

The growth, pilodyn penetration, and wood properties of 12 *Neolamarckia cadamba* provenances at 42 months old

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Abstract. Anna N, Supriyanto, Karlinasari L, Sudrajat DJ, Siregar IZ. 2020. The growth, pilodyn penetration, and wood properties of 12 *Neolamarckia cadamba* provenances at 42 months old. *Biodiversitas* 21: 1091-1100. Jabon (*Neolamarckia cadamba* (Roxb) Bosser) is a potential tree species for the development of plantation forests and community forests to supply timber demands. Information on the growth characteristics and wood properties of *N. cadamba* is important for the present and future development, yet. Those data is not available. This study aimed to assess the variations on growth (height, diameter), pilodyn (Pilodyn®) penetration, and physical properties of wood from core sample; and characterize the wood properties of 12 *N. cadamba* provenances at Parung Panjang, Bogor. The assessment of growth characteristics, pilodyn penetration, and physical properties of wood from core sample was carried out through census (1030 trees) on all provenance (using non-destructive method). The wood properties analysis was carried out using destructive method to one sample for each of the 12 *N. cadamba* provenances. Growth characteristics observed were the height (numerical scale pole), diameter (calipers), and pilodyn penetration. Meanwhile, the wood properties consisted of wood density, specific gravity, moisture content, fiber length (light microscope), MFA (x-ray diffraction), MOE, and MOR. The results showed that the correlation between the height and moisture content with pilodyn penetration was weak and positive, while the correlation between diameter, wood density, and specific gravity was weak and negative. The result of non-destructive test showed that Gowa provenance is superior. The results of destructive tests to investigate the wood properties of the twelve provenances showed that Batu Licin provenance is superior in terms of specific gravity and MOE, while Gowa provenance is superior in terms of MOR and fiber length. The results of the wood properties (i.e. density, specific gravity, moisture content, MOE, MOR, MFA, and fiber length) of the 12 *N. cadamba* provenances showed that the woods can be potentially used as non-structural materials only.

Keywords: Growth, jabon, *Neolamarckia cadamba*, pilodyn penetration, provenance, wood properties

INTRODUCTION

Jabon (*Neolamarckia cadamba* (Roxb) Bosser, family Rubiaceae) is a widely and naturally distributed species in Australia, China, India, Malaysia, Papua New Guinea, the Philippines, Singapore, Vietnam, and Indonesia (Orwa et al. 2009). *N. cadamba* is a reliable species for timber because it is easy to process, soft and light, creamy white to reddish in color, shining, and slightly porous (Ministry of Forestry of Indonesia 1989). The wood can be utilized for many products including light construction, veneer, pulp, fiberboard, blockboard, particleboard, lighters, packaging boxes, concrete molds, children's toys, and plywood. The wood is classified in class III-IV for strength and class V for durability with a specific gravity of 0.42 g/cm³ (Soerianegara and Lemmens 1993). With its reliable quality and rapid growth, *N. cadamba* is an important species for the development of community and plantation forestry to meet the increasing demand of timber industries while timber supply coming from natural forests is declining.

The tree improvement program is one alternative to increase the forest plantation productivity for timber supply, both in quantity and quality. In Indonesia, the program for *N. cadamba* has been carried out in Yogyakarta (Yudohartono 2013) and West Java (Sudrajat et al. 2016). Previous studies were focused on increasing growth and adaptive properties, while studies on wood properties have never been done. Information on the growth and properties of *N. cadamba* wood is vital to solve the diverse demand for timber forest products from the industry.

Accelerating tree growth can affect the wood properties, affecting the performance and final product value (Zhang et al. 2002). Faster growth can lead to shorter rotation periods as well as to a greater proportion of juvenile wood (Gardiner and Moore 2013). The proportion of early and latewood in fast-growing and slow-growing species is different. In some studies, fast-growing species usually have more earlywood and less latewood compared to slow-growing species (Zhang et al. 1998; Wang et al. 2002; Makinen et al. 2002). The compositions are prone to

cause a low modulus of elasticity (MOE), modulus of rupture (MOR), and density (Clark et al. 2006).

Previous studies reported that tree improvement programs affect the growth and properties of wood, especially its density, for example in *Pinus pinaster* (Gaspar et al. 2009), *Picea glauca* (Lenz et al. 2013), *Pinus banksiana* (Hébert et al. 2016), and *Pinus contorta* (Hayatgheibi et al. 2019). It is crucial to investigate wood density to obtain basic information on wood quality at a certain age and for consideration in the selection program. This activity, can be done using Pilodyn®. Pilodyn® (hereafter mentioned as pilodyn) is a portable handheld device that is used by flatly firing to a tree with a fixed force to evaluate the hardness as well as the density of outer wood on standing trees, and this instrument has been used for various species (Cown 1978; Taylor 1981; Sprague et al. 1983; Villeneuve et al. 1987; Rozenberg and Sype 1996; Raymond and MacDonald 1998; Wang et al. 2000; Kien et al. 2008; Ishiguri et al. 2008; Ishiguri et al. 2012; Kha et al. 2012; Hidayati et al. 2013; Warriar and Venkataramanan 2014; Anna et al. 2018).

