Original Article
J. Korean Wood Sci. Technol. 2023, 51(3): 222-237
https://doi.org/10.5658/WOOD.2023.51.3.222

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

Evaluation of Genetic Parameters of Growth Characteristics and Basic Density of *Eucalyptus pellita* Clones Planted at Two Different Sites in East Kalimantan, Indonesia

Alfia Dewi FADWATI[1,2] · Fanny HIDAYATI[1,†] · Mohammad NA'IEM[1]

ABSTRACT

Eucalyptus pellita is one of the fast-growing tree species and has become predominant in Indonesian forest plantations. Meanwhile, tree breeding programs with clone development are the best way to provide greater genetic advantages. A better understanding of genetic control on growth and basic density in *E. pellita* is important for increasing wood productivity and quality. In this study, growth characteristics (tree height, diameter, and volume), basic density and its genetic parameters (heritability, genetic gain and genetic correlation) were determined. The number of clones tested in both trials was 50, divided into 5 blocks, and 5 trees/plot. The results showed that there were significant differences in growth and basic density among clones. There was an interaction between genetics and the environment further indicating the existence of unstable clones. The high heritability was found in tree height (0.82–0.86), diameter (0.82–0.90), and basic density (0.91–0.93). This implies that *E. pellita* has good opportunities for genetic improvement to increase wood productivity and quality. In addition, the results of genetic correlations among growth characteristics (height, diameter, and volume) and basic density showed positive moderate to highly significant value. It is suggested that these characters may be used to the advantage of the breeder for bringing improvement in these traits simultaneously. Therefore, this study provides important information of the genetic improvement of wood quality in *E. pellita* in Indonesia.

Keywords: *Eucalyptus pellita*, growth characteristics, basic density, heritability, genetic gain, genetic correlation

1. INTRODUCTION

Eucalyptus pellita F. Muell is one of the fast-growing species widely distributed in Indonesia, Papua New Guinea, and Queensland-Australia. It is prioritized for industrial forest plantations and has great potential as an alternative species to replace *Acacia mangium* which is currently experiencing a decline due to root rot disease in the tropics (Lee, 1993). This species has high adaptability and grows fast with single trunk, straight stem, free of high branches, as well as resistant to pests and diseases (Harwood *et al*., 1997). Diseases rendered *A. mangium* unviable in south and central Sumatra, and the industry responded by changing the species to *E. pellita* (Nambiar *et al*., 2018). This species has also been widely selected for the development of forest plantations

Date Received December 7, 2022, Date Revised February 15, 2023, Date Accepted May 1, 2023
[1] Faculty of Forestry, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia
[2] Department of Research and Development, PT. Itci Hutani Manunggal, Penajam Paser Utara, East Kalimantan 76147, Indonesia
[†] Corresponding author: Fanny HIDAYATI (e-mail: fanny_hidayati@ugm.ac.id, https://orcid.org/0000-0003-0914-4636)

in Indonesia and Southeast Asia (Lukmandaru *et al*., 2016). Plantation forest development in Indonesia has reached 10.8 million hectares (Hadi *et al*., 2019). Currently, *E. pellita* had replaced *A. mangium* in about 465,000 ha in Sumatra and 225,500 ha in Kalimantan, Indonesia (Hardiyanto *et al*., 2021). Several forest plantations are located in East Kalimantan and there is limited information on the results of research (growth characteristics and wood properties) on *E. pellita* in East Kalimantan. In contrast, the wood pulp industry still appears to be a top government priority of Indonesia to the expected increased supplies from industrial forest plantations.

Forest plantations have an important role in meeting the wood needs of the forest industry as they meet about a third of the world's timber demand (Barua *et al*., 2014). *Eucalyptus* plantation dominates the tropics and sub-tropics with proportions of 42% and 26% (Binkley *et al*., 2017), as well as the hardwood plantations (Ghani and Lee, 2021). The high productivity increase in plantation forests is currently dominated by clonal forestry. The clones were selected because they have advantages, namely high productivity, applicable as hybrids (Griffin, 2014), and can also maximize genetic gain (White *et al*., 2007). However, to supply many improved productions clones, a large clonal plantation needs to be supported by a program of breeding and clonal development and testing (Kha *et al*., 2012). Identified the critical issues that would help to increase the wood productivity by practicing an integrated approach to applications research and comparable environment (Nambiar *et al*., 2018). This will provide clones adapted to the range of target planting environments, as well as yield improvement in performance and wood properties (Burdon and Aimers-Halliday, 2006).

To meet the demand for *E. pellita* wood in Indonesia, both for carpentry such as log timber, plywood and for other materials such as wood pulp, the strategy used by forest plantations is not sufficient only focused on developing clones to enhance plantation productivity and product uniformity. In this context, the determining of basic density is crucial in determining the best strategies for clonal breeding and testing and in predicting genetic parameter from developing the best clones (Osorio *et al*., 2001). Basic density is important in the value of timber and pulpwood also other material. It is highly correlated with major strength characteristics and pulp and paper properties (Wu *et al*., 2011b). Therefore, to increasing the growth rate of *E. pellita*, improving wood quality has become an urgent goal for genetic improvement.

The increasing volume and higher basic density at harvest are desirable traits for all stakeholders, especially in plantation forests. The process of clonal forestry starts with the creation of clone-based plantation forests which are carried out by selection, propagation, evaluation, and management (Wendling *et al*., 2014). Plantation companies must provide clones with a broad genetic base that can adapt to different environments. Genetic responses can be influenced by the environment which might cause a decrease in genetic advantage when selected simultaneously (dos Santos *et al*., 2016). Ideally, clonal forestry should be selected for stable performance across a variety of environments (combination sites) or no interaction between genetic by environment (G × E). The interaction between the genotype and environment can lead the selection clone of most productive genotype (clone) for planting at specific site because the most productive ones at one site may not be the most productive at another site. There are numerous strategies of minimizing interaction effects of G × E that become unstable clone in performance for example, by identifying genotypes exhibiting specific adaptation to specific environments (Cruz and Castoldi, 1991) or the stratification of a heterogeneous area into more homogeneous parts, referred to as breeding zones, where the genotype selection is performed separately in each zone or site (Santos *et al*., 2015). Error in selecting species at the designated

site is usually the main factor that causes low growth of *Eucalyptus* sp. in North Sumatra (Latifah *et al*., 2014). Therefore, an understanding of environmental effects is very important in the selection of genetic material (Oliveira *et al*., 2018).

