Original Article
J. Korean Wood Sci. Technol. 2026, 54(3): 243-255
https://doi.org/10.5658/WOOD.2026.54.3.243

Journal of the Korean Wood Science and Technology
pISSN: 1017-0715 eISSN: 2233-7180
http://www.woodj.org

Assessment of Stem Canker Impact on Xylem Quality of Hybrid *Eucalyptus pellita* × *Eucalyptus urophylla* Using Stress Wave Non-Destructive Testing

Ananto TRIYOGO[1,†] · Bayu Anggita WIRABUMI[1] · Sapto INDRIOKO[1] · Yeni Widyana Nurchahyani RATNANINGRUM[1] · Fanny HIDAYATI[2]

ABSTRACT

This research aimed to assess the presence and impact of stem canker disease on hybrid *Eucalyptus pellita* × *Eucalyptus urophylla* trees, and evaluate internal xylem quality using non-destructive testing (NDT). In this context, 536 individual trees were observed before measuring stem diameters. A *t*-test was applied to compare diameters between the two groups, while the severity of stem canker symptoms was recorded using a categorical scoring system. Stress wave velocity and relative velocity decrease were also measured to assess the internal integrity of xylem by using a commercial handheld stress wave timer (FAKOPP). Correlation analysis was conducted to examine relationships between stem diameter, stress wave velocity, relative velocity decrease, and disease severity. The results showed that only 5.6% of observed trees reported visible symptoms of stem canker, with a damage intensity of 4%. There was no significant difference in stem diameter between healthy and diseased trees. Stress wave velocity tended to increase with diameter in healthy trees, while symptomatic trees showed lower and more inconsistent velocities. Relative velocity decrease correlated positively with stem diameter and severity scores, suggesting that larger and more severely infected trees experienced greater internal degradation. Moreover, stem canker disease compromised structural integrity in hybrid Eucalyptus and reported the usefulness of stress wave NDT as an effective tool for early detection of internal xylem defects in plantation management.

Keywords: *Eucalyptus* hybrid, stem assessment, standing tree, stress wave non-destructive testing

1. INTRODUCTION

Eucalyptus is a plant group widely cultivated by forestry industry sector in Indonesia. This plant, with *Acacia mangium*, is among the preferred species and has become a principal commodity of Industrial Timber Plantations (HTI), serving as a primary raw material for pulp and paper production (Hardiyanto *et al*., 2024). The quality of pulp produced by *Eucalyptus* is better due to long wood fibers (Carrillo-Varela *et al*., 2019; Ramos *et al*., 2024). The plants can be used to develop wood and non-wood products. The wood is classified as moderately to highly durable (Class III; Carvalho *et al*., 2016) and is suitable as a reference material for construction.

Date Received August 8, 2025; Date Revised October 2, 2025; Date Accepted Janaury 7, 2026; Published May 25, 2026
[1] Department of Silviculture, Faculty of Forestry, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia
[2] Department of Forest Product Technology, Faculty of Forestry, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia
[†] Corresponding author: Ananto TRIYOGO (e-mail: ananto.triyogo@ugm.ac.id, https://orcid.org/0000-0002-7254-9217)

Certain *Eucalyptus* leaves can be processed into essential oils useful in preventing the human influenza virus and have potential as an inhibitor of COVID-19 development (Ak Sakallı *et al.*, 2022; Sharma and Kaur, 2021).

Several research have shown that *Eucalyptus* plants are susceptible to damage caused by pests and disease. In Indonesia, diseases commonly found in *Eucalyptus* are leaf spot, leaf blight, root rot, stem rot, canker disease, bacterial wilt, and stem canker caused by *Mycosphaerella* spp., *Quambalaria eucalypti* (Pérez *et al.*, 2016; Siregar *et al.*, 2020, 2022), *Ganoderma* spp. (Coetzee *et al.*, 2015; Gafur, 2023) *Fusarium* spp. (Gafur *et al.*, 2023), *Chrysoporthe deuterocubensis* (Suzuki *et al.*, 2022), *Ralstonia solanacearum* (Oliveira *et al.*, 2023; Siregar *et al.*, 2020), and *Colletogloeopsis zuluensis,* respectively. In several other countries, *Eucalyptus* plantations are also attacked by stem canker caused by *Cryptometrion aestuescens* gen. sp. nov. (Gryzenhout *et al.*, 2010), pests such as *Chrysophtharta bimaculata* (de Aguiar Coelho *et al.*, 2024), the gold beetle *Thaumastocoris peregrinus* (Dlamini *et al.*, 2019), and more species of herbivorous insects (Paine *et al.*, 2010).

Wanagama Educational Forest is owned by the Faculty of Forestry, Universitas Gadjah Mada, featuring field research facilities that comprise various genetic test plantings of different species. An important *Eucalyptus* species is a hybrid stand of *Eucalyptus pellita* × *Eucalyptus urophylla*. The species has been planted and selected to be a collection of new superior individuals combining the characters from parental genes (Hardiyanto *et al.*, 2024; Nirsatmanto *et al.*, 2022). This hybrid stand creates a new population with better performance compared to the parent species. In particular, *E. pellita* has been proposed as a primary raw material due to its rapid growth (Lukmandaru *et al.*, 2016). Initial observations on *Eucalyptus* hybrid stand showed that most of the plants exhibited symptoms of stem canker disease. Symptoms of the disease include swelling of stem, the exudation of liquid, and cracking in advanced stages. Research on the quality of xylem resulting from bark disease in *Eucalyptus* trees has not been previously conducted.