Information on other wood properties such as fiber length, microfibril angle (MFA), and MOE is also important in supporting tree improvement programs (Moore et al. 2009; Lenz et al. 2013; Hébert et al. 2016; Hayatgheibi et al. 2019) related to the usefulness of wood. Therefore, it is essential to know the wood properties and the relationship between growth, wood density (Raymond et al. 1998; Zhang et al. 2003; Monteuis et al. 2011), pilodyn penetration, and other wood properties.

This study aimed to assess variations in growth and wood density using pilodyn and to determine the wood properties of 12 *N. cadamba* provenances at Parung Panjang, Bogor. This research can be important in continuing the development of the *N. cadamba* improvement program and to provide guidance for the selection of future generations in supporting the development of plantation forests and more productive *N. cadamba* wood utilization that can satisfy the industry demands.

MATERIALS AND METHODS

Study area

The research was conducted at the Parung Panjang Research Forest Station, Bogor, Indonesia. The samples used were *N. cadamba* provenance-progeny test originated from 12 provenances (105 families) in Indonesia. For a total of 5 blocks, each family consisted of 4 individuals (a 4-rows tree plot) for each of the blocks. Planting space applied in the research location was 3 x 3 m. The total individuals of *N. cadamba* provenance of 42 months old surviving were 1030 trees which grow at the Forest Station with specific site conditions (Table 1). Twelve *N. cadamba* provenance are: Rimbo Panti (SRP), Kampar (SKR), Ogan Komering (SOK), Garut Selatan (JGS), Nusakambangan (JNK), Alas Purwo (JAP), Kapuas Tengah (KKT), Batu Licin (KBL), Gowa (CPG), Pomalaa (CPK), Batu Hijau (NBH), Kuala Kencana (PKK).

Table 1. Environmental conditions of *Neolamarckia cadamba* provenance-progeny test in Parung Panjang, Bogor, West Java, Indonesia

Characteristics	Parung Panjang, Bogor
Geographical location	06°2' LS, 106°0' BT
Altitude (m asl)	52
Precipitation rate (mm/year)	2990
Average temperature (°C)	28
Soil pH	Acid-very acid
Drainage	Moderate, although puddles will likely to form during heavy rains
Other notes	The area is designed for research, relatively flat, weed growth is very fast after clearing
Soil chemistry:	
KCl	Neutral
C-Organic (Walkey&Black)	Low-high
N-total (Kjeldahl)	Moderate
P (Bray I)	Low
P (HCl 25%)	High-very high
Ca	Low-Moderate
Mg	Moderate-high
K	Low and high
Na	Low and moderate
KTK	Moderate-very high
KB	Very low-moderate

Table 2. Summary of statistical analysis of variance (ANOVA) for variables of plant height, diameter, pilodyn penetration, wood density, specific gravity, and moisture content in the provenance-progeny test of *Neolamarckia cadamba* of 42 months old standing trees (n = 1030 trees)

Source of variation	Degrees of freedom	Mean square					
		Height (m)	Diameter (cm)	Pilodyn penetration (cm)	Wood density (g/cm ³)	Specific gravity	Moisture content (%)
Block	4	222.33**	319.90**	0.26**	0.12**	0.06**	4970.58**
Provenance	11	7.48**	15.77**	0.70**	0.01**	0.010**	440.88**
Fam (Prov)	93	6.40**	10.26**	0.16**	0.009**	0.004**	764.17**
Block#Prov	42	6.74**	10.06**	0.21**	0.009**	0.004**	753.87**
Block#Fam (Prov)	267	5.67**	8.51**	0.14**	0.009**	0.005**	810.03**
Error	612	1.73	4.75	0.07	0.004	0.002	543.18

Notes: ** = significant $P < 0.05$, ns = not significant

Growth variation, pilodyn penetration, physical wood properties from core sample (nondestructive method)

Measurement of growth characteristics, pilodyn penetration, and physical properties of wood from core sample was carried out by census to all (1030 trees). Total height was measured by numerical scale poles and diameter at breast height (1.3 m) using calipers. Pilodyn penetration was done using Pilodyn® (with the specification of the strength = 6 J, pin diameter = 2.5 cm). The penetration was carried out on xylem of wood. The ability of the tool in the penetration was related to the hardness of wood which can be expressed by the wood density. Pilodyn penetration was conducted at breast height (1.3 m) at 3 radial-horizontal positions for each tree without removing the bark. The distance between each penetration was 120° (Hansen 2000). The small core wood samples in diameter about 5 cm at a height of 1.3 m were taken out from 1030 standing trees to determine the physical properties of moisture content, specific gravity, and wood density.