Growth and basic density of wood is a genetic control that can support improvement (Hung *et al*., 2014) as an effort to increase the productivity of *E. pellita* plantations in Indonesia. To determine performance, it is necessary to estimate genetic parameters such as heritability, expected gain, and genetic correlation (Hodge and Dvorak, 2012). The selection of genetic performance in the most accurate clone test is carried out at half-cycle age. Many studies have been carried out on Eucalyptus, both on its growth performance and its wood properties (Augustina *et al*., 2020; Harrand *et al*., 2009; Iswanto *et al*., 2021; Kien *et al*., 2010; Lukmandaru *et al*., 2016; Luo *et al*., 2012; Schulz *et al*., 2021). However, in the case of *E. pellita* in early growth in Indonesia, there are few reports in the literature regarding genetic parameters for growth and wood quality of clonal material. This information is very important for the next plantation in Indonesia to increase productivity and wood quality of the *E. pellita*. Therefore, this study aims to determine growth characteristics (height, diameter, and volume of the tree) and basic density and its genetic parameters (heritability, genetic gain and genetic correlation) on 3.5-year-old *E. pellita* planted in two different sites in Kutai Kartanegara, East Kalimantan, Indonesia. The results are expected to provide information for ongoing breeding, clonal selection, and deployment strategies of *E. pellita* clonal forestry for industrial forest plantation companies to support short cycle forestry with high productivity in Indonesia.

2. MATERIALS and METHODS

2.1. Materials

The clonal test was conducted at two locations, namely sites 1 and 2 located in Kutai Kartanegara Regency, East Kalimantan Province, Indonesia. The first clone is located at site 1 at WGS 1984/ UTM Zone 50M latitude coordinate: 9913706 (North) and longitude: 475419 (East) with an area of 2.5 ha and planting was carried out in May 2018. Meanwhile, the second clone test location is located at WGS 1984/ UTM Zone 50M latitude coordinates: 9937153 (North) and Longitude: 441947 (East) with an area of 2.5 ha and planting was conducted in May 2018, for detail in Table 1. The climate type of both sites was based on the Schmidt-Ferguson classification, while rainfall was ranged from 1,600–2,000 mm per year.

About 3.5-year-old *E. pellita* trees were used for the analysis of growth characteristics such as diameter, height, and volume of trees, as well as basic density.

Table 1. Enviromental conditions of the sites

Characteristics	Site 1	Site 2
Soil texture	Smooth, clay (clay stone, clay content > 35%)	Rather rough, sandstone (sand stone, clay content 18%–35%)
Landform	Tectonic plains, undulating land	Cuesta escarpment
Elevation	101 masl	99 masl
Slope	35%, middle slope	34%, upper slope
Topography	Hills with rather steep slopes	Low hills are slightly slope

masl: meter above sea level.

Both clone test sites were designed using a completely randomized block design. The number tested in both trials was 50 clones, divided into 5 blocks, and 5 trees/plot (Fig. 1). Tree diameter of 1.3 m from ground level was measured using a diameter band (phi band), while tree height was measured using a vertex hypsometer. Tree height and diameter were measured for all trees. For the measurement of basic density, samples were taken from 5 trees per clone using a Resistograph (1 sample tree/block), samples were selected randomly from each block. The Resistograph was assessed as a means of quantifying basic density in individual standing plantation trees (Downes *et al*., 2018). This instrument drives a 3 mm diameter needle through a tree at a set forward speed (feed speed) and rotation rate (rpm), while also measuring the resistance to turning. A 400 mm long trace can be taken from a single tree in less than 20 seconds, with tests conservatively showing that over 40 trees/hour were sampled (Downes *et al*., 2018). The trace represents a profile of resistance every 0.1 mm and indicates the radial variation in density (Gao *et al*., 2012). The results of resistograph measurement are traces or commonly referred to Resi traces. Then, the Resi traces were transferred to the resistograph tools Pro software and exported as text files. To get the basic density value, a model must be built in using the software. The Resistograph value as the needles travels through the disc was initially accounted for using a linear friction correction (Downes *et al*., 2018). Furthermore, the Resistograph predicted basic density for each sampling interval at every 0.1 mm was defined from the linear relationship between laboratory- measured density and mean drilling resistance amplitude for segment (slope and intercept). The mean predicted basic density value was calculated for each segment (Gendvilas *et al*., 2021). A company has developed a resistograph model for quantifying the basic density. This model was then used for all Eucalypt in the material breeding program. Previous study showed that the relationship between mean Resistograph value and core basic density was strong in Eucalyptus (Downes *et al*., 2018).

2.2. Statistical analysis

The stem volume (VOL) was calculated using the following formula by West (2009):

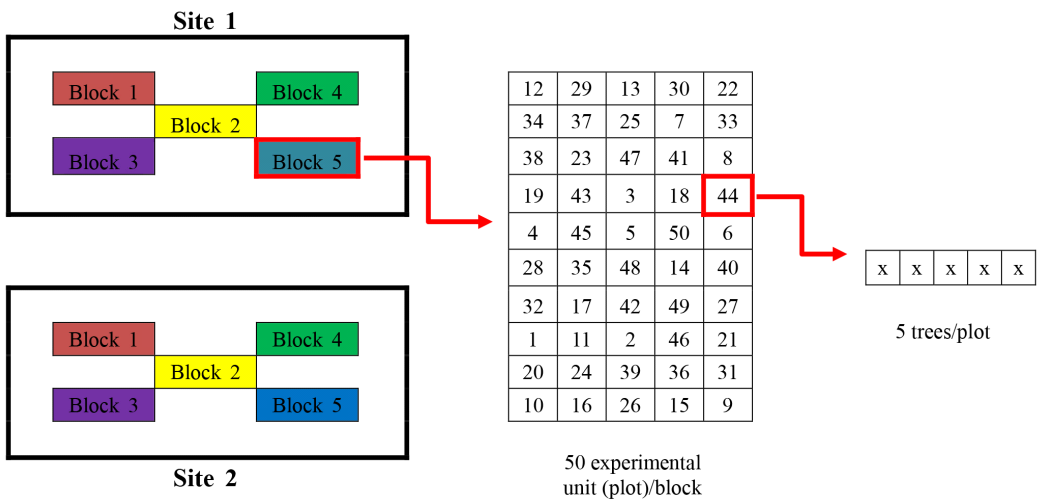

Fig. 1. Diagram of experimental design.

$$VOL = 0.3 \times HT \times DBH^2 \quad (1)$$

where: VOL is tree stem volume, HT is tree total height in m, DBH is tree diameter at breast height in cm.