Detecting deterioration in trees can be analyzed through various methods based on different concepts. For instance, a common method includes striking the tree with a tool to assess the health. This method can help identify decay or cavities in the trunk but tends to be less effective on larger trees with thick bark (Boyce, 1948; McCracken, 1985). X-ray and neutron radiography, computer tomography, and magnetic resonance are methods explored in-depth for examining the internal features of logs and trees. These imaging methods provide a unique method to examine the internal structure, uncovering the hidden structures and characteristics invisible from the outside (Beaulieu and Dutilleul, 2019; Karlinasari *et al.*, 2018; Wei *et al.*, 2011). These methods can provide one- to three-dimensional spatial locations of various defects and internal wood characteristics. However, the application to trees has been limited due to the high costs associated with the use. Another method used is the utilization of stress wave non-destructive testing (NDT; Lin *et al.*, 2016; Wei *et al.*, 2022). The propagation of stress waves in wood is a dynamic process that directly correlates with the physical and mechanical properties of the wood. Typically, stress waves propagate at a faster pace through sound and high-quality wood compared to degraded and low-quality types (Lin and Wu, 2013; Liu and Gao, 2014). An assessment of the internal condition of a tree is conducted with reasonable accuracy by measuring the transmission time of waves through the radial direction of stem (Wang *et al.,* 2004). Stress wave NDT was also used in the wood property evaluation of the progeny material in many species, such as *Acacia mangium*, *Neolamarckia machrophylla*, and *Ficus variegata* (Dharmawati *et al.*, 2024; Haryjanto *et al.*, 2024;

Hidayati *et al*., 2019; Masendra *et al*., 2023)

Based on the description above, this research aims to determine the level of stem canker disease in hybrid *E. pellita* × *E. urophylla* trees planted in Wanagama Forest, Gunungkidul. Furthermore, the quality of xylem affected by the disease will be evaluated using a stress wave NDT device known as stress wave timer. The method includes answering the following questions: (1) What is the level of Stem canker disease in hybrid *E. pellita* × *E. urophylla* trees? (2) What is the relationship between the level of stem damage caused by disease and xylem quality in hybrid *E. pellita* × *E. urophylla*?

2. MATERIALS and METHODS

This research was conducted in compartment 18 of Wanagama Forest, Gunungkidul, Indonesia, containing a plot planted with hybrid species of *E. pellita* × *E. urophylla*. *Eucalyptus* trees were planted at a distance of 3 × 3 meters, resulting in a total of 536 observed trees. Hybrid plantation was established in 2000, since the trees were 24 years old during the evaluation (Mulawarman *et al*., 2003).

2.1. Observation of diseased trees

Observations of plant health were conducted specifically on the sections exhibiting symptoms of damage from stem canker. These assessments followed Forest Health Monitoring Method (Tallent-Halsell, 1994). A comprehensive evaluation was performed on all trees (100% census) to identify the section showing symptoms of canker. Additionally, measurements of symptom severity were taken using a scoring system, as reported in Table 1.

After gathering the data, the first parameter was analyzed using a formula to measure the intensity of bark damage, which assessed the severity of a specific type in the stand (Pratama *et al*., 2021). The formula for calculating the intensity of the damage is as follows:

$$DI = \frac{\Sigma(ni \times vi)}{N \times Z} \times 100\% \quad (1)$$

DI: damage intensity (%), ni: number of trees with a certain score (tree), vi: score (Table 1), N: total number of observed trees, Z: highest score.

2.2. Observation on xylem quality

A total of 536 individual trees were selected for diameter measurement using different methods for symptomatic and healthy trees. The first measurement was conducted on the diameter of healthy and diseased trees. For healthy trees, the diameter was measured at breast height (DBH), which was 1.35 m from the base,

Table 1. The level of severity for stem damage on tree with stem canker

Level of severity	0%	1%–25%	26%–50%	51%–75%	> 75%
Score	0	1	2	3	4
Description	Morphologically, the stem is still in a normal state like any other tree stem.	The cancer is sized between 1–10 cm, located only on one side of the stem, and has not caused any swelling on the stem.	The cancer is 11–20 cm in size, located on one side of the stem, and has not caused any swelling on the stem.	The cancer found on the trunk is larger than 20 cm and has started to cause swelling in the trunk but has not yet broken the bark.	The cancer that is found on the trunk with a size > 20 cm causes the trunk to swell and crack open the bark.

Fig. 1. Measurement of tree diameter on (a) a healthy tree, the diameter was measured at breast height (DBH), which is 1.35 m from the tree base, and (b) diseased trees, measurements were taken at the infected area (the arrows indicate the measurement positions).

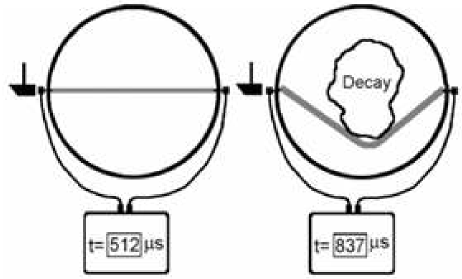

Fig. 2. Experimental setup for acoustic stress wave velocity measurement using the FAKOPP Microsecond Timer with two transducers inserted into the tree stem. Data from Bt (2022); Wang *et al*. (2004).

to obtain the average values and SD of DBH across all healthy individuals [Fig. 1(a)]. Meanwhile, for symptomatic trees, measurements were taken at the infected area [Fig. 1(b)].

Stress wave velocity was assessed by measuring acoustic velocity using a microsecond timer (FAKOPP Microsecond Timer, FAKOPP Enterprise). This tool was equipped with two transducers for transmitting and receiving probes. The starter probe was inserted into tree stem at the infected area, while the receiving probe was driven into the opposite hitting point to connect the accelerometer and detect stress wave propagated perpendicular to the grain (Fig. 2).

The start sensor was hit with a small hammer to create a stress wave. After the stop sensor received stress wave, the time taken was recorded as stress wave propagation time (μs). The distance was stem diameter (cm) of the measured position of trees (Wang *et al.*, 2004). A total of 10 measurements of stress wave propagation time were obtained for each tree, and the mean value was calculated. Stress wave velocity was calculated from the following formulas (Bt, 2022):

$$\text{Velocity (m/s)} = \text{Distance (cm)} / \text{Time } (\mu\text{s}) \times 10{,}000 \tag{2}$$

After stress wave velocity of symptomatic and healthy trees was calculated, relative velocity decrease (RVD) was obtained. RVD is a ratio given by the formula (Bt, 2022):

$$\text{Relative velosity decrease (\%)} = \left(\frac{(V_{ref} \times V_{meas})}{Vref}\right) \times 100 \tag{3}$$

Where V_{ref} is the radial velocity for a healthy tree, and V_{meas} is the measured velocity.