Assessment of wood properties on 12 *N. cadamba* provenance (destructive method)

From the 1030 sample trees, twelve trees representing 12 *N. cadamba* provenances (one tree per provenance) were chosen and then felled to prepare wood samples to determine physical and mechanical properties that were tested destructively. The wood sample was prepared from the pith to the outer bark parts based on transversal section and conditioned with natural drying until achieving air-dried moisture content conditions. Physical parameters of wood characteristics observed were density, specific gravity, and moisture content. The standards used referred to ASTM D 4442-92 (ASTM 2005) and ASTM D 2395-02 (ASTM 2005). The equations used to calculate wood density (ρ), specific gravity (G), and moisture content (MC) are as follows:

$$MC (\%) = \frac{(W_1 - W_0)}{W_0} \times 100$$

$$\rho (\text{g/cm}^3) = \frac{W_1}{V_1}$$

$$G = \frac{\rho_{\text{in } W_0}}{\rho_{\text{water}}}$$

Where, MC = moisture content (%), ρ = wood density (g/cm^3), G = specific gravity, W_1 = weight of sample at test (g), W_0 = oven-dry weight (g), V_1 = volume of sample at test (cm^3), $\rho_{\text{water}} = 1 \text{ g/cm}^3$

The assessment of the mechanical wood properties of static bending or flexure (modulus of elasticity, MOE, and modulus of rupture, MOR) was carried out using British Standard BS 373: 1957 (BS 1957) for Methods of Testing Small Clear Specimens of Timber. The mechanical properties tested were MOE and MOR. MOE and MOR values were calculated using the formula:

$$MOE = \frac{PL^3}{4yb^3}$$

$$MOR = \frac{3P \max L}{2bh^2}$$

Where, MOE = modulus of elasticity (kg/cm^2), MOR = modulus of rupture (kg/cm^2), P = increment of applied load on flexure below proportional limit (kg), L = span of flexure (cm), Pmax = maximum load (kg), y = increment deflection of neutral axis of flexural (cm), b : sample width (cm), h : sample thickness (cm)

The assessment of the anatomical wood properties was performed by determining the boundaries of juvenile and mature wood areas using the segmented regression model as developed by Rahayu et al. (2014). The limit of juvenility was obtained by measuring fiber length and microfibril angle (MFA). The maceration process was carried out using the Schlutz method, and the length of the fiber was measured using a light microscope. Measurement of the MFA angle was done by X-ray Diffraction (XRD). Samples were taken starting from the pith to bark with a dimension of 1 x 1 x 2 cm^3 .

Data analysis

The factors influencing growth, pilodyn penetration, and physical properties of wood from core sample were analyzed using a completely randomized block design. Statistical analysis was performed using SAS 9.4 for windows.

Heritability was measured from the variance component (Falconer and Mackay 1996). The average heritability of individuals and families for each character was measured using the following formulas:

$$h^2i = \frac{4\sigma^2 A}{\sigma^2 U} = \frac{4\sigma^2 F(P)}{\sigma^2 U}; h^2f = \frac{\sigma^2 F(P)}{\sigma^2 fm}$$

Where, h^2i = individual heritability, $\sigma^2 A$ = additive genetic variance, $4\sigma^2 F(P)$ = component of inter-family variance in the provenance, $\sigma^2 U$ = variety of phenotypes, which calculated by $\sigma^2 U = \sigma^2 F(P) + \sigma^2 RF(RF)P + \sigma^2 e$, where $\sigma^2 F(P)$ = variance caused by interactions between blocks and family in the provenance (experimental error), $\sigma^2 e$ = variation between individuals in the family (sampling error), h^2f = family heritability, $\sigma^2 fm$ = family phenotype variation which is calculated by $\sigma^2 fm = \sigma^2 F(P) + (k^2/k^3)\sigma^2 RF(P) + (1/k^3)\sigma^2 e$, where k^2 and k^3 are the coefficients for $\sigma^2 RF(P)$ and $\sigma^2 F(P)$ in the expected middle square.

Pearson correlation test was used to determine the relationship between growth character, pilodyn penetration, and physical properties of wood from core sample.

Data on wood properties of 12 *N. cadamba* provenances were analyzed using Microsoft Excel 2013. The Principal Component Analysis (PCA) using Minitab 17. PCA was used to explain the relationship among variables (the form of interaction between the growth character and the wood properties of *N. cadamba* provenance).

RESULTS AND DISCUSSION

Growth variation, pilodyn penetration, physical wood properties from core sample (non-destructive test)

The difference in growth, pilodyn penetration, and physical properties of wood from core sample between each provenance, family, block, families within provenance, and interaction between the two were analyzed with variance analysis. Variance analysis showed a significant effect of provenance and families within provenance for variables of height, diameter, pilodyn penetration, wood density, specific gravity, and moisture content (Table 2).

The data distribution of height growth, diameter, penetration of pilodyn, and physical wood properties from core sample was highly diverse. Pomalaa provenance had higher variation than others in height growth. Batu Hijau had the highest variation in diameter growth, while Kampar had the highest in pilodyn penetration. For physical properties of wood, Kampar provenance had the highest variation in wood density and specific gravity, while Pomalaa had the highest variation in moisture content. For the growth characteristics (height and diameter), the whisker line for the 12 provenances located above the boxplot was longer than those below (Figure 1), suggesting. That all 12 provenances had good growth because the dominant value was higher than average.