Analysis of variance (ANOVA) was applied to evaluate differences in the growth traits and basic density. ANOVA was performed using individual clone data based on analysis of one location (single site) or a combination of two location (combination site/multiple site). In the combined ANOVA for determine the interaction between clone and environment, environmental variation parameters tested included: site 1 and site 2. The model used as follows by Leksono and Kurinobu (2005):

For each location:

$$Y_{ijk} = \mu + B_i + F_j + E_{ijk} \quad (2)$$

where: Where Y_{ijk} is the phenotype observation of the *k*th individual tree in the *i*th block and the *j*th clone, μ is the overall mean, B_i is the block effect of the *i*th, F_j is the clone effect of the *j*th and E_{ijk} is the error effect of the *ijk*th.

For the combination of locations:

$$Y_{ijkl} = \mu + L_i + B_j(L)_i + F_k + FL_{ki} + E_{ijkl} \quad (3)$$

where: Y_{ijkl} is the phenotypic observation of the *l*th individual tree in the *i*th location, the *j*th block and the *k*th clone, μ is the overall mean, L_i is the location effect of the *i*th, $B_j(L)_i$ is the block effect of the *j*th in the *i*th location, F_k is the clone effect of the *k*th, FL_{ki} is the interaction effect of the clone *k*th with the *i*th location, E_{ijkl} is the error effect of the *ijkl*th. Based on the measurement carried out, data analysis was conducted using ANOVA. It was obtained through the general linear model procedure using plot mean data, while genetic variance and covariance were estimated using proc varcomp type 1 and REML (Residual Maximum Likelihood or Restricted Maximum Likelihood) in the SAS On Demand for Academics software. Average clone heritability on each location (A) and combination location (B), were determined by expressions by White and Hodge (1989); Zobel and Talbert (1984):

(A) Each location:

$$H^2 = \frac{\sigma^2_k}{\sigma^2_k + \left(\sigma^2_{kb} / B\right) + \left(\sigma^2_e / NB\right)} \quad (4)$$

(B) Combination location:

$$H^2 = \frac{\sigma^2_k}{\sigma^2_k + \left(\sigma^2_{kl} / L\right) + \left(\sigma^2_{kb(l)} / BL\right) + \left(\sigma^2_e / NBL\right)} \quad (5)$$

where: H^2 = heritability in a broad sense; σ^2_k = component variance of clone; σ^2_{kb} = component of the clone-block variance; σ^2_{kl} = component of the clone-location interaction variance; $\sigma^2_{kb(l)}$ = component of in-location clone-block interaction variance; σ^2_e = component of error variance; L = number of locations; B = number of blocks per location; and N = number of ramets/tree per plot.

Expected gain (Pg) was calculated using the formula used by Luechanimitchit *et al*. (2017):

$$P_G = i\ (\sigma_P)\ H^2 \quad (6)$$

$$P_{G\%} = [P_G / \bar{x}] \times 100 \quad (7)$$

where: i = intensity of selection; P = SD of the phenotype; H^2 = heritability and $\bar{x}$ is the phenotypic mean of each trait. Genetic correlation results from calculating the covariance with the SD for two different traits. The genetic correlation was assessed using the formula proposed by Zobel and Talbert (1984):

$$rG = \frac{\sigma k\ (xy)}{\sqrt{\sigma^2_{k(x)} \cdot \sigma^2_{k(y)}}} \quad (8)$$

where: rG = genetic correlation; σk (xy) = covariance component for properties x and y; $\sigma^2_{k(x)}$ = component of clone variance for trait x; $\sigma^2_{k(y)}$ = component of clone variance for trait y.

3. RESULTS and DISCUSSION

3.1. Growth characteristics and basic density

Clonal variations for growth parameters including diameter, height, and volume of trees, as well as basic density were evaluated in this study. Table 2 shows the mean values of diameter, height, and volume of trees, where the mean values in each site were 6.4–13.8 cm, 11.2–20.9 m, and 0.02–0.13 m^3 in site 1; 6.0–14.6 cm, 7.9–20.5 m, and 0.01–0.15 m^3 in site 2; as well as 7.0–13.6 cm, 10.2–19.8 m, and 0.02–0.13 m^3, in the combination site, respectively. Ramadan *et al*. (2018) reported that tree height, diameter and tree volume of 4-year-old *E. pellita* clone planted in East Kalimantan were 18.6–18.8 m, 11.7–12.5 cm, and 0.082–0.098 m^3, respectively. Tree height and diameter of 9-year-old *E. pellita* planted in North Sumatra, Indonesia were 16.7 m and 16.8 cm, respectively (Prasetyo *et al*., 2017). In Brazil, tree height and diameter of 8-year-old *E.* hybrid were 17.64 m and 14.43 cm (Oliveira *et al*., 2018). Tree height, diameter and volume of 3- and 4-year-old *E. pellita* planted in Central Java, Indonesia were 10.9 and 12.75 m; 7.79–8.91 cm, and 0.0296–0.0456 m^3 (Kartikaningtyas *et al*., 2020). The tree height, diameter, and tree volume of 7-year-old *E.* hybrid planted in China were 17.93–18.82 m, 11.98–12.60 cm, and 0.093–0.106 m^3, respectively (Wu *et al*., 2011a). In Brazil, growth characteristics of 4.5-year-old *Eucalyptus grandis* were 18.82–22.32 m and 15.59–19.87 for tree heigh and stem diameter (Harrand *et al*., 2009). In the present study, the average value of growth characteristics was lower comparing to the previous results (Kartikaningtyas *et al*., 2020; Oliveira *et al*., 2018; Prasetyo *et al*., 2017; Ramadan *et al*., 2018; Wu *et al*., 2011a). These differences are due to the differences of genetic materials, ages, site, and environment. Development of the clones is sensitive to the site condition and environment (Ramadan *et al*., 2018). Leslie *et al*. (2012) state that increasing of the tree growth is varies depend on the environment (soil, climate, and biotic factor) and genetic factor.

Table 2. Average values of growth characteristics and basic density

Characteristics	Site 1	Site 2	Combination site
Height (m)			
Average	15.6	15.0	15.3
Min	11.2	7.9	10.2
Max	20.9	20.5	19.8
CV (%)	19.7	23.1	22.2
Diameter (cm)			
Average	9.9	10.2	10.1
Min	6.4	6.0	7.0
Max	13.8	14.6	13.6
CV (%)	23.6	22.6	24.0
Volume (m^3)			
Average	0.06	0.06	0.06
Min	0.02	0.01	0.02
Max	0.13	0.15	0.13
CV (%)	56.58	57.19	58.78
Basic density (kg/m^3)			
Average	472.0	482.0	477.0
Min	409.0	400.0	407.0
Max	547.0	562.0	555.0
CV (%)	4.1	4.5	4.9

Min: minimum, Max: maximum, CV: coefficient of variance.