To explore the association of the diameter of tree size with disease presence, an independent two-sample *t*-test (at a 5% significance level) was conducted to compare stem diameters between healthy and diseased trees. After calculating the decrease in relative velocity, a simple correlation analysis was carried out to determine 1) the relationship between velocity and stem diameter, and 2) the decrease in relative velocity and the severity of stem canker disease.

3. RESULTS and DISCUSSION

3.1. Diseased trees

Approximately 30 of 536 observed hybrid *Eucalyptus* trees showed visible signs of stem canker, as assessed using Forest Health Monitoring Method (Tallent-Hansel, 1994; Table 2). Trees with higher severity scores exhibited more extensive bark lesions, swelling, or tissue necrosis compared to lower scores. The severity of symptoms varied across individuals, while most symptomatic trees fell into the lower severity categories of scores 1 and 2. An important proportion exhibited moderate to severe symptoms of scores 3 and 4 (Table 2). Our results show low number of diseased trees most possibly reflects a combination of host genetics (*E. pellita* × *E. urophylla*), stand age (25 years), and the relatively dry seasonal conditions at research site. Previous studies have explained that the variation in canker incidence on *Eucalyptus* is caused by the type or complex of pathogens involved, the host tree genotype, and favorable environmental conditions, particularly humidity and temperature (Aylward *et al*., 2019; Cortinas *et al*., 2006; Nakabonge *et al*., 2006). In Southeast Asia, stem cankers have been documented on *Eucalyptus* (including *E. pellita* hybrids) that causes cracking and swelling on trees with variable impacts across sites (Awing *et al*., 2023; Dahali *et al*., 2023; Tarigan *et al*., 2023).

The symptoms of bark lesions, swelling, and tissue necrosis are consistent with various stem canker diseases affecting *Eucalyptus* species (Ambrose *et al*., 2023; Dahali *et al*., 2021). Among the 536 observed hybrid trees, only 5.6% showed visible symptoms, with DI of 4%, suggesting a relatively low incidence. Previous research has reported that the cultivation of hybrid plants aims to enhance tree performance by incorporating superior traits, including improved resistance to pests and diseases, compared to pure species (Thompson, 2013; Wang and Chen, 2020). This has been effectively shown in the planting of hybrid *Eucalyptus* at Wanagama.

The observed range of stem canker severity scores, from 1 to 4, reflects the diverse symptom expression among infected *Eucalyptus* hybrid individuals. As mentioned in previous research, the variation of canker severity suggests that disease development is not uniform across the stand and may be influenced by multiple interacting factors (Chungu *et al*., 2019). A critical factor is genetic variation among trees (Dahali *et al*., 2021; Guimarães *et al*., 2010; Syofuna *et al*., 2021, 2025). Even though the population consisted of hybrid clones, variability in host resistance to canker-causing pathogens may still be present. Another factor contributing to the observed difference in severity is that certain individuals may possess stronger chemical defense traits. Previous research reported that infected *Eucalyptus* hybrids (*E. urophylla* × *Eucalyptus grandis*) showed changes in chemical properties, such as increased lignin and extractives, suggesting a chemical defense adaptation (Dahali *et al*., 2021). In pure stands, observations on *E. globulus* infected bark found differences in the response of lesion margin compounds and in *E. grandis* with moderate resistance levels. There were different levels of salicylic acid compared to susceptible types (Eyles *et al*., 2003; Mangwanda *et al*., 2016; Zwart *et al*., 2017).

Table 2. The number of trees according to severity level of stem canker symptoms

Score of severity level	0	1	2	3	4
Number of trees	506 (94.4)	4 (0.75)	7 (1.31)	14 (2.61)	5 (0.93)

Score of severity level no symptom = 0; mild = 1; moderate = 2; moderate–severe = 3; and severe = 4.
Values in parentheses represent the percentage of total trees in each severity level.

An independent two-sample *t*-test assuming unequal variances was performed to compare stem diameters between healthy and diseased trees. The mean diameters for healthy and diseased trees were 22.80 cm and 23.07 cm, with coefficient variation of 31% and 34%, respectively (Fig. 3). The result showed no significant difference (p = 0.843), indicating that stem diameter did not differ significantly between the two groups. Stem diameter is not be directly associated with susceptibility to stem canker in the population. This result implies that disease incidence is not size-dependent, and the different types of trees may be equally vulnerable to infection. A possible explanation is that factors such as pathogen virulence, environmental stressors, or entry wounds may play a more dominant role in disease development than host size or growth rate. The presence of disease across a range of diameters may reflect underlying genetic variability in resistance, independent of tree age or size. Previous research has suggested that trees with higher canker severity show reduced growth rates compared to healthy types. Therefore, canker severity impacts tree vigor independently of stem diameter (Ribeiro *et al.*, 2023). Comprehensive health assessments should consider visible symptoms and other additional parameters to detect damage caused by stem canker.

3.2. Xylem quality

There is no difference in diameter size, but the calculation of velocity in healthy and symptomatic trees leads to a difference based on class [Fig. 4(a) and (b)]. These results are consistent with previous research indicating that in healthy tropical hardwood species, such as *Eucalyptus* hybrids and *Acacia mangium*, exhibit a significant positive correlation between stem diameter and stress wave velocity (Hidayati *et al.*, 2019; Prasetyo *et al.*, 2019). In *E. pellita* planted in East Kalimantan, wood basic density increases with stem diameter (Fadwati *et al.*, 2023). Trees with diameters of 1–5 cm and 46–50 cm have an average stress wave velocity of 1,763.77 m/s and 3,009.54 m/s, indicating that xylem in faster growth trees has higher density and better quality [Fig. 4(a)]. In case of a symptomatic tree, the trees with diameters of 6–10 cm and 31–35 cm have velocity of 1,724.83 m/s and 1,939.38 m/s, respectively [Fig. 4(b)]. This is lower than the same diameter class in healthy

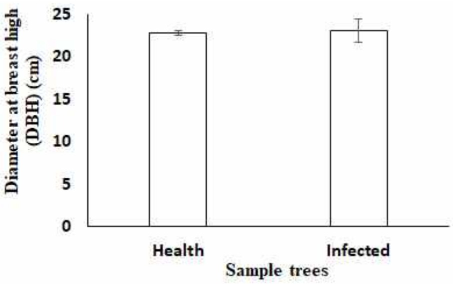

Fig. 3. Observation of the diameter between (a) healthy and (b) diseased trees.