The Pearson correlation analysis was applied to determine the relationship between observed variables (growth character, pilodyn penetration, and physical properties of wood from core sample). Pearson correlation between growth characteristic (height and diameter) on *N. cadamba* wood from 12 provenances was positive and very strong with a confidence level of 0.01% (correlation coefficient $r = 0.817$). It means that the taller the tree was the bigger the diameter. While the correlation between growth character and pilodyn penetration was weak, for the parameters of height ($r = 0.068$), and diameter ($r = -0.038$). The correlation between pilodyn penetration with wood density was found in negative and weak relationship ($r = -0.172$), as well as with specific gravity ($r = -0.282$). Meanwhile, the relationship with moisture content was positive and weak ($r = 0.199$) (Table 3). Furthermore, the Pearson correlation between each variable on the 42 months old *N. cadamba* provenance of was still weak.

Individual heritability in growth character, pilodyn penetration, and physical wood properties from core sample was low to moderate (ranged from 0.025 to 0.181). Family heritability values were higher than individual heritability values, which ranged from 0.040 to 0.296 as presented in Table 4.

Table 3. Statistical analysis of Pearson correlation between growth characteristics, pilodyn penetration, and physical properties from core sample

Pearson correlation	Height (m)	Diameter (cm)	Wood density (g/cm ³)	Specific gravity	Moisture content (%)	Pilodyn penetration (cm)
Height (m)	1	0.817**	-0.198**	-0.067*	-0.078*	0.068*
Diameter (cm)		1	-0.038	0.047	-0.071*	-0.038
Wood density (g/cm ³)			1	0.530**	0.254**	-0.172**
Specific gravity				1	-0.613**	-0.282**
Moisture content (%)					1	0.199**
Pilodyn penetration (cm)						1

Note: ** = correlation is significant at the 0.01 level, * = correlation is significant at the 0.05 level

Wood properties of 12 *Neolamarckia cadamba* provenances (destructive test)

Growth characteristics are important to be tested regularly and continuously, while wood properties should be tested early to predict the quality of wood itself. The 12 *N. cadamba* provenances from the Forest Research Station were expected to have good growth as well as wood quality, since they can be recommended as seeds source. Alas Purwo provenance had the highest height growth rate (12.7 m), while Kuala Kencana provenance had the lowest (7.00 m). Along with its height growth, Alas Purwo provenance had the highest diameter growth rate (13.30 cm), and the smallest belonged to Nusakambangan provenance (8.74 cm). The deepest pilodyn penetration was obtained in Kuala Kencana provenance (3.43 cm) and the shallowest in Batu Licin provenance (2.27 cm). The variable of wood density, specific gravity, as well as the moisture content, were not too different between each provenance. The average wood density was 0.94 g/cm³, specific gravity was 0.46, and green moisture content was 105.13%. The highest MOE value was obtained at Batu Licin provenance (67751.04 kg/cm²) and the lowest at the Kuala Kencana provenance (37847.07 kg/cm²). Gowa provenance had the greatest MOR (639.87 kg/cm²), while Kuala Kencana provenance possessed the lowest (361.15 kg/cm²). MOE and MOR were carried out in air-dried moisture content. The average air-dried moisture content was 13.62%. The highest MFA of 18.84° was observed in Gowa provenance, and the lowest in Kapuas Tengah provenance (of 7.06°). Gowa provenance had the longest fiber (1314.10 μm), while Garut provenance possessed the shortest value (1041.64 μm) (Table 5). The research found that the twelve *N. cadamba* provenance had different growth and wood properties, although planted in the same location and received the same treatment.

Table 4. Estimation of the heritability of individuals and families growth characteristics, pilodyn penetration, and physical properties of wood from core sample

Variables	Individual heritability (h ² i)	Family heritability (h ² f)
Height	0.025 (low)	0.040 (low)
Diameter	0.077 (low)	0.160 (moderate)
Pilodyn penetration	0.181 (moderate)	0.296 (moderate)
Wood density	0.069 (low)	0.125 (moderate)
Specific gravity	0.073 (low)	0.152 (moderate)
Moisture content	0.080 (low)	0.195 (moderate)

Note: Heritability categories according to Cotterill and Dean (1990): heritability <0.1 = low, 0.1-0.3 = moderate, and > 0.3 = high

