Environment's Effect on Wood Characteristics of White Jabon Grown in West Java and Banten Area, Indonesia

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This study analyzed the diversity of physical properties and mechanical properties of white jabon (*Neolamarckia cadamba* (Roxb.) Bosser) from various locations and ecological conditions in West Java and Banten Indonesia. White jabon wood samples were taken from 8 locations in West Java and the Banten region. Tree ages ranged from 5 to 6 years. This wood was then tested to compare physical characteristics (density or specific gravity) and mechanical characteristics (modulus of rupture (MOR) and modulus of elasticity (MOE)). The results showed that wood density ranged from 0.29 to 0.43 $g.cm^{-3}$, MOR ranged from 361 to 641 $kg.cm^{-2}$, and MOE ranged from 31,117 to 58,910 $kg.cm^{-2}$. The highest density average (0.43 ± 0.004 $g.cm^{-3}$) was produced from Cianjur, and the lowest density average (0.29 ± 0.010 $g.cm^{-3}$) was from Tanjungsari Sumedang. Environmental factors (precipitation and altitude) affect the density of wood. Separately, rainfall has a low effect and a negative relationship to jabon wood density, while altitude has a high influence and a negative relationship to jabon wood density. Andosol soil types tend to produce low density wood.

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INTRODUCTION

Wood characteristics from the tree are affected by two main categories of factors, genetic and environmental. Genetic factors are the factors of the wood itself and environmental factors are external factors that affect growth. Environmental factors that affect growth include climate (temperature, humidity, and air circulation), availability of water (rainfall), physical and chemical properties of soil, topography, and other organisms growing around the tree (Fritts 1976; Fitter and Hay 1987; Suhaya *et al*. 2015; Cienciala *et al*. 2016).

The significant site variables affecting growth of trees include soil chemistry (C/N ratio, potassium, pH), precipitation, and altitude (Suhaya *et al*. 2015; Cienciala *et al*. 2016; Zhang *et al*. 2017). Tree heights have been found to increase with increasing mean temperature and precipitation (Zhou *et al*. 2019). Soil types and tree species influence average wood density (Ramananantoandro *et al*. 2016). Silviculture techniques to manage tree growth and wood production as a forest management practice can be used to improve wood quality (Zhang *et al*. 2020). Silvicultural techniques by mixing Calabrian pine and European beech have been carried out by Russo *et al*. (2020); the admixture of wood species increased stand productivity and improved wood quality.

White jabon (*Neolamarckia cadamba* (Roxb.) Bosser sinonim *Anthocephalus cadamba* (Roxb.) Miq., *Anthocephalus chinensis* Lamk: family Rubiaceae) is one of the fast-growing tree species that can contribute to the needs of wood raw materials in Indonesia. Jabon trees can be harvested in a short time of around 5 to 6 years. This jabon also has a high prospect for forest plantations and reforestation in Indonesia, due to its fast growth, ability to adapt to various growing conditions, relatively easy silvicultural treatment, and because it is relatively free of pests and diseases (Krisnawati *et al*. 2011; Wahyudi 2012; Abdulah *et al*. 2013; Junaedi *et al*. 2021). Jabon trees are becoming increasingly important for the Indonesian timber industry in the future, especially when it is estimated that woodworking raw materials from natural forests will decrease (Krisnawati *et al*. 2011; Mindawati *et al*. 2015).

Jabon wood can be used as raw material for making furniture, including chairs, tables, and office cabinets. Jabon wood is easily dried and has a specific gravity averaging 0.42 (ranging from 0.29 to 0.56); it is classified as strong class III to IV and durable class V (Martawidjaya *et al*. 1989). Based on Rahman *et al*. (2018), jabon wood does not show any difference in properties in the elongated or radial directions, tends to have uniform properties, and is suitable for composite wood raw materials.

The aim of this study was to analyze the diversity of physical properties and mechanical properties of white jabon (*Neolamarckia cadamba* (Roxb.) Bosser) originating from a variety of places and ecological conditions in West Java and Banten Province, Indonesia.