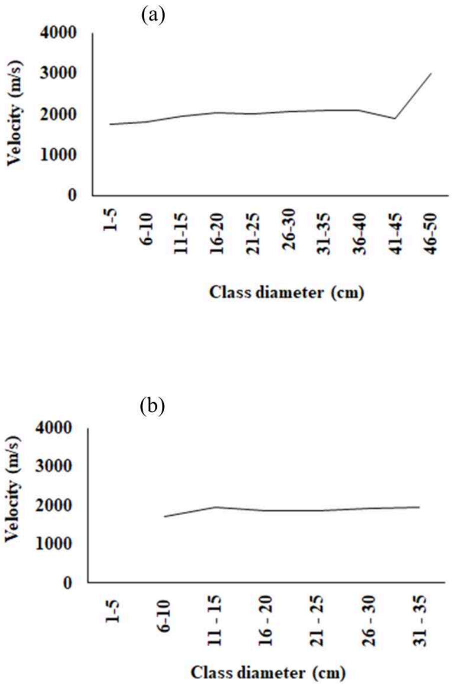

Fig. 4. Observation of velocity in different diameter classes on (a) healthy trees and (b) diseased trees.

trees at 2,093.81 m/s. In addition, a two-sample *t*-test was performed to compare stress wave velocity between healthy and symptomatic trees. The analysis results showed that stress wave velocity was significantly different at 5% level (p = 0.01). This indicated a statistically significant difference in stress wave velocity between healthy and symptomatic trees. Specifically, healthy trees exhibited a higher mean stress wave velocity of 2,021.23 m/s compared to symptomatic trees at 1,885.48 m/s.

Several previous research related to non-destructive technology have used velocity as an indicator to assess the quality of wood in relation to tree health (Proto *et al*., 2017; Wang and Allison, 2008). The use of stress waves to detect decay in trees has been explored (Goh *et al*., 2018; Wang and Allison, 2008; Wang *et al*., 2004). In NDT, velocity is a critical parameter that indicates the time required for sound to propagate through a material (Nainggolan, 2022; Pahade *et al*., 2024). Changes in velocity properties show the presence of flaws, cracks, or other defects in the material (Khan *et al*., 2016; Yadav *et al*., 2022). In healthy trees [Fig. 4(a)], velocity tends to increase with stem diameter. Furthermore, stem diameter of some fast-growing hardwood species in the tropics, such as *Eucalyptus* hybrid and *Acacia mangium,* has a positive correlation with stress wave velocity (Hidayati *et al*., 2019; Prasetyo *et al*., 2019). However, in *Paraserianthes falcataria, Neolamarckia cadamba, Neolamarckia macrophylla, Ficus variegata*, stem diameter does not correlate with stress wave velocity (Dharmawati *et al*., 2024; Haryjanto *et al*., 2024; Ishiguri *et al*., 2007; Pertiwi *et al*., 2017).

For trees with stem cancer diseases [Fig. 4(b)], velocity tends to be lower and does not show a consistent increase. No symptomatic trees with a diameter greater than 35 cm were recorded in our dataset, therefore, it was not possible to evaluate the trend in stress wave velocity for larger diameter classes (e.g., ≥ 41 cm) as observed in healthy trees. This result supports the application of NDT velocity measurements as a reliable indicator of internal stem health, where significant reductions or irregularities may reflect structural degradation, such as stem canker or decay.

The correlation analysis between diameter and stress wave velocity showed different trends between healthy trees and those with cancer symptoms [Fig. 5(a) and (b)]. In healthy trees, a larger diameter indicates more individuals with high stress wave velocity. Therefore, healthy trees possess higher wood density and stress wave velocity, followed by regression y = 8.9161x + 1,818 [Fig. 5(a)]. This increase in stress wave velocity is due to the high density of trees. In other fast-growing species such as *E. pellita*, basic density increased with stem diameter (Fadwati *et al*., 2023). Furthermore, in *Gmelina arborea*, stem diameter has a positive correlation with stress wave velocity (Hidayati *et al*., 2017).

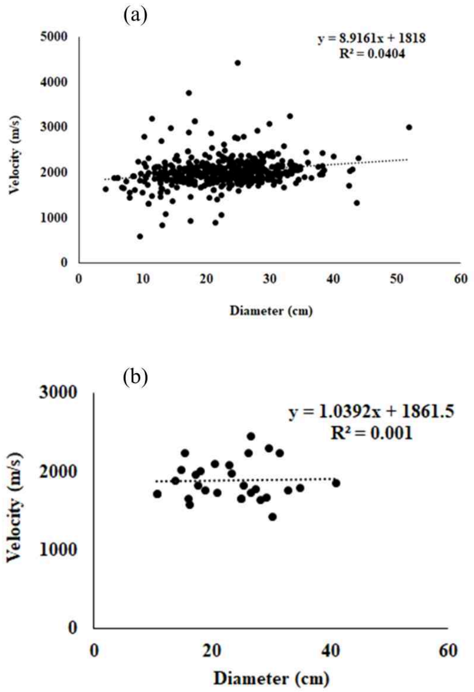

Fig. 5. The relationship between stem diameter and velocity in (a) healthy trees and (b) diseased trees.