Table 2 also shows the mean values of basic density,

where the mean values in each site were 409−547 kg/m^3 in 1, 400−562 kg/m^3 in site 2; and 407−555 kg/m^3 in the combination site, respectively. Ramadan *et al*. (2018) reported that basic density of 4-year-old *E. pellita* planted in East Kalimantan was 450−465.2 kg/m^3. Basic density of 9-year-old *E. pellita* planted in North Sumatra, Indonesia was 400−450 kg/m^3 (Prasetyo *et al*., 2017). The basic density of 7-year-old *E.* hybrid planted in China were 404−427 kg/m^3 (Wu *et al*., 2011a). Basic density of the present study was lower comparing result by Ramadan *et al*. (2018). However, the result is higher comparing results by Prasetyo *et al*. (2017) and Wu *et al*. (2011a) even though their samples were older. The differences of the basic density could be due to the different genetic material, sites, age, etc. Further research is needed to clarify the effect of tree age on the basic density in *E. pellita*.

The results of ANOVA are shown in Table 3, and significant differences were observed in all measured characteristics, among the 50 clones either on individual site or on combination sites, and between two sites. Similar results were found by Kartikaningtyas *et al*. (2020) which was tree diameter, height and volume showed significant differences between 15 clones of 3.8-year-old *E. pellita*, planted in Wonogiri, Central Java, Indonesia. Dhillon and Singh (2010) who discovered significant differences for tree diameter and heigth among the progenies of about 23 trees of *E. tereticornis* at the age of 3.5 years old from different sites in Punjab at Regional Research Station, India. Similarly, significant differences in growth characteristics and basic density among 19 clones were reported in *E. hybrid* at the age of 4.2-year-old in southern China (Wu *et al*., 2011b), as well as *E. pellita* at 4 years old in East Kalimantan, Indonesia (Ramadan *et al*., 2018). Hidayati *et al*. (2019) also found significant differences for growth traits (tree diameter dan height) and wood properties between 65 families of *A. mangium* at the age of 6-year-old in Indonesia. Moreover, this result is in line with Prasetyo *et al.* (2017) who reported that growth characteristics (tree diameter, height, dan volume) and basic density of 9-year-old *E. pellita* planted in North Sumatra, Indonesia

Table 3. Variance analysis for growth characteristics and basic density at each site and in the combination site

Characteristics	Location	Site	Block	Clone	Clone × site
Diameter	Site 1		< 0.0001**	< 0.0001**	
	Site 2		0.5082^{ns}	< 0.0001**	
	Combination site	0.0001**	< 0.0001**	< 0.0001**	< 0.0001**
Height	Site 1		< 0.0001**	< 0.0001**	
	Site 2		0.0002**	< 0.0001**	
	Combination site	< 0.0001**	< 0.0001**	< 0.0001**	< 0.0001**
Volume	Site 1		< 0.0001**	< 0.0001**	
	Site 2		0.1862^{ns}	< 0.0001**	
	Combination site	0.041*	< 0.0001**	< 0.0001**	< 0.0001**
Basic density	Site 1			< 0.0001**	
	Site 2			< 0.0001**	
	Combination site	< 0.0001**		< 0.0001**	0.0012**

* Significant difference at 5% level, ** Significant differences at 1% level, ^{ns}: no significant.

were significantly different. In the present study, the results are also consistent with previous studies (Dhillon and Singh, 2010; Hidayati *et al*., 2019; Kartikaningtyas *et al*., 2020; Prasetyo *et al*., 2017; Ramadan *et al.*, 2018; Wu *et al*., 2011b). Differences in the growth characteristics and basic density between clones is effect of genetic factor. It is provided a potential to increase wood productivity and quality of the *E. pellita* (Kartikaningtyas *et al*., 2020).

The differences in growth characteristics (height and diameter) and basic density were found between two sites (Table 3). This is due to the differences in the topography of the location, where site 1 has a rather steep topography while site 2 has a slightly slope (flatter than site 1; Table 1). Soil texture is also thought to have an effect on clone performance where site 1 is with clay stone and site 2 with sandy stone. Hardiyanto *et al*. (2021) stated that the soil influences productivity on tree growth. In general, site 2 show the better result of diameter and the basic density. It could be related to the relatively flat topography and soil type of sandy stone in site 2. However, the tree volume is the same for both of site (Table 2). Similar result of the growth characteristics between two site was also found by other researchers in another Eucalypt (Harrand *et al*., 2009; Wu *et al*., 2011a).

Table 3 shows the results of the interaction variation between clones and locations (G × E). Significant differences were found in all growth characteristics (diameter, height, and volume of trees) and basic density (Table 3). This indicates that there is genetic instability in all traits where the ranking of the best clones at site 1 is not necessarily the best clone at site 2. Khasa *et al*. (1995) reported that significant site × provenance interactions were found in *Acacia auriculiformis* and *A. mangium*. *A. auriculiformis* in Vietnam was also observed to have significant interactions between site × clone, hence, clonal development and different clones should be used for different sites (Hai *et al*., 2008). According to Luo *et al*. (2012), the selection of clones suitable for their environment will increase maximum results even though in practice it requires a significant investment. The significant genotype by environment interaction might be attributable to factors such as environmental effects, narrow genetic expression changes (Bouvet *et al*., 2005), and the diversity of environments examined (Hardner *et al*., 2010). In the present study, result of G × E interaction was similar to the previous studies (Hai *et al*., 2008; Khasa *et al*., 1995). This indicates that G × E effects are practically important for selection growth parameters and basic density. Consequently, different clones should be used on different sites and not in combination for the next breeding strategies for *E. pellita*. To manage G × E interactions, the best clones can be selected for specific sites to maximize deployment gains (Libby and Rauter, 1984). Ramburan *et al*. (2011) reported clay is generally considered an important site factor causing variation in cultivar responses in the interaction genotype by environment. However, in other species Lee *et al.* (2022) reported that the growth of *Pinus densiflora* conditions were found to have a significant effect in the relationship between the annual ring growth and climate also in Korean Pine was significant different between microfibil angle with climate (Kim *et al*., 2020).