EXPERIMENTAL

Study Area

White jabon wood samples were taken from eight locations in West Java and Banten region (Fig. 1).

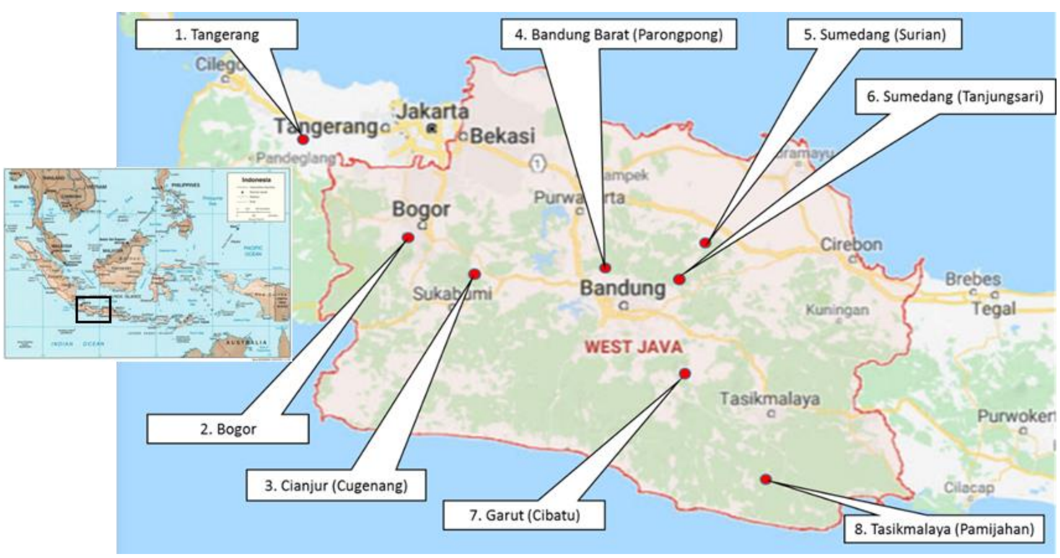

Fig. 1. Locations for taking wood samples from 8 areas in West Java and Banten Province, Indonesia

Tree ages ranged from 5 to 6 years and were taken from community plantation forests. This wood was tested to compare physical characteristics (moisture content (MC), density, and specific gravity) and mechanical characteristics (modulus of rupture (MOR) and modulus of elasticity (MOE)).

Procedure

The jabon wood sampled in this study was from three trees for each location, and three samples were taken from each tree. The stems used for testing were taken 2 m from the base of the tree. The logs are then sawn to obtain tangential boards with a thickness of 25 mm and dried to a MC of 10% to 12%. Drying was carried out in two stages, namely natural drying under a roof to a moisture content of around 30% and continued using an oven at 50 °C, to a moisture content of 10% to 12%. After drying, the boards were sawn and planed to make test samples as boards of dimensions of 20 mm × 20 mm × 20 mm (thickness × width × length).

The wood testing method for bending static used the BS 373 (1957) standard for testing small clear specimens of timber. White jabon specimens were prepared for determination of its following physical and mechanical properties, which include MC, density or specific gravity, MOR, and MOE. These mechanical properties can indicate the strength of its wood.

The wood samples for testing physical properties (MC and density/ specific gravity) were made with a size of 20 mm × 20 mm × 20 mm (width × depth × length), and the wood samples for testing the mechanical properties of wood (MOR and MOE) were made with sizes 20 mm × 20 mm × 300 mm (width × depth × length). The tests underwent three repetitions each and the test position in the tangential direction.