Velocity is relatively stable, with no significant increase despite the diameter of symptomatic trees. The nearly flat regression line (y = 1.0392x + 1,861.5) [Fig. 5(b)] shows that stem canker disease causes uniform xylem degradation. Diseased trees do not exhibit an increase in wood density, despite the size. These results confirm that stem canker has a negative impact on *Eucalyptus* xylem structure (Dahali *et al*., 2021, 2023).

RVD was examined for symptomatic trees, focusing on the relationship with stem diameter as an indicator of internal degradation. RVD should be interpreted as the percentage decrease in radial (Bt, 2022; Hidayati *et al.*, 2017). In symptomatic trees, larger diameters cause a greater reduction in RVD and relative velocity decreased with increasing severity score [Fig. 6(a) and (b)], indicating a negative relationship between disease severity and stress wave transmission. This suggests that structural damage to the wood is getting worse with the increased severity of infection. The relationship between RVD and stem diameter in diseased trees is described by the regression equation y = 0.4064x + 2.5527, with a coefficient of determination (R^2) of 0.211 [Fig. 6(a)]. The low R^2 value (0.211) suggests that the relationship is not strong, and other factors, including the severity of infection, wood density, tree age, and environmental factors, also play a role.

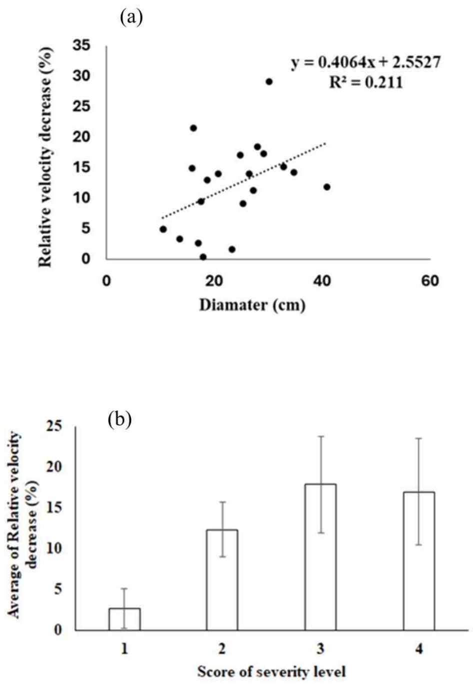

Fig. 6. Relationship of relative velocity decrease with stem diameter and severity score. (a) Stem diameter and relative velocity decrease; (b) severity score and relative velocity decrease.

Symptomatic trees with larger diameters exhibit more significant xylemstructural degradation due to the longer duration of stem canker infection. These results were consistent with previous investigations where *Eucalyptus* trees were infected by *Teratosphaeria gauchensis*. The pathogen responsible for stem canker led to an increase in bark diameter (Aylward *et al.*, 2019; Silva *et al*., 2015). This response is part of the natural defense mechanism, aimed at compartmentalizing the pathogen and limiting the spread (Zwart *et al*., 2017). Similarly, research on Iranian beech trees (*Fagus orientalis*) shows that internal decay leads to a marked reduction in wave velocity since the size of the cavities increases (Kazemi-Najafi *et al.*, 2009).

Even though large-diameter symptomatic trees may decrease xylem quality due to disease, the genetic characteristics of *Eucalyptus* hybrid individuals differ, and the impact varies among individuals. In symptomatic, larger-diameter trees experience more significant xylem degradation and are more susceptible to severe infection impacts. This confirms that stem canker disease directly affects xylem integrity, reduces the density, and causes a drastic decrease in the ability to conduct stress waves.

4. CONCLUSIONS

In conclusion, stem canker disease significantly affected the structural integrity of hybrid *E. pellita* × *E. urophylla* trees, as reported by reduced stress wave velocity in symptomatic individuals. Even though stem diameter was not significantly different between healthy and diseased trees, symptomatic types exhibited inconsistent and lower wave velocities, suggesting internal xylem degradation. RVD correlated with stem diameter and disease severity, reporting that larger and more severely infected trees suffered greater structural damage. These results showed the reliability of stress wave NDT for detecting internal xylem quality deterioration caused by stem canker and supported the application for early diagnosis and health monitoring in plantation management.

CONFLICT of INTEREST

No potential conflict of interest relevant to this article was reported.

ACKNOWLEDGMENT

The authors gratefully acknowledge Wanagama Educational Forest, Universitas Gadjah Mada, Yogyakarta, Indonesia for providing access to the hybrid stands used in this study.

REFERENCES

Ak Sakallı, E., Teralı, K., Karadağ, A.E., Biltekin, S.N., Koşar, M., Demirci, B., Hüsnü Can Başer, K., Demirci, F. 2022. *In vitro* and *in silico* evaluation of ACE2 and LOX inhibitory activity of *Eucalyptus* essential oils, 1,8-cineole, and citronellal. Natural Product Communications 17(6): 1934578X221109409.

Ambrose, A., Peter Remun, A.B., Shamsul Kamar, N.A., Mohamad Pazi, A.M., Wan Azhar, W.M.A., Awing, N.H., Liam, J., Terhem, R. 2023. Evaluation of fungicides as protective and curative treatments against canker disease of *Eucalyptus urograndis* caused by *Chrysoporthe deuterocubensis* in Malaysia. Forests 14(12): 2337.

Awing, N.H., Ambrose, A., Abdu, A., Hassan, A., 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): 1660.

Aylward, J., Roets, F., Dreyer, L.L., Wingfield, M.J. 2019. Teratosphaeria stem canker of eucalyptus: Two pathogens, one devastating disease. Molecular Plant Pathology 20(1): 8-19.

Beaulieu, J., Dutilleul, P. 2019. Applications of computed tomography (CT) scanning technology in forest research: A timely update and review. Canadian Journal of Forest Research 49(10): 1173-1188.

Boyce, J. 1948. Forest Pathology. McGraw Hill, New York, NY, USA.

Bt, F.E. 2022. Microsecond Timer Manual. Fakopp, Sopron, Hungary.