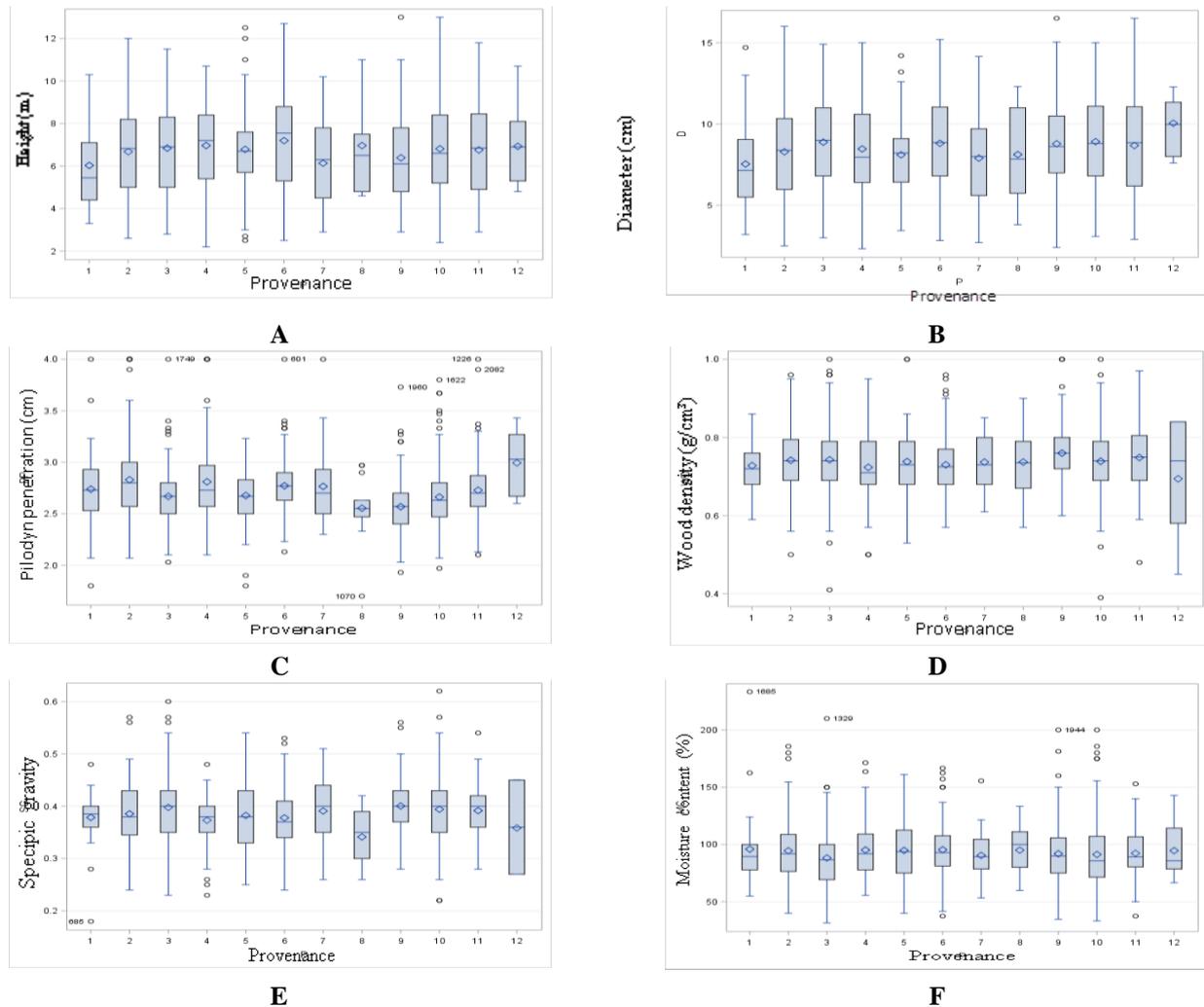


Figure 1. Variations of growth in height, diameter, pilodyn penetration, and physical properties from core sample (non-destructive test) at twelve *Neolamarckia cadamba* provenances. A. height, B. diameter, C. pilodyn penetration, D. wood density, E. specific gravity, F. moisture content. Notes: 1. Rimbo Panti, 2. Kampar, 3. Ogan Komering, 4. Garut Selatan, 5. Nusakambangan, 6. Alas Purwo, 7. Kapuas Tengah, 8. Batu Licin, 9. Gowa, 10. Pomalaa, 11. Batu Hijau, 12. Kuala Kencana

The PCA analysis obtained four main components having eigenvalues above 1 with a cumulative variance of 86.60%. The first and second main components produced 43.70% and 17% diversity of the total characters, respectively. The first component was characterized by three variables, namely pilodyn penetration, MOR, and specific gravity. The first component was the identity of the characteristics of the wood properties. The second component was characterized by height and diameter, which was the identity of the growth character. There were four groups formed in Figure 2, the first provenance groups of SRP, SOK, KKT, and JAP; the second provenance groups of JGS, CPK, NBH, and CPG; the third provenance group SKR, JNK, and PKK; and KBL provenance groups themselves.

Discussion

The growth characteristic, pilodyn penetration, and the physical properties of wood are important parameters in the

development of *N. cadamba* improvement programs as well as to guide the selection of the best provenance to support the development of plantation forests and satisfying the industry demands in term of wood supply. Analysis of variance showed that there were differences among provenances, families in provenance, interaction both between blocks with provenance and between blocks and families within provenance influenced the growth characters (height, diameter), pilodyn penetration, and physical properties (wood density, specific gravity, moisture content). These results explained that growth, pilodyn penetration, and physical wood properties are not solely caused by genetic factors but also from the interaction between genetic and the environment. It means that there might be an opportunity to obtain genetic improvement in the next generation. As in line with the study conducted by Sudrajat et al. (2016) and Anna et al. (2018) at the age of 12 and 36 months on the same test-plot.