Fig. 2. One white jabon specimen being tested of its static bending using a universal testing machine (UTM)

Mechanical testing was performed using a universal testing machine (UTM) with air-dry wood. In this study, a three-point static bending test was used, which is a center point loading with two supporting bearings, and where the pressure of loading is perpendicular to the grain of the specimens of wood. This test is used for determination of the strength of wood. Generally bending strength is used to quantify the stress required to cause failure. Speed of testing (displacement control) of the UTM was set at 2.50 mm/min. Before the test started, the specimens were checked for MC and density.

Data Analysis

Quantitative analysis was performed after the data collected from the results of physical and mechanical testing. Data analysis was performed by simple analysis with comparison of physical data (density) and mechanical properties (MOR and MOE) from 8 locations in West Java. To determine the effect of environmental variables on the characteristics of wood, a multivariate analysis was performed.

RESULTS AND DISCUSSION

Comparison of Wood Properties Diversity Inter-Growing Location

The results of testing the physical and mechanical properties of white jabon wood from 8 locations showed differences in both physical (density) and mechanical properties (MOR and MOE). Physical and mechanical properties of white jabon in West Java and Banten are listed in Table 1.

Table 1. Properties of White Jabon in West Java and Banten

Site/District	Tree Diameter (cm)	MC After Drying (%)	Density ($g.cm^{-3}$)	MOR ($kg.cm^{-2}$)	MOE ($kg.cm^{-2}$)
Tangerang	23.3 ± 0.6	11.15 ± 0.22	0.42 ± 0.01	542 ± 37	58,910 ± 1,007
Bogor	24.7 ± 1.2	11.99 ± 0.38	0.37 ± 0.04	444 ± 74	37,244 ± 4,116
Cianjur	23.3 ± 2.1	10.94 ± 0.16	0.43 ± 0,00	641 ± 40	56,980 ± 1,565
West Bandung	25.3 ± 0.6	12.32 ± 0.87	0.32 ± 0.02	407 ± 3	38,701 ± 839
Sumedang (Tanjungsari)	24.3 ± 0.6	11.90 ± 0.35	0.29 ± 0.01	421 ± 10	39,414 ± 4,433
Sumedang (Surian)	25.7 ± 1.5	11.89 ± 0.38	0.39 ± 0.02	519 ± 25	41,165 ± 7,320
Garut	24.3 ± 1.5	12.20 ± 0.36	0.36 ± 0.02	506 ± 55	39,045 ± 1,624
Tasikmalaya	23.3 ± 0.6	12.94 ± 0.23	0.35 ± 0.02	361 ± 41	31,117 ± 2,410

Wood density ranged from 0.29 to 0.43 $g.cm^{-3}$, MOR ranged from 361 to 641 $kg.cm^{-2}$, and MOE ranged from 31,100 to 58,900 $kg.cm^{-2}$.

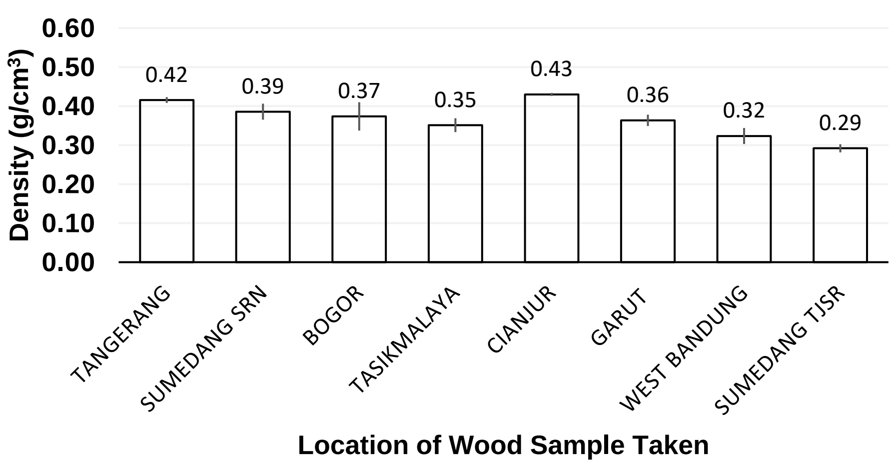

Fig. 3. Physical properties (density) of white jabon from West Java and Banten Area, Indonesia

Differences that occur are thought to be due to different growth speeds. Fast-growing wood produces wood densities that tend to be lower (Suhaya *et al*. 2015). The comparison results of jabon wood properties between groups growing locations are ordered from the highest altitude to the lowest altitude as shown in Figs. 3, 4, and 5.

