread of damage. Trees accomplish this by strengthening the walls between cells. Essentially, this begins the process of isolating whatever may be harming the living tissues. This is done via chemical means. In living sapwood, it is the result of changes in the chemical environment within each cell. In heartwood, enzymatic changes work on the structure of the already deceased cells. Though the process is still poorly understood, these chemical changes are surprisingly similar to the process of tanning leather. Compounds like tannic and gallic acids are created, which protect tissues from further decay. They also result in a discoloration of the surrounding wood. The second step in the CODIT process involves the construction of new walls around the damaged area. This is where the real compartmentalization process begins. The cambium layer changes the types of cells it produces around the area so that it blocks that compartment off from the surrounding vascular tissues. These new cells also exhibit highly altered metabolisms so that they begin to produce even more compounds that help resist and hopefully stave off the spread of whatever microbes may be causing the injury. Many of the defects seen in wood products are the result of these changes [40]. Another study by Paiman et al. [41] using a natural regeneration (non-stressed) and planted (stressed) *Acacia mangium* × *A. auriculiformis* hybrid observed that non-stressed wood produced a smoother surface cut than stressed wood. This finding was similar to Tan [42] who found that the sawing process of stressed wood produced a rougher surface than non-stressed wood. Stressed and non-stressed wood tend to have different wood qualities as a result of different fibre lengths and wall thicknesses caused by different growth conditions [43].

3.4. Surface Roughness

For surface roughness, Ra is the average roughness of a surface while Rz is the difference between the tallest peak and the deepest valley in the surface. As presented in Table 10, the sawn, bored, and planed *E. urograndis* wood showed a similar trend in surface roughness as samples from class 1 (healthy) and class 2 (moderate) has lower Ra values than that of class 3 and 4, implying a better surface quality of the former classes. However, Rz values displayed an inconsistent trend whereas, for sawing, the Rz value decreased as the severity classes increased. Meanwhile, for boring, the Rz values increased as the severity classes increased. On the other hand, severity class 3 has the lowest Rz value for planing. Lower Ra and Rz values are advantageous since they improve paint performance and need less paint to cover a smooth surface [44]. Overall, planing resulted in higher average surface roughness (Ra) compared to that of sawing and boring as planed samples displayed a higher percentage of the defective area (16.40 to 28.29%, see Table 6) such as chip mark, chipped grain, and fuzzy grain that existed on the surface after being planed. Statistical analyses for machinability characteristics (Table 10) show that both planing and boring tests are significantly different ($p > 0.05$) between infection classes. The surface roughness of sawn samples did not differ significantly within infection classes.

A study by Gunduz et al. [40] reported that the surface of Chestnut disease (*Cryphonectria parasitica*) infected *Castanea sativa* Mill. wood has a rougher surface than healthy ones. The authors observed that the physiological and cambial activities of the infected part of the trees were slowed down by the Chestnut disease. Although the shapes of the vessel elements are still intact, the transverse section of the infected wood has vessels with smaller lengths and diameters as well as frequency. Through examining the morphologies of the fibre cells, fibres of infected wood showed abnormal formation. Additionally, bifurcations and other abnormal structures were seen at the extremities of the infected wood's fibres. Additionally, bifurcations and other abnormal structures were seen at the extremities of the infected wood's fibres, most likely brought on by the fungus's stress-induced increase in anticlinal divisions in the vascular cambium. In addition, the authors also found various sizes of the parenchyma cells by light microscope images using SEM/EDX on the tangential sections of the infected wood, and in some of the parenchyma cells, starch grains were observed. As a result of this observation, the surface was found to be smooth in healthy wood, while some granular formation was observed on the infected wood as a result of the activity of the pathogen. As stated by Tulik et al. [45], this phenomenon can also be seen in compression wood in gymnosperms as a result of developmental processes. Some would be pondering that the infected wood might then have a coarser surface as a result, which might make processing the wood more difficult. However, it should be noted that these formations have no impact on the wood's economic worth because they are incredibly uncommon and easy to remove [40].

Table 10. Mean reading of surface roughness on the sawing, planing, and boring quality.

Infection Classes		Sawing			Planing			Boring		
	Value	**Ra (μm)**	**Rz (μm)**	**Rmax (μm)**	**Ra (μm)**	**Rz (μm)**	**Rmax (μm)**	**Ra (μm)**	**Rz (μm)**	**Rmax (μm)**
1 (Healthy)	Mean [1]	7.82 [a]	31.24 [a]	54.99 [a]	8.31 [a]	27.81 [a]	52.96 [a]	6.90 [a]	56.6 [a]	73.40 [a]
	SD	1.91	9.78	11.66	1.92	10.89	16.79	0.96	7.58	8.41
2 (Moderate)	Mean	7.62 [a]	30.67 [a]	54.54 [a]	8.76 [ab]	27.92 [a]	52.78 [a]	6.69 [a]	56.64 [a]	74.68 [a]
	SD	1.76	10.37	11.56	1.80	7.69	10.73	0.87	7.81	9.37
3 (Severe)	Mean	8.06 [a]	29.28 [a]	53.99 [a]	9.48 [b]	26.25 [a]	52.66 [a]	7.76 [b]	57.25 [a]	71.95 [a]
	SD	1.20	10.12	11.82	2.12	12.85	13.75	0.93	7.65	7.53
4 (Very severe)	Mean	8.10 [a]	29.54 [a]	51.32 [a]	9.80 [b]	29.17 [a]	55.77 [a]	8.25 [b]	58.15 [a]	73.96 [a]
	SD	1.61	10.10	11.28	2.28	12.86	21.71	1.14	7.33	10.25
p-Value		0.640	0.859	0.629	0.023 **	0.797	0.859	0.000 ***	0.846	0.684

Notes. [1] Means followed by the same letter a, b in the same column are not significantly different at $p < 0.05$ according to Duncan multiple range test. ** high significance ($p < 0.01$); *** very high significance ($p < 0.001$).

4. Conclusions

Generally, wood samples from class 1 produced a cleaner and smoother surface than infected samples from classes 2, 3, and 4. However, the difference in the severity of class infection did not give significantly different results toward the sawing, planing, and boring quality, as the lowest grade that was attained, was grade III (average). The machining properties of all the samples are excellent and within the grade range of I to III. Therefore, this research confirmed that the infected medium-density plantation-grown of *E. urograndis* can perform well during sawing, planing, and boring processes. According to the machining properties results, the infected *E. urograndis* can be used in many applications. One method of preventing disease spread in plantations or forests is to remove the infected trees. To make these methods/scenarios useful, these logs can be utilized to produce high-quality timber for furniture, ships, wooden buildings, and musical instruments. Heat treatment may be recommended in order to improve the dimensional stability, durability, and, in particular, sterilisation of timber obtained from infected trees.

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