3.2. Genetic parameter

Table 4 shows the estimates of heritability for growth characteristics and basic density of *E. pellita* clones, where the heritability values of tree diameter, height, volume and basic density in each site were 0.83, 0.86, 0.87, and 0.91 in site 1; and 0.90, 0.87, 0.90, and 0.93 in site 2, respectively. Ramadan *et al*. (2018) reported the heritability of tree diameter, height, volume and basic density to be 0.53, 0.66, 0.63, and 0.89, respectively for the 4-year-old *E. pellita* clones planted in East Kalimantan, Indonesia. Furthermore, heritability was reportedly 0.82, 0.82, and 0.95, for tree diameter, height,

Table 4. Estimates of heritability (H^2) for growth characteristics and basic density

Characteristics	Site 1 (SE)	Site 2 (SE)	Combination site (SE)
Diameter	0.83 (0.05)	0.90 (0.06)	0.82 (0.05)
Height	0.86 (0.06)	0.87 (0.06)	0.82 (0.05)
Volume	0.87 (0.06)	0.90 (0.06)	0.83 (0.05)
Basic density	0.91 (0.05)	0.93 (0.05)	0.92 (0.05)

volume and basic density respectively in 3.5-year-old *Eucalyptus camaldulensis* planted in Ba Vi, North Vietnam (Kien *et al*., 2010). Wu *et al*. (2011b) also mentioned that the heritability among 19 clones in *E. hybrid* at the age of 4.2 years old in Shankou, Southern China was 0.86, 0.73, 0.83, and 0.74 for tree diameter, height, volume and basic density. Meanwhile, the estimated values for 8-year-old *Eucalyptus urophylla* × *E. tereticornis* clones planted in southern China were 0.91 for tree diameter and heigth, as well as 0.87 for basic density (Yang *et al*., 2018). The heritability results of growth and basic density were higher than those in previous studies (Kien *et al*., 2010; Ramadan *et al.*, 2018; Wu *et al*., 2011b), hence, there is a potential for improving growth characteristics and basic density in *E. pellita*, through the breeding program. Additionally, the growth characteristics heritability in this study was lower than previous results from Yang *et al*. (2018) at the age of 8-year-old, suggesting their ability to increase with tree age.

The estimated heritability of basic density in this study is higher than that of growth characteristics. This result indicate that basic density exhibits genetic control and is one of the preferred traits for wood quality improvement. This result is in line with Pliura *et al.* (2007) who reported that the value of the basic density heritability was higher than growth characteristics. Therefore, basic density has strong genetic control compared to environmental factors. Heritability is a parameter that describes the number of parental traits passed on to the offspring and is very important because it is closely related to expected gain and tree breeding strategies to obtain genetic enhancement (Zobel and Talbert, 1984). The basic density, which has been shown to have high heritability, affects timber strength, machinability and hardness (Xiao *et al*., 2021). Generally, density in eucalypts has been reported to be under strong genetic control with individual heritabilities ranging between 0.4 and 0.84 (*Borralho et al*., 1992). Based on the results, *E. pellita* has good opportunities for genetic improvement of the examined traits to increase wood productivity and quality.

The expected genetic gain value which is the response to the selection was calculated based on the estimated value of heritability. Table 5 shows the expected gain for growth characteristics and basic density of *E. pellita* clones, where the values (%) of tree diameter, height, volume and basic density in each site by choosing the best 1−5 clones were 25%, 24%, 70%, and 11% in site 1; and 31%, 29%, 80%, and 13% in site 2, respectively. Meanwhile, in *E. urophylla* × *E. grandis* clones at 5 years old in Congo, the expected gain was 26% direct selection for height and 62% for volume by selecting the best two clones (Makouanzi *et al*., 2017). Ramadan *et al*. (2018) also reported that the expected gain of *E. pellita* at 4 years old in East Kalimantan, Indonesia was 31.8% selection for volume and 7.4% for basic density by selecting 1−7 best clones.

The genetic gain of measured parameters is in the range of the previous results (Makouanzi *et al*., 2017). Proper use of clones will increase the expected gain by 20%–25% compared to the use of seed origin even when

Table 5. Estimates of expected genetic gain for growth characteristics and basic density

Location	Characteristics	Average	Expected gain (%)		
			5 Clones	10 Clones	15 Clones
Site 1	Diameter (cm)	9.8	25	21	19
	Height (m)	15.5	24	20	18
	Volume (m^3)	94.1	70	61	54
	Basic density (kg/m^3)	472.2	11	10	9
Site 2	Diameter (cm)	10.4	31	27	24
	Height (m)	15.2	29	25	22
	Volume (m^3)	102.6	80	69	61
	Basic density (kg/m^3)	480.9	13	11	10
Combination site	Diameter (cm)	10.1	24	20	18
	Height (m)	15.4	22	19	17
	Volume (m^3)	98.3	63	54	48
	Basic density (kg/m^3)	476.6	12	10	9

carried out in a breeding population of the same location and silvicultural technique (Rezende *et al*., 2014). The high expected genetic gain in clonal forestry might be due to the large proportion of additive genetic variation, ability to capture all non-additive genetic variations and exploit genetic as well as environmental interactions (White *et al*., 2007). However, the expected gain of basic density in this study is lower compared to that of the growth characteristics. Similar results were also found in the 5-year-old *E. camaldulensis* clones where in the growth characteristics increased by 22%–32% which is relatively small compared to basic density (Kien *et al*., 2010). Despite of this difference, the basic density character displays strong genetic control as demonstrated by the high heritability value in Table 4. This indicates that parental selection can improve wood quality.

The next genetic parameter examined was the correlation between traits. It was assessed to determine the relationship between one trait and another. Genetic correlation has an essential role in tree breeding programs, especially to develop two different characters or characteristics based on the application of selection on one character (Zobel and Talbert, 1984). The value of genetic correlation (rG) between height and diameter showed a close and positive relationship, ranging from 0.93 to 0.96 (Table 6). A similar result was also found in a 5-year-old *E. camaldulensis* clone planted in Vietnam with a genetic correlation value of 0.85–0.90 (Kien *et al*., 2010) and a 9-year-old *E. urophylla* clone with a value of 0.87 (Kien *et al*., 2009). High genetic correlation between height and diameter of 0.94 was also found in a 4-year-old *E. globulus* clone in Tasmania (Silva *et al*., 2013). Furthermore, the 4.2-year-old *E. hybrid* in China had a genetic correlation between height and diameter of 0.90–0.91 (Wu *et al*., 2011b). The results are also in line with Harrand *et al*. (2009), which found that *E. grandis* at the age of 4.5 years and 8.5 years had a genetic correlation of > 0.90 in the growth characteristics of height, diameter and volume of trees. Meanwhile, the

Table 6. Genetic correlation for growth characteristics and basic density

Character	Site 1 (SE)	Site 2 (SE)	Combination site (SE)
Diameter × height	0.93 (0.01)**	0.96 (0.00)**	0.94 (0.01)**
Diameter × volume	0.99 (0.00)**	0.98 (0.00)**	0.99 (0.00)**
Diameter × basic density	0.23 (0.05)ns	0.33 (0.04)**	0.31 (0.05)**
Height × volume	0.93 (0.01)**	0.92 (0.01)**	0.93 (0.01)**
Height × basic density	0.37 (0.05)**	0.47 (0.04)**	0.44 (0.04)**

** Significant at 1% level, ns: no significant.

results are higher than those obtained by Ramadan *et al.* (2018) in a 4-year-old *E. pellita* which ranged from 0.71 to 0.79 in East Kalimantan, Indonesia.