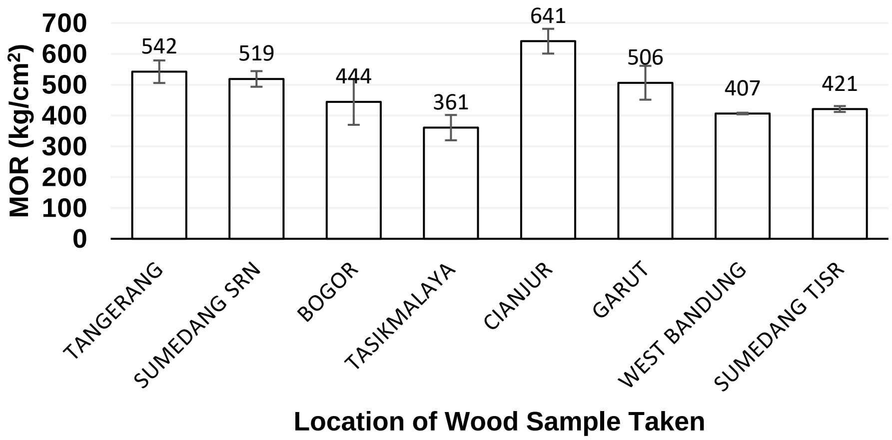

Fig. 4. MOR of white jabon from West Java and Banten Area, Indonesia

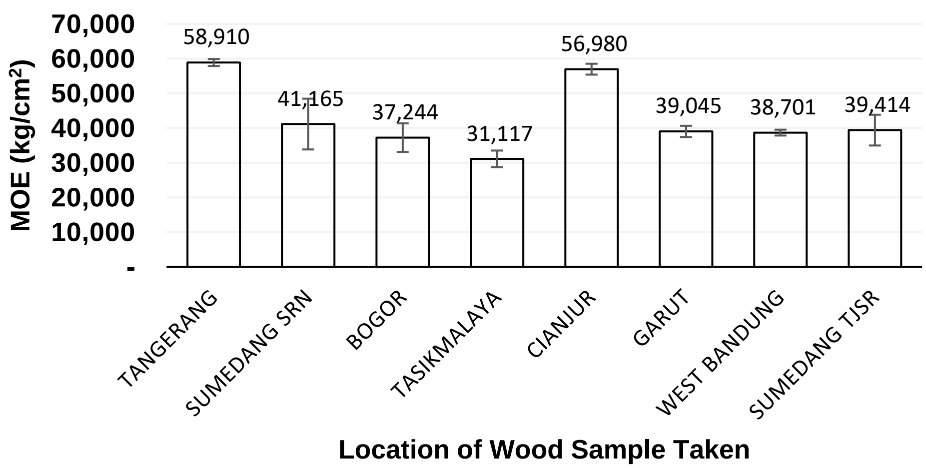

Fig. 5. MOE of white jabon from West Java and Banten Area, Indonesia

From Figs. 3, 4, and 5, the density, MOR, and MOE of white jabon wood were found to be remarkably different between sites. The location where they grow was observed to influence the physical and mechanical properties (density, MOR, and MOE) of white jabon. The results of analysis of variance (ANOVA) for density, MOR, and MOE showed that location had a significant effect on density, MOR, and MOE. The highest density average of 0.43 ± 0.004 g.cm^{-3} was associated with Cianjur and the lowest density average of 0.29 ± 0.010 g.cm^{-3} was from Tanjungsari Sumedang. Hadi *et al*. (2013) report that the density of jabon wood was 0.35 g.cm^{-3} in their study.