Carrillo-Varela, I., Valenzuela, P., Gacitúa, W., Mendonca, R.T. 2019. An evaluation of fiber biometry and nanomechanical properties of different *Eucalyptus* species. BioResources 14(3): 6433-6446.

Carvalho, D.E., Martins, A.P.M., Santini, E.J., de Freitas, L.S., Talgatti, M., Susin, F. 2016. Natural durability of *Eucalyptus dunnii* Maiden, *Eucalyptus robusta* Sm., *Eucalyptus tereticornis* Sm. and *Hovenia dulcis* Thunb. wood in field and forest environment. Revista Árvore 40(2): 363-370.

Chungu, D., Siyingwa, J., Ng'andwe, P., Chitala Chungu, B. 2019. Lesion size induced by Chrysoporthe fungal pathogens varies between *Eucalyptus* species and geographic locations in Zambia. Southern Forests: A Journal of Forest Science 81(1): 39-44.

Coetzee, M.P.A., Marincowitz, S., Muthelo, V.G., Wingfield, M.J. 2015. *Ganoderma* species, including new taxa associated with root rot of the iconic *Jacaranda mimosifolia* in Pretoria, South Africa.

IMA Fungus 6(1): 249-256.
Cortinas, M.N., Crous, P.W., Wingfield, B.D., Wingfield, M.J. 2006. Multi-gene phylogenies and phenotypic characters distinguish two species within the *Colletogloeopsis zuluensis* complex associated with *Eucalyptus* stem cankers. Studies in Mycology 55: 133-146.
Dahali, R., Lee, S.H., Md Tahir, P., Salim, S., Hishamuddin, M.S., Che Ismail, A., Khoo, P.S., Krystofiak, T., 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): 350.
Dahali, R., Md. Tahir, P., Roseley, A.S.M., Hua, L.S., Bakar, E.S., Ashaari, Z., Abdul Rauf, M.R., Zainuddin, N.A., Mansoor, N.S. 2021. Influence of *Chrysoporthe deuterocubensis* canker disease on the physical and mechanical properties of *Eucalyptus urograndis*. Forests 12(5): 639.
de Aguiar Coelho, F., Farnezi, P.K.B., de Sá, M.C., Viotti, J., Moreira, V.H., Batista, A.C., Mendes, D.S., de Araújo, T.A., de Assis Júnior, S.L., Soares, M.A., Picanço, M.C., da Silva, R.S. 2024. Risk analysis for invasion of the forest pest *Paropsisterna bimaculata* present in Tasmania to areas of the world. Neotropical Entomology 54(1): 10.
Dharmawati, U.L.D., Nezu, I., Ishiguri, F., Hidayati, F., Ngadianto, A., Pertiwi, Y.A.B., Nirsatmanto, A., Sunarti, S., Irawati, D., Takahashi, Y., Yokoyama, H., Ohshima, J., Yokota, S. 2024. Among-family variations in growth traits, the stress-wave velocity of stems, and log characteristics of the first-generation *Neolamarckia macrophylla* (Roxb.) Bosser in Indonesia. Tropics 33(2): 119-128.
Dlamini, L.S., Little, K.M., Sivparsad, B., Nadel, R. 2019. Quantifying the impact of foliar insects on two *Eucalyptus* hybrids in Zululand, northern KwaZulu-Natal, South Africa. South African Journal of Plant and Soil 36(2): 129-135.
Eyles, A., Davies, N.W., Yuan, Z.Q., Mohammed, C. 2003. Host responses to natural infection by *Cytonaema* sp. in the aerial bark of *Eucalyptus globulus*. Forest Pathology 33(5): 317-331.
Fadwati, A.D., Hidayati, F., Na'iem, M. 2023. Evaluation of genetic parameters of growth characteristics and basic density of *Eucalyptus pellita* clones planted at two different sites in East Kalimantan, Indonesia. Journal of the Korean Wood Science and Technology 51(3): 222-237.
Gafur, A. 2023. Red Root Rot Disease of Tropical Estate Forests: Pathogen Identification, Dispersal and Management. In: Detection, Diagnosis and Management of Soil-borne Phytopathogens, Ed. by Singh, U.B., Kumar, R., and Singh, H.B. Springer Nature, Singapore. pp. 159-178.
Gafur, A., Naz, R., Nosheen, A., Sayyed, R.Z. 2023. Role of Plant Growth Promoting Microbes in Managing Soil-Borne Pathogens in Forestry. In: Plant Growth Promoting Microorganisms of Arid Region, Ed. by Mawar, R., Sayyed, R.Z., Sharma, S.K., and Sattiraju, K.S. Springer Nature, Singapore. pp. 213-227.
Goh, C.L., Abdul Rahim, R., Fazalul Rahiman, M.H., Mohamad Talib, M.T., Tee, Z.C. 2018. Sensing wood decay in standing trees: A review. Sensors and Actuators A: Physical 269: 276-282.
Gryzenhout, M., Tarigan, M., Clegg, P.A., Wingfield, M.J. 2010. *Cryptometrion aestuescens* gen. sp. nov. (Cryphonectriaceae) pathogenic to *Eucalyptus* in Indonesia. Australasian Plant Pathology 39(2): 161-169.
Guimarães, L.M.S., de Resende, M.D.V., Lau, D., Rosse, L.N., Alves, A.A., Alfenas, A.C. 2010. Genetic control of *Eucalyptus urophylla* and *E. grandis* resistance to canker caused by *Chrysoporthe cubensis*. Genetics and Molecular Biology 33(3): 525-531.

Hardiyanto, E.B., Inail, M.A., Nambiar, S., Mendham, D.S. 2024. Sustaining plantation forest productivity in Sumatra over three decades: From acacias to eucalypts. Forest Ecology and Management 553: 121613.

Haryjanto, L., Indrioko, S., Nirsatmanto, A., Hidayati, F. 2024. Genetic variation in growth characteristics and wood properties of *Ficus variegata* blume first generation progeny trials in Indonesia. Journal of the Korean Wood Science and Technology 52(5): 473-487.