The genetic correlation between height and basic density was 0.37−0.47; while for diameter and basic density, it was 0.23−0.33 as described in Table 6. Therefore, the relationship between growth characteristics namely height and diameter, as well as basic density is moderate ranging from 0.23−0.47. At site 1, the correlation between growth characteristics and basic density was 0.23−0.37, while site 2 showed the highest genetic correlation range, of 0.33−0.47 and 0.31−0.44 in the combination of sites. Basic density is positively correlated with many of the mechanical properties of solid wood. Then, to improve these properties, should identify clones which give the highest wood density on a particular site type if performance of the clone is unstable. According to Kien *et al*. (2010), the genetic correlation between tree height and basic density of 5 years old clones of *E. camaldulensis* was 0.01−0.21 in Vietnam. Ramadan *et al.* (2018) also reported that the genetic correlation between height and basic density in the *E. pellita* planted in East Kalimantan, Indonesia was 0.04−0.23. Furthermore, a negative weak genetic correlation (−0.03) between diameter and basic density was reported by Yang *et al.* (2018) for 8-year-old *E. uropyhlla* × *E. tereticornis* clones planted in China. There was no correlation between the diameter and basic density of *E. globulus* (Apiolaza *et al*., 2005). Wu *et al*. (2011b) also stated that the genetic correlation between height and basic density was −0.12, while that of diameter and basic density was 0.28 in *E. urophylla* at the age 5.9-year-old planted in Guangdong, China. Moreover, Hidayati *et al.* (2019), found highly positive correlations between the growth characteristics, but no significant correlations were established with wood properties such as pilodyn penetration and stress wave velocity of *A. mangium* at the age 6-year-old in Indonesia. The growth characteristics, including tree height, diameter, and volume, had a strong correlation with a value > 0.90. These results illustrate that in making the selection, only one trait, namely diameter, can be used. This is because by prioritizing the actual diameter, improvements will occur indirectly to other properties. However, correlations between all growth characteristics and basic density were moderate and it is potentially good results for clone selection. This results genetic correlations among growth characteristics (height, diameter, volume) and basic density showed positive moderate to highly significant value. It is interesting to note that none of the character had shown negative correlation with each other, thus suggested that these characters may be used to the advantage of the breeder for bringing improvement in these characteristics simultaneously.

4. CONCLUSIONS

A total of 50 clones of *E. pellita* from two different sites in Kutai Kartanegara, East Kalimantan, Indonesia

was used in this study. Growth characteristics namely diameter, height, and volume of trees, as well as basic density, were significantly different among clones and sites. The results showed that there was an interaction between genetics and the environment which further will require separate clonal test locations and deployment populations for growth traits and basic density. Therefore, different clones should be used on various sites for the next breeding strategies for *E. pellita*. The heritability value of growth characteristics (tree diameter, height and volume) and basic density were high in each site, 0.83, 0.86, 0.87, and 0.91 in site 1; and 0.90, 0.87, 0.90, and 0.93 in site 2, respectively. It is suggesting that these characteristics are genetically controlled. This implies that *E. pellita* has great potential for genetic improvement to increase wood productivity and quality. The value of the expected genetic gain for growth characteristics was higher than that of basic density (tree diameter, height, volume and basic density in each site by choosing the best 1−5 clones were 25%, 24%, 70%, and 11% in site 1; and 31%, 29%, 80%, and 13% in site 2, respectively). Furthermore, the genetic correlation between growth characteristics showed a strong relationship ranging from 0.93 to 0.96, while that of growth characteristics and basic density was positive and significantly moderate ranging from 0.23 to 0.47. The results of the responses also indicate that using growth characteristics and basic density as selection traits together will be very beneficial to increase the productivity and wood quality of *E. pellita* clones.

CONFLICT of INTEREST

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

ACKNOWLEDGMENT

We are grateful to the management of PT. Itci Hutani Manunggal (IHM) and PT. Riau Andalan Pulp & Paper (RAPP) for their commitment to support long term research and publication of results. We thank R&D manager and Silviculture Team at the Research and Development, PT. IHM for various support, assistance in experiment works and data collection. This study was also funded by Thesis Recognition Program Year of 2022 Universitas Gadjah Mada, Indonesia (Letter of Assignment Number: 5722/UN1.P.III/Dit-Lit/PT.01.05/2022).

REFERENCES

Apiolaza, L.A., Raymond, C.A., Yeo, B.J. 2005. Genetic variation of physical and chemical wood properties of *Eucalyptus globulus.* Silvae Genetica 54(4/5): 160-166.

Augustina, S., Wahyud, I., Darmawan, I.W., Malik, J., Basri, E., Kojima, Y. 2020. Specific gravity and dimensional stability of boron-densified wood on three lesser-used species from Indonesia. Journal of the Korean Wood Science and Technology 48(4): 458-471.

Barua, S.K., Lehtonen, P., Pahkasalo, T. 2014. Plantation vision: Potentials, challenges and policy options for global industrial forest plantation development. International Forestry Review 16(2): 117-127.

Binkley, D., Campoe, O.C., Alvares, C., Carneiro, R.L., Cegatta, Í., Stape, J.L. 2017. The interactions of climate, spacing and genetics on clonal *Eucalyptus* plantations across Brazil and Uruguay. Forest Ecology and Management 405: 271-283.

Borralho, N. M. G., Cotterill, P. P., Kanowski, P. J. 1992. Genetic parameters and gains expected from selection for dry weight in *Eucalyptus globulus* ssp. globulus in Portugal. For Sci (38): 80-94.

Bouvet, J.M., Vigneron, P., Saya, A. 2005. Phenotypic plasticity of growth trajectory and ontogenic allometry in response to density for *Eucalyptus hybrid* clones and families. Annals of Botany 96(5): 811-

821.