The results of measuring the moisture content (MC) after drying obtained a range of 10.9% to 12.9%. This is in accordance with the target MC, namely 10% to 12%. Density, MOR, and MOE tests were carried out at these MC conditions.

Wood density is an important wood property that correlates with several functional tree traits and mechanical wood properties. Density is an excellent indicator of wood strength; in general, a higher density results in stronger wood (Izekor *et al*. 2010; Gindl *et al*. 2001). Furthermore, wood density is often used in forest biomass and carbon stock estimates. The variation in wood density depends on a range of intrinsic or environmental factors (Ramananantoandro *et al*. 2016).

The highest MOR average of 641 ± 40 kg.cm^{-2} was found for wood from Cianjur and the lowest density average of 361 ± 41 kg.cm^{-2} was from Tasikmalaya. The MOE values were significantly different between sites too. Similar with density and MOR, location or site where they grow was found to greatly affect the MOE. The highest MOE average of 58,910 ± 1,007 kg.cm^{-2} was obtained from Tangerang and the lowest value of 31,117 ± 2,410 kg.cm^{-2} was from Tasikmalaya.

Jabon wood with high density has high MOR and MOE values as well. Jabon wood from the Cianjur and Tangerang locations had high densities of 0.43 ± 0.004 g.cm^{-3} and 0.42 ± 0.007 g.cm^{-3}, resulting in high mechanical strengths of MOR 641 ± 40 kg.cm^{-2} and 542 ± 37 kg.cm^{-2}. Jabon wood characteristics in West Java turned out to be varied; this is thought to occur due to different environmental factors (Nicholls and Wright 2011).

It was found that African Black Wood (*Dalbergia melanoxylon*) was widely distributed under various environmental conditions with intensive population, and that their growth form depended on environmental factors (Nakai *et al*. 2019). Due to variations in characteristics that are so high, the use of wood must be careful, because not all wood has the same quality. Before it is used, it is better to know the characteristics of the wood to be used, especially its density.

Wood Strength Classification of White Jabon (*Neolamarckia cadamba* (Roxb.) Bosser) in West Java and Banten

Wood strength classification of white jabon (*Neolamarckia cadamba* (Roxb.) Bosser) in West Java and Banten based on the density/specific gravity of wood and MOR values are listed in Table 2.

Table 2. Strength Wood Classification of White Jabon in West Java and Banten

Site/District	Density (g.cm^{-3})	MOR (kg.cm^{-2})	Wood Strength Class *
Tangerang	0.42 ± 0.01	542 ± 37	III
Bogor	0.37 ± 0.04	444 ± 74	IV
Cianjur	0.43 ± 0.00	641 ± 40	III
West Bandung	0.32 ± 0.02	407 ± 30	IV
Sumedang (Tanjungsari)	0.29 ± 0.01	421 ± 10	IV-V
Sumedang (Surian)	0.39 ± 0.02	519 ± 25	III-IV
Garut	0.36 ± 0.02	506 ± 55	III-IV
Tasikmalaya	0.35 ± 0.02	361 ± 41	IV

* Source: Den Berger Classification (1923) in Martawijaya *et al*. 1981

The range of wood strength class of white jabon (*Neolamarckia cadamba* (Roxb.) Bosser) in West Java and Banten is class III to IV-V. Jabon wood from Tangerang and Cianjur has the strongest class, that is class III. Strength class, judged on wood density and MOR values, refer to Den Berger Classification (1923) in Martawijaya *et al*. (1981). The average value of wood density and MOR of jabon from Tangerang and Cianjur is the highest.

With the uniform physical characteristics of wood (Rahman *et al*. 2018), and with a density value that is not too high, jabon wood is suitable as raw material for making pencils. Additionally, jabon wood is good for use as laminated wood (glulam). The results of Lestari *et al*. (2018) showed that jabon glulam using isocyanate adhesives achieved values of all mechanical properties (MOE, MOR, and shear strength) that were higher than the values for its solid wood counterpart. The MOR of jabon glulam was higher than that of its solid wood counterpart by 17.2%.