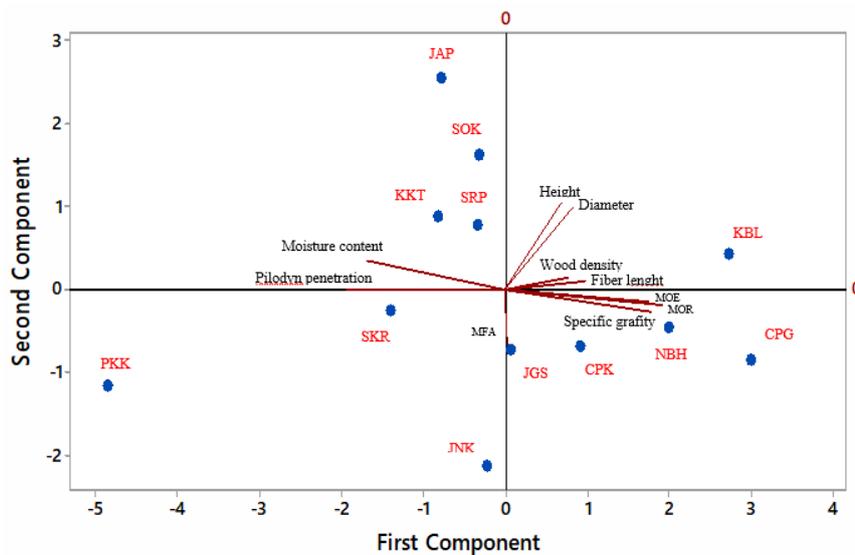


Figure 2. PCA analysis results of growth (height, diameter), pilodyn penetration, and wood properties of 12 *Neolamarckia cadamba* provenances. Notes: (SRP) Rimbo Panti, (SKR) Kampar, (SOK) Ogan Komering, (JGS) Garut Selatan, (JNK) Nusakambangan, (JAP) Alas Purwo, (KKT) Kapuas Tengah, (KBL) Batu Licin, (CPG) Gowa, (CPK) Pomalaa, (NBH) Batu Hijau, (PKK) Kuala Kencana. H (Height), D (Diameter), PP (Pilodyn Penetration), WD (Wood Density), SG (Specific Gravity), MC (Moisture Content), MOE (Modulus of Elasticity), MOR (Modulus of Rupture), MFA (Microfibril Angel), FL (Fiber Length)

Table 5. The growth (height and diameter) and pilodyn penetration in standing trees, wood characteristics of wood density, specific gravity, green moisture content from disk samples, and MOE, MOR, air-dried moisture content, MFA, and fiber length of 12 *Neolamarckia cadamba* provenances

Provenance	Height (m)	Diameter (cm)	Pilodyn penetration (cm)	Green Moisture content (%)	Wood density (g/cm ³)	Specific gravity	Air-dried Moisture content (%)	MOE (kg/cm ²)	MOR (kg/cm ²)	MFA (°)	Fiber length (µm)
SRP	10.30	11.70	2.87	104.06	0.95	0.47	14.32	43672.20	449.12	10.07	1199.35
SKR	8.60	11.00	2.90	107.53	0.93	0.45	13.63	44869.12	440.15	12.20	1247.93
SOK	10.60	13.24	2.77	103.98	0.93	0.46	14.02	45593.83	430.00	8.51	1192.43
JGS	8.20	10.30	2.43	107.94	0.94	0.46	13.65	57812.78	524.01	9.73	1041.64
JNK	7.50	8.74	2.83	100.94	0.95	0.47	12.48	50533.87	466.09	12.93	1176.04
JAP	12.70	13.30	2.73	112.21	0.94	0.45	13.30	49151.75	466.12	10.49	1127.83
KKT	8.50	11.75	2.80	111.75	0.95	0.45	12.68	47273.14	465.56	7.06	1282.88
KBL	11.00	11.60	2.50	98.65	0.94	0.49	13.43	67751.04	572.54	7.28	1150.21
CPG	9.95	12.08	2.27	102.72	0.94	0.47	13.68	64383.33	639.87	18.84	1314.10
CPK	9.10	12.44	2.40	99.49	0.92	0.47	14.73	53664.24	525.92	15.81	1165.31
NBH	7.60	12.70	2.47	96.62	0.95	0.49	14.05	49525.45	517.85	10.73	1248.53
PKK	7.00	9.83	3.43	115.71	0.93	0.44	13.50	37847.07	361.15	14.87	1053.06
Mean	9.25	11.56	2.70	105.13	0.94	0.46	13.62	51006.48	488.20	11.54	1183.28
SD	1.69	1.38	0.31	5.97	0.00	0.02	0.37	8667.76	72.96	3.56	83.87