Burdon, R.D., Aimers-Halliday, J. 2006. Managing risk in clonal forestry. CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources 1(035): 9.

Cruz, C.D., Castoldi, F.L. 1991. Decomposicao da interacao genotipos × ambientes em partes simples e complexa. Revista Ceres 38(219): 422-430.

Dhillon, G.P.S., Singh, A. 2010. Variation in growth traits among progenies of *Eucalyptus tereticornis* Sm. under flood-plain conditions of Punjab. Indian Journal of Agroforestry 12(1): 91-94.

dos Santos, G.A., Nunes, A.C.P., de Resende, M.D.V., Silva, L.D., Higa, A., de Assis, T.F. 2016. An index combining volume and pilodyn penetration to study stability and adaptability of *Eucalyptus* multi-species hybrids in Rio Grande do Sul, Brazil. Australian Forestry 79(4): 248-255.

Downes, G.M., Lausberg, M., Potts, B.M., Pilbeam, D.L., Bird, M., Bradshaw, B. 2018. Application of the IML Resistograph to the infield assessment of basic density in plantation *Eucalypts*. Australian Forestry 81(3): 177-185.

Gao, S., Wang, X., Brashaw, B.K., Ross, R.J., Wang, L. 2012. Rapid assessment of wood density of standing tree with nondestructive methods: A review. In: Changsha, China, Proceedings of 2012 International Conference on Biobase Material Science and Engineering, pp. 262-267.

Gendvilas, V., Downes, G.M., Neyland, M., Hunt, M., Jacobs, A., O'Reilly-Wapstra, J. 2021. Friction correction when predicting wood basic density using drilling resistance. Holzforschung 75(6): 508-516.

Ghani, R.S.M., 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.

Griffin, A.R. 2014. Clones or improved seedlings of *Eucalyptus*? Not a simple choice. International Forestry Review 16(2): 216-224.

Hadi, Y.S., Massijaya, M.Y., Zaini, L.H., Pari, R. 2019. Physical and mechanical properties of methyl methacrylate-impregnated wood from three fast-growing tropical tree species. Journal of the Korean Wood Science and Technology 47(3): 324-335.

Hai, P.H., Jansson, G., Harwood, C., Hannrup, B., Thinh, H.H. 2008. Genetic variation in growth, stem straightness and branch thickness in clonal trials of *Acacia auriculiformis* at three contrasting sites in Vietnam. Forest Ecology and Management 255(1): 156-167.

Hardiyanto, E.B., Inail, M.A., Sadanandan Nambiar, E.K. 2021. Productivity of *Eucalyptus pellita* in Sumatra: *Acacia mangium* legacy, response to phosphorus, and site variables for guiding management. Forests 12(9): 1186.

Hardner, C.M., Dieters, M., Dale, G., DeLacy, I., Basford, K.E. 2010. Patterns of genotype-by-environment interaction in diameter at breast height at age 3 for *Eucalypt hybrid* clones grown for reafforestation of lands affected by salinity. Tree Genet Genomes 6(6): 833-851.

Harrand, L., Hernandez, J.J.V., Upton, J.L., Valverde, G.R. 2009. Genetic parameters of growth traits and wood density in *Eucalyptus grandis* progenies planted in Argentina. Silvae Genetica 58: 1-2.

Harwood, C.E., Alloysius, D., Pomroy, P., Robson, K.W., Haines, N.W. 1997. Early growth and survival of *Eucalyptus pellita* provenances in a range of tropical environments, compared with *E. grandis, E. urophylla* and *Acacia mangium*. New Forests 14(3): 203-219.

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.

Hodge, G.R., Dvorak, W.S. 2012. Growth potential and genetic parameters of four Mesoamerican pines planted in the Southern Hemisphere. Southern Forests: A Journal of Forest Science 74(1): 27-49.

Hung, T.D., Brawner, J.T., Meder, R., Lee, D.J., Southerton, S., Thinh, H.H., Dieters, M.J. 2014. Estimates of genetic parameters for growth and wood properties in *Eucalyptus pellita* F. Muell. to support tree breeding in Vietnam. Annals of Forest Science 72(2): 205-217.

Iswanto, A.H., Tarigan, F.O., Susilowati, A., Darwis, A., Fatriasari, W. 2021. Wood chemical compositions of Raru species originating from central Tapanuli, North Sumatra, Indonesia: Effect of differences in wood species and log positions. Journal of the Korean Wood Science and Technology 49(5): 416-429.

Kartikaningtyas, D., Nirsatmanto, A., Sunarti, S., Setyaji, T., Handayani, B.R., Surip. 2020. Trends of genetic parameters and stand volume productivity of selected clones of *Eucalyptus pellita* observed in clonal trials in Wonogiri, Central Java. IOP Conference Series: Earth and Environmental Science 522: 012005.

Kha, L.D., Harwood, C.E., Duc Kien, N., Baltunis, B.S., Dinh Hai, N., Huy Thinh, H. 2012. Growth and wood basic density of *Acacia hybrid* clones at three locations in Vietnam. New Forests 43(1): 13-29.

Khasa, P.D., Vallée, G., Li, P., Magnussen, S., Camiré, C., Bousquet, J. 1995. Performance of five tropical tree species on four sites in Zaïre. The Commonwealth Forestry Review 74(2): 129-137.

Kien, N.D., Jansson, G., Harwood, C., Almqvist, C. 2010. Clonal variation and genotype by environment interactions in growth and wood density in *Eucalyptus camaldulensis* at three contrasting sites in Vietnam. Silvae Genetica 59(1): 17-28.

Kien, N.D., Quang, T.H., Jansson, G., Harwood, C., Clapham, D., von Arnold, S. 2009. Cellulose content as a selection trait in breeding for kraft pulp yield in *Eucalyptus urophylla.* Annals of Forest Science 66(7): 711.

Kim, J.Y., Kim, S.C., Kim, B.R. 2020. Microfibril angle characteristics of Korean pine trees from depending on provinces. Journal of the Korean Wood Science and Technology 48(4): 569-576.

Latifah, S., Villanueva, T.R., Carandang, M.G., Bantayan, N.C., Florece, L.M. 2014. Predicting growth and yield models for *Eucalyptus* species in Aek Nauli, North Sumatera, Indonesia. Agriculture, Forestry and Fisheries 3(4): 209-216.

Lee, K.H., Jo, S.Y., Kim, S.C. 2022. The relationship between tree-ring growth in *Pinus densiflora S. et Z.* and the corresponding climatic factors in Korea. Journal of the Korean Wood Science and Technology 50(2): 81-92.