Relationship between Environmental Conditions and Characteristics of Wood

Data on environmental conditions and characteristics of jabon wood (*Neolamarckia cadamba* (Roxb.) Bosser) in West Java and Banten are listed in Table 3.

Table 3. Environmental Conditions and Characteristics of White Jabon Wood (*Neolamarckia cadamba* (Roxb.) Bosser)

Site/District	Precipitation (mm/year)*	Altitude (m asl)*	Soil *	Density ($g.cm^{-3}$)	MOR ($kg.cm^{-2}$)
Tangerang	1,799	31	Dystric Fluvisol (FLd)	0.42 ± 0.01	542 ± 37
Bogor	3,973	271	Haplic Acrisol (ACh)	0.37 ± 0.04	444 ± 74
Cianjur	2,521	402	Eutric Fluvisol (FLe)	0.43 ± 0,00	641 ± 40
West Bandung	2,371	649	Umbric Andosol (ANu)	0.32 ± 0.02	407 ± 3
Sumedang (Tanjungsari)	2,851	1200	Haplic Andosol (ANh)	0.29 ± 0.01	421 ± 10
Sumedang (Surian)	2,810	209	Eutric Vertisol (VRe)	0.39 ± 0.02	519 ± 25
Garut	2,329	590	Haplic Andosol (ANh)	0.36 ± 0.02	506 ± 55
Tasikmalaya	3,349	386	Vitric Andosol (ANz)	0.35 ± 0.02	361 ± 41
* Source : CGIAR (2020)					

The results showed that wood density is influenced by both precipitation and altitude, as determined using multivariate analysis. Nevertheless, the results of the multivariate analysis indicated that the mechanical characteristics of wood (MOE and MOR) are affected substantially by the wood density rather than environmental factors. Thus, it can be concluded that there is a correlation between environmental factors and wood density only.

The equation obtained was as follows:

$$Y = 0.452 - 1.39X_1 - 9.9X_2 \quad (1)$$

where Y describes the density of jabon wood in $g.cm^{-3}$, X_1 describes the amount of annual rainfall in $mm.year^{-1}$ in the area where the jabon tree grows, and X_2 describes the altitude (m asl) of the location where the jabon tree grows. Regression results show a coefficient of determination (R^2) of 0.604.

Separately, the regression results show that rainfall has a low effect and has a negative relationship to wood density, while altitude has a high influence and a negative relationship to jabon wood density. This is in line with the results of Kiaei and Samariha's (2011), who studied the relationship between altitude index and wood properties of *Pinus eldarica* Medw. They found that the wood from high altitude has a low density, and the wood from intermediate altitude has a high density.

Dias *et al*. (2018) determined the effect of altitude, annual mean precipitation, and the average temperature on the wood density of European black pine (*Pinus nigra* Arnold) wood from six Portuguese sites. The authors were reported that wood density had a positive correlation with temperature, but it had a negative correlation with altitude and precipitation. The research results of Dias *et al*. (2018) also showed a not too close relationship between rainfall and wood density, as indicated by the low R^2 value.

Jabon is a type of wood that grows fast and can thrive in tropical forests with an ecological range including an altitude of 0 to 1000 m above sea level, with average rainfall between 1500 and 5000 mm/year, estimated temperature of 21 to 26 °C, and reaction conditions soil (pH) 4.5 to 7.5 (Martawijaya *et al.* 1989; Krisnawati *et al.* 2011). Rainfall tends to be quite high in each research location (West Java and Banten region). It was in the range of 1,799 to 3,973 mm/year, which is thought to be the cause of the low influence of rainfall on wood density.

The regression relationship between rainfall and altitude with wood density is shown in the image below (Figs. 6).