Hidayati, F., Ishiguri, F., Makino, K., Tanabe, J., Aiso, H., Prasetyo, V.E., Marsoem, S.N., Wahyudi, I., Iizuka, K., Yokota, S. 2017. The effects of radial growth rate on wood properties and anatomical characteristics and an evaluation of the xylem maturation process in a tropical fast-growing tree species, *Gmelina arborea*. Forest Products Journal 67(3-4): 297-303.

Hidayati, F., Lukmandaru, G., Indrioko, S., Sunarti, S., Nirsatmanto, A. 2019. Variation in tree growth characteristics, pilodyn penetration, and stress-wave velocity in 65 families of *Acacia mangium* trees planted in Indonesia. Journal of the Korean Wood Science and Technology 47(5): 633-643.

Ishiguri, F., Eizawa, J., Saito, Y., Iizuka, K., Yokota, S., Priadi, D., Sumiasri, N., Yoshizawa, N. 2007. Variation in the wood properties of *Paraserianthes falcataria* planted in Indonesia. IAWA Journal 28(3): 339-348.

Karlinasari, L., Lestari, A.T., Nababan, M.Y.S., Siregar, I.Z., Nandika, D. 2018. Assessment of urban tree condition using sonic tomography technology. IOP Conference Series: Earth and Environmental Science 203: 012030.

Kazemi-Najafi, S., Shalbafan, A., Ebrahimi, G. 2009. Internal decay assessment in standing beech trees using ultrasonic velocity measurement. European Journal of Forest Research 128(4): 345-350.

Khan, S.Z., Khan, T.M., Joya, Y.F., Khan, M.A., Ahmed, S., Shah, A. 2016. Assessment of material properties of AISI 316L stainless steel using non-destructive testing. Nondestructive Testing and Evaluation 31(4): 360-370.

Lin, C.J., Huang, Y.H., Huang, G.S., Wu, M.L. 2016. Detection of decay damage in iron-wood living trees by nondestructive techniques. Journal of Wood Science 62(1): 42-51.

Lin, W.S., Wu, J.Z. 2013. Study on application of stress wave for nondestructive test of wood defects. Applied Mechanics and Materials 401-403: 1119-1123.

Liu, H., Gao, J. 2014. Effects of moisture content and density on the stress wave velocity in wood. Journal of Beijing Forestry University 36(6): 154-158.

Lukmandaru, G., Zumaini, U.F., Soeprijadi, D., Nugroho, W.D., Susanto, M. 2016. Chemical properties and fiber dimension of *Eucalyptus pellita* from the 2nd generation of progeny tests in Pelaihari, South Borneo, Indonesia. Journal of the Korean Wood Science and Technology 44(4): 571-588.

Mangwanda, R., Zwart, L., van der Merwe, N.A., Moleleki, L.N., Berger, D.K., Myburg, A.A., Naidoo, S. 2016. Localization and transcriptional responses of *Chrysoporthe austroafricana* in *Eucalyptus grandis* identify putative pathogenicity factors. Frontiers in Microbiology 7: 1953.

Masendra, Nezu, I., Ishiguri, F., Hidayati, F., Nirsatmanto, A., Sunarti, S., Surip, Kartikaningtyas, D., Takashima, Y., Takahashi, Y., Ohshima, J., Yokota, S. 2023. Variations of growth and wood traits in standing trees of the third-generation *Acacia mangium* families in Indonesia. Silvae Genetica 72(1): 150-162.

McCracken, F.I. 1985. Using sound to detect decay in standing hardwood trees. In: Pullman, WA, USA, Proceedings of the 5th International Symposium on

Nondestructive Testing of Wood, pp. 9-11.

Mulawarman, Sastrosumarto, S., Na'iem, M. 2003. Crossability in interspecific hybrid between *Eucalyptus pellita* and *E. urophylla*. Zuriat 14(2): 99-104.

Nainggolan, C.R. 2022. Study of distance and number of rebars on velocity measurement using non-destructive test. International Journal of GEOMATE 22(94): 121-127.

Nakabonge, G., Roux, J., Gryzenhout, M., Wingfield, M.J. 2006. Distribution of Chrysoporthe canker pathogens on *Eucalyptus* and *Syzygium* spp. in eastern and southern Africa. Plant Disease 90(6): 734-740.

Nirsatmanto, A., Sunarti, S., Kartikaningtyas, D., Handayani, B.R., Setyaji, T., Surip, Pudjiono, S., Kartikawati, N.K., Kardiansyah, T., Krisdianto, Indrawan, D.A., Pari, R., Razoki, M., Herdyantara, A.B., Marsoem, S.N., Hidayati, F. 2022. Evaluation of the characteristics of *Eucalyptus pellita* and *Acacia* hybrid superior clones selected from breeding program in Indonesia as materials for pulp and papermaking. Wood Research 67(5): 847-865.

Oliveira, L.S.S., Sirait, B.A., Saha, M.A., Sipayung, J., Maretha, M.V., Tarigan, M., Duran, A. 2023. Integrated management of *Eucalyptus* bacterial wilt in Sumatra, Indonesia. Tropical Plant Pathology 48(6): 685-695.

Pahade, C., Parmar, U., Salaam, A., Rao, D.S.N.M., Manjunatha, Singla, A., Rambabu, G.V. 2024. Comparatively study of non-destructive test with different methods in various curing days. E3S Web of Conferences 552: 01090.

Paine, T.D., Millar, J.G., Daane, K.M. 2010. Accumulation of pest insects on *Eucalyptus* in California: Random process or smoking gun. Journal of Economic Entomology 103(6): 1943-1949.

Pérez, S., Renedo, C., Ortiz, A., Ortiz, F., Tejedor, C. 2016. Strategies to combat mycosphaerella leaf fisease in *Eucalyptus globulus* plantations in northern Spain. Forests 7(9): 190.