Lee, S.S. 1993. Diseases. In: *Acacia mangium* Growing and Utilization, Ed. by Awang, K. and Taylor, D. Winrock International, Bangkok, Thailand.

Leksono, B., Kurinobu, S. 2005. Trend of within family-plot selection practised in three seedling seed orchards of *Eucalyptus pellita* in Indonesia. Journal of Tropical Forest Science 17(2): 235-242.

Leslie, A.D., Mencuccini, M., Perks, M. 2012. The potential for Eucalyptus as a wood fuel in the UK. Applied Energy 89(1): 176-182.

Libby, W.J., Rauter, R.M. 1984. Advantages of clonal forestry. The Forestry Chronicle 60(3): 145-149.

Luechanimitchit, P., Luangviriyasaeng, V., Laosakul, S., Pinyopusarerk, K., Bush, D. 2017. Genetic parameter estimates for growth, stem-form and branching traits of *Casuarina junghuhniana* clones grown in Thailand. Forest Ecology and Management 404: 251-257.

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 Pelahairi, South Borneo, Indonesia. Journal of the Korean Wood

Science and Technology 44(4): 571-588.

Luo, J.Z., Arnold, R.J., Cao, J.G., Lu, W.H., Ren, S.Q., Xie, Y.J., Xu, L.A. 2012. Variation in pulp wood traits between *Eucalypt* clones across sites and implications for deployment strategies. Journal of Tropical Forest Science 24(1): 70-82.

Makouanzi, G., Chaix, G., Nourissier, S., Vigneron, P. 2017. Genetic variability of growth and wood chemical properties in a clonal population of *Eucalyptus urophylla* × *Eucalyptus grandis* in the Congo. Southern Forest: A Journal of Forest Science 80(2): 151-158.

Nambiar, E.K.S., Harwood, C.E., Mendham, D.S. 2018. Paths to sustainable wood supply to the pulp and paper industry in Indonesia after diseases have forced a change of species from acacia to eucalypts. Australian Forestry 81(3): 148-161.

Oliveira, T.W.G., Paula, R.C., Moraes, M.L.T., Alvares, C.A., Miranda, A.C., Silva, P.H.M. 2018. Stability and adaptability for wood volume in the selection of *Eucalyptus saligna* in three environments. Pesquisa Agropecuária Brasileira, Brasília 53(5): 611-619.

Osorio, L.F., White, T.L., Huber, D.A. 2001. Age trends of heritabilities and genotype-by-environment interactions for growth traits and wood density from clonal trials of *Eucalyptus grandis* Hill ex Maiden. Silvae Genetica 50(1): 30-36.

Pliura, A., Zhang, S.Y., Mackay, J., Bousquet, J. 2007. Genotypic variation in wood density and growth traits of poplar hybrids at four clonal trials. Forest Ecology and Management 238(1-3): 92-106.

Prasetyo, A., Aiso, H., Ishiguri, F., Wahyudi, I., Wijaya, I.P.G., Ohshima, J., Yokota, S. 2017. Variations on growth characteristics and wood properties of three *Eucalyptus* species planted for pulpwood in Indonesia. Tropics 26(2): 59-69.

Ramadan, A., Indrioko, S., Hardiyanto, E.B. 2018. Genetic parameters for growth and basic density of *Eucalyptus pellita* F. Muell clones at two different sites in East Kalimantan. Jurnal Pemuliaan Tanaman Hutan 12(2): 115-125.

Ramburan, S., Zhou, M., Labuschagne, M. 2011. Interpretation of genotype x environment interaction of surgancane: Identifying significant envornmental factors. Field Crops Research 124: 392-399.

Rezende, G.D.S.P., de Resende, M.D.V., de Assis, T.F. 2014. *Eucalyptus* Breeding for Clonal Forestry. In: Challenges and Opportunities for the World's Forests in the 21st Century, Ed. by Fenning, T. Springer, Dordrecht, Netherlands.

Santos, G.A., Resende, M.D.V., Silva, L.D., Higa, A., Assis, T.F. 2015. Interacao genotypos × ambientes para productividade de lones de *Eucalyptus* no Rio Grande do Sul. Revista Árvore 39(1): 81-91.

Schulz, H.R., Acosta, A.P., Barbosa, K.T., Junior, M.A.P.S., Gallio, E., Delucis, R.Á., Gatto, D.A. 2021. Chemical, mechanical, thermal, and colorimetric features of the thermally treated *Eucalyptus grandis* wood planted in Brazil. Journal of the Korean Wood Science and Technology 49(3): 226-233.

Silva, J.C., Potts, B.M., Tilyard, P. 2013. Stability of genetic effects across clonal and seedling populations of *Eucalyptus globulus* with common parentage. Forest Ecology and Management 291: 427-435.

Wendling, I., Trueman, S.J., Xavier, A. 2014. Maturation and related aspects in clonal forestry: Part II: Reinvigoration, rejuvenation and juvenility maintenance. New Forests 45(4): 473-486.

West, P.W. 2009. Tree and Forest Measurement. Springer, Dordrecht, Netherlands.

White, T.L., Hodge, G.R. 1989. Predicting Breeding Values with Applications in Forest Tree Improvement. Springer, Dordrecht, Netherlands.

White, T.L., Thomas Adams, W., Neale, D.B. 2007. Forest Genetics. CABI, Wallingford, UK.

Wu, S.J., Xu, J., Li, G., Risto, V., Du, Z., Lu, Z., Li, B., Wang, W. 2011a. Genotypic variation in wood properties and growth traits of *Eucalyptus hybrid* clones in southern China. New Forests 42(1): 35-50.

Wu, S.J., Xu, J.M., Li, G.Y., Risto, V., Lu, Z.H., Li, B.Q., Wang, W. 2011b. Estimation of basic density and modulus of elasticity of *Eucalypt* clones in southern China using non-destructive methods. Journal of Tropical Forest Science 23(1): 51-56.

Xiao, Y., Wang, J., Yun, H., Yang, G., Ma, J., Qu, G. 2021. Genetic evaluation and combined selection for the simultaneous improvement of growth and wood properties in *Catalpa bungee* clones. Forests 12(7): 868.

Yang, H., Weng, Q., Li, F., Zhou, C., Li, M., Chen, S., Ji, H., Gan, S. 2018. Genotypic variation and genotype-by-environment interactions in growth and wood properties in a cloned *Eucalyptus urophylla* × *E. tereticornis* family in southern China. Forest Science 64(3): 225-232.

Zobel, B., Talbert, J. 1984. Applied Forest Tree Improvement. John Wiley & Sons, New York, NY, USA.