Note: (SRP) Rimbo Panti, (SKR) Kampar, (SOK) Ogan Komering, (JGS) Garut Selatan, (JNK) Nusakambangan, (JAP) Alas Purwo, (KKT) Kapuas Tengah, (KBL) Batu Licin, (CPG) Gowa, (CPK) Pomalaa, (NBH) Batu Hijau, (PKK) Kuala Kencana. H (Height), D (Diameter), PP (Pilodyn Penetration), WD (Wood Density), SG (Specific Gravity), MC (Moisture Content), MOE (Modulus of Elasticity), MOR (Modulus of Rupture), MFA (Microfibril Angel), FL (Fiber Length)

The growth characteristics of the 42 months old *N. cadamba* at the Forest Research Station in Parung Panjang varied. The varieties were found in height, diameter, leaf shape, and crown shape. However, the pilodyn penetration, as well as the physical wood properties of wood density, specific gravity, and moisture content, were significantly different. Growth variation is caused by external factors

(e.g. climate, soil, temperature, precipitation, and humidity) and genetic factors along with the interaction between external and genetic factors. The variety of seed source or provenance plays an important role in tree growth and survival rates (Weber et al. 2008). The seeds used in this research were from 12 different locations with variations in altitude, latitude, and longitude and genetically superior

compared to their surrounding trees of the same species. The seed from genetically superior trees produces high-quality seeds. Although they were given similar treatment in the field, the growth varied. According to Zobel and Talbert (1995), regardless of the species, the variance will be expressed because of the difference in provenance, family, tree age (physiological age), silviculture, and the environment.

Pilodyn® is an instrument to measure wood quality of the standing tree based on wood density approach. The hardness in xylem or wood was related to wood density which the higher pilodyn penetration pointed out the lower wood density. The average of pilodyn penetration of the 42 months old *N. cadamba* provenance by the census method was 2.73 cm. This result was lower compared to 36 months old *N. cadamba* provenance (2.86 cm) (Anna et al. 2018). This decreasing trend in penetration depth. Indicate the increasing wood density as the *N. cadamba* trees growing older. Pilodyn penetration can be used as an indicator of wood density, the higher the value, was the lesser the wood density, and vice versa (Kha et al. 2012).

This might be related to the plant age and the type of wood formed, which were juvenile woods formed. This finding strengthens the study by Rahayu et al. (2014), who stated that *N. cadamba* wood on 5 to 6 years old was still classified as juvenile. A similar penetration depth was reported on fast-growing species of 4 years old of *Acacia auriculiformis* with a penetration depth of 2 - 3 cm (Kha et al. 2012), as well as found in *Pinus nigra* (Liana et al. 2015). The study of pilodyn penetration was also reported by Ishiguri et al. (2012) on 54 years old of *Agathis* sp. and Hidayati et al. (2013) on 12 years old of *Tectona grandis*. Pilodyn penetration depth decrease in the 36 to 42-month-old wood. The pilodyn penetration value will decrease following the age, which meant the xylem or wood mass is getting harder.

The study also obtained the correlation between pilodyn penetration and growth characteristics (height and diameter) as well as correlation between pilodyn penetration and wood physical properties (i.e. wood density, specific gravity, and moisture content). The information will valuable for farmers (to distinguish high-quality seed), for breeders (for seed selection in tree improvement program), and also for administrators of plantation forest (for determining the precise harvest season aligned with the timber utilization purpose) in developing the decision of tree improvement. Correlation between pilodyn penetration with the height was positive and weak ($r = 0.068$ *), while the diameter was negative and weak ($r = -0.038$). Inline study was reported by Kien et al. (2008), correlation between pilodyn penetration with the height was negative and weak on the 8 years old and 9 years old *E. urophylla* (-0.18 and -0.29), while the diameter was negative and weak (-0.25 and -0.14). The correlation between growth character and pilodyn penetration should be negative and strong, which means that the better growth of tree will have lower in pilodyn penetration (as shown by the increase of wood or xylem hardness).

The accuracy of wood quality, which calculated with Pilodyn® can be estimated through the correlation between

pilodyn penetration and wood physical properties. The correlation between wood density and pilodyn penetration was negative and weak ($r = -0.172$), as well as the specific gravity ($r = -0.282$), yet the correlation with moisture content was positive and weak ($r = 0.199$). Couto et al. (2013) reported the correlation between wood density and pilodyn penetration of the 42 months old *E. grandis* and *E. urophylla* were 0.00 and -0.44. Carrillo et al. (2017) stated that the correlation between density and pilodyn on the 6 years old *E. globulus* and *E. nitens* was negative and strong. Similar results were reported by Shi-jun et al. (2010) on 56 months old Eucalyptus, Warriar and Venkataramanan (2014) on 4 years old of *Casuarina equisetifolia*, Kien et al. (2008) on 8 and 9 years old *E. urophylla*, and Kha et al. (2012) on *Acacia hybrid* planted in Yen Tanh. Micko et al. (1982) reported that the correlation between specific gravity and pilodyn penetration on white spruce (*Picea glauca*) was negative and strong. A study by Cown (1978) found the same results for *Pinus radiata*. A different result was found on 4-year-old *Casuarina equisetifolia* where the result was positive and weak (Warriar and Venkataramanan 2014). From this discussion, it can be concluded that the species and tree age can influence the correlation between pilodyn penetration and wood physical properties (specifically wood density and specific gravity). Overall, the correlation between the height growth and moisture content with pilodyn penetration was weak and positive, while the correlation between diameter, wood density, and specific gravity with pilodyn penetration was weak and negative. However, it seems that the Pilodyn® is potentially used to determine the wood density of *N. cadamba* provenance.