Pertiwi, Y.A.B., Aiso, H., Ishiguri, F., Wedatama, S., Marsoem, S.N., Ohshima, J., Iizuka, K., Yokota, S. 2017. Effect of radial growth rate on wood properties of Neolamarckia cadamba. Journal of Tropical Forest Science 29(1): 30-36.

Prasetyo, A., Aiso-Sanada, H., Ishiguri, F., Wahyudi, I., Wijaya, I.P.G., Ohshima, J., Yokota, S. 2019. Variations in anatomical characteristics and predicted paper quality of three *Eucalyptus* species planted in Indonesia. Wood Science and Technology 53(6): 1409-1423.

Pratama, R., Muslim, A., Suwandi, S., Damiri, N., Soleha, S. 2021. First report of characterisation and pathogenicity of bullet wood (*Mimusops elengi*) sudden decline disease by ceratocystis in Indonesia. Biodiversitas Journal of Biological Diversity 22(5): 2636-2645.

Proto, A.R., Macrì, G., Bernardini, V., Russo, D., Zimbalatti, G. 2017. Acoustic evaluation of wood quality with a non-destructive method in standing trees: A first survey in Italy. IForest -Biogeosciences and Forestry 10(4): 700-706.

Ramos, R.D., Longue Júnior, D., Gomes, F.J.B., de Medeiros, N.C.G. 2024. Influência da densidade básica e da composição química da madeira para a indústria de polpa celulósica: Um estudo de caso. Ciência Florestal 34(3): e85566.

Ribeiro, A., Sangiogo, M., de Sousa, R.M., Ferraz Filho, A.C. 2023. Evolution of canker severity and stem quality on African mahogany growth. Pesquisa Agropecuária Brasileira 58: e03380.

Sharma, A.D., Kaur, I. 2021. Homology modeling and molecular docking of natural metabolites from *Eucalyptus* essential oil against SARS-CoV-2 spike protein. Arabian Journal of Medicinal and Aromatic Plants 7(3): 282-300.

Silva, M.R.C., Diogo, E., Bragança, H., Machado, H., Phillips, A.J.L. 2015. *Teratosphaeria gauchensis* associated with trunk, stem and foliar lesions of *Eucalyptus globulus* in Portugal. Forest Pathology 45(3): 224-234.

Siregar, B.A., Giyanto, Hidayat, S.H., Siregar, I.Z., Tjahjono, B. 2020. Epidemiology of bacterial wilt disease on *Eucalyptus pellita* F. Muell. in Indonesia. IOP Conference Series: Earth and Environmental Science 468(1): 012033.

Siregar, B.A., Liantiqomah, D., Halimah, Gafur, A., Tjahjono, B. 2022. Screening of endophytic *Trichoderma* isolates to improve the growth and health of *Eucalyptus pellita* seedlings. IOP Conference Series: Earth and Environmental Science 974(1): 012084.

Suzuki, H., Marincowitz, S., Wingfield, B.D., Wingfield, M.J. 2022. Genetic diversity and population structure of *Chrysoporthe deuterocubensis* isolates from melastoma and *Eucalyptus* in Malaysia and Indonesia. Forest Pathology 52(4): e12762.

Syofuna, A., Nakabonge, G., Banana, A., Nagawa, C.B., Tumwebaze, S.B., Ssekuubwa, E., Tweheyo, M. 2025. Assessment of *Eucalyptus* canker diseases in plantations of Uganda. Forest Pathology 55(3): e70025.

Syofuna, A., Nakabonge, G., Namayengo, S., Tumwebaze, S., Banana, A. 2021. Pathogenicity of *Teratosphaeria* species on *Eucalyptus grandis* and selected hybrids in Uganda. Journal of Forest Research 26(1): 86-90.

Tallent-Hansel, N. 1994. Forest Health Monitoring. Field Methods Guide EPA/620/R-94/027. U.S. Environmental Protection Agency, Washington, DC, USA.

Tarigan, M., Wingfield, M.J., Marpaung, Y.M.A.N., Durán, A., Pham, N.Q. 2023. *Quambalaria eucalypti* found on *Eucalyptus* in Indonesia. Forest Pathology 53(5): e12829.

Thompson, I.M. 2013. Early growth results of three *Eucalyptus grandis* × *Eucalyptus nitens* hybrid clonal trials and their response to snow events. Southern Forests: A Journal of Forest Science 75(4): 185-188.

Wang, Q.C., Chen, S. 2020. *Calonectria pentaseptata* causes severe leaf disease of cultivated *Eucalyptus* on the Leizhou Peninsula of Southern China. Plant Disease 104(2): 493-509.

Wang, X., Allison, R.B. 2008. Decay detection in red oak trees using a combination of visual inspection, acoustic testing, and resistance microdrilling. Arboriculture & Urban Forestry 34(1): 1-4.

Wang, X., Divos, F., Pilon, C., Brashaw, B.K., Ross, R.J., Pellerin, R.F. 2004. Assessment of Decay in Standing Timber Using Stress Wave Timing Nondestructive Evaluation Tools: A Guide for Use and Interpretation. General Technical Report FPL-GTR-147. United States Department of Agriculture, Washington, DC, USA.

Wei, Q., Leblon, B., La Rocque, A. 2011. On the use of X-ray computed tomography for determining wood properties: A review. Canadian Journal of Forest Research 41(11): 2120-2140.

Wei, X., Du, C., Xu, S., Tian, C., Yang, X., Hu, L., Pang, P. 2022. Research on stress wave wood nondestructive testing technology. Journal of Physics: Conference Series 2366(1): 012035.

Yadav, K., Yadav, S., Dubey, P.K. 2022. Metrological investigation and calibration of reference standard block for ultrasonic non-destructive testing. Metrology and Measurement Systems 29(3): 525-538.

Zwart, L., Berger, D.K., Moleleki, L.N., van der Merwe, N.A., Myburg, A.A., Naidoo, S. 2017. Evidence for salicylic acid signalling and histological changes in the defence response of *Eucalyptus grandis* to *Chrysoporthe austroafricana*. Scientific Reports, 7(1): 45402.