The heritability estimation in this study was categorized from low to moderate for all variables measured (Table 4). The heritability value is needed to explain whether the character is affected by genetic or environmental factors. Heritability value ranged from 0 to 1. If the heritability value is close to 1 (one), it means that heritability is high, meaning that the character's appearance is influenced by genetic factors. If the heritability value is close to 0 (null), heritability is low, meaning the character's appearance is influenced by environmental factors. The family heritability was higher than individual heritability. It indicates that the likelihood of genetic acquisition will be higher by selection among families rather than among individuals. Similar results on growth character (height and diameter) were reported by Sudrajat et al. (2016), in contrast to Setyadi et al. (2013) study on 2-year-old *N. cadamba* growth.

For the growth characteristic of height and diameter, the heritability showed increasing from 36 to 42 months old. Anna et al. (2018) reported that the heritability of the height character of the 36 and 42 months old *N. cadamba* provenance was 0.011 and 0.025, respectively; while the heritability of diameter characters were 0.052 and 0.077 for 36 and 42 months old, respectively. The heritability appears to be decreased following the penetration of pilodyn, wood density, as well as specific gravity. Following the age, the heritability may decrease because of

the increasing rate of phenotype diversity compared with the additive diversity (Surles et al. 1995). Result as reported by Aguiar et al. (2003), found that the heritability of *Pinus pinaster* was low for height and diameter on 5 years old and 12 years old in two different planting locations, while the heritability value of pilodyn penetration was low to moderate. Sanhueza et al. 2002 reported that the heritability of *E. globulus* for height variables was low but high for pilodyn penetration.

The results indicated that the heritability value in the pilodyn penetration and the wood physical properties are greater than the heritability of growth (height), but did not differ from the heritability of diameter (Hallingbäck et al. 2008; Wu et al. 2008; Chen et al. 2014; Hong et al. 2014; Hayatgheibi et al. 2019).

Information on wood properties is needed in terms of the use of wood as raw material. Physical as well as mechanical properties of wood were important for optimum utilization. The green properties of *N. cadamba* wood from the 12 provenances showed that the average of wood density was 0.94 g/cm³, the specific gravity was 0.46, with the moisture content was 105.13% (Table 6).

Static flexural testing of MOE and MOR explains that the MOE value represents the wood stiffness. Meanwhile, the MOR points out the external load capacity that can be carried out by a wood beam (Mardikanto et al. 2011). The average value of MOE and MOR of 42 months old from 12 *N. cadamba* provenances were 51039.93 kg/cm², and 488.37 kg/cm², respectively (Table 4) at air-dried condition. Nugroho et al. (2011) found that the average MOE and MOR values at the age of 7 years were 65100 kg/cm² and 631 kg/cm², respectively. As comparison, the MOE and MOR values for *Acacia mangium* at the age of 10 years old were 89814.4 kg/cm² and 651.97 kg/cm², respectively (Nurhasybi and Sudrajat 2019). The MOE and MOR values of the study are lower than the 7-year-old *N. cadamba* and 10-year-old *A. mangium*. The study of *N. cadamba* wood conducted by Rahayu et al. (2014) found that the MOR value of the 5- and 6-years old (60 and 72 months old) were 454 and 464 kg/cm², respectively. Referring to Indonesia Strength Class classification as mentioned in Mardikanto et al. (2011), the *N. cadamba* wood was categorized in strength class IV based on MOR value.

The MFA with XRD of this study was average of 11.54°. A study by Rahayu et al. (2014) using Iodine method found the MFA was 24° and 22° for 60 and 72 months old. The difference in MFA values can be caused by the differences in age, location, growing conditions, and methods used.

The average fiber length of the 12 *N. cadamba* provenance was 1183.28 µm. A slightly different result was reported by Rahayu et al. (2014) at the age of 5 and 6 years (1190 and 1245 µm) and *N. cadamba* at 7 years (1288 µm) (Fajriani et al. 2013).

In conclusion, the results of this study suggest that non-destructive tests using pilodyn might be not optimal in representing the wood quality of *N. cadamba* at 42 months old. Future research is suggested to repeat the study to test the *N. cadamba* provenances using similar method at the

older age. The result of non-destructive test showed that Gowa provenance is superior. The results of destructive tests to investigate the wood properties of the twelve provenances showed that Batu Licin provenance is superior in terms specific gravity and MOE, while Gowa provenance is superior in terms of MOR and fiber length. Overall, based on the wood properties of 12 *N. cadamba* provenance can be utilized as non-structural raw materials only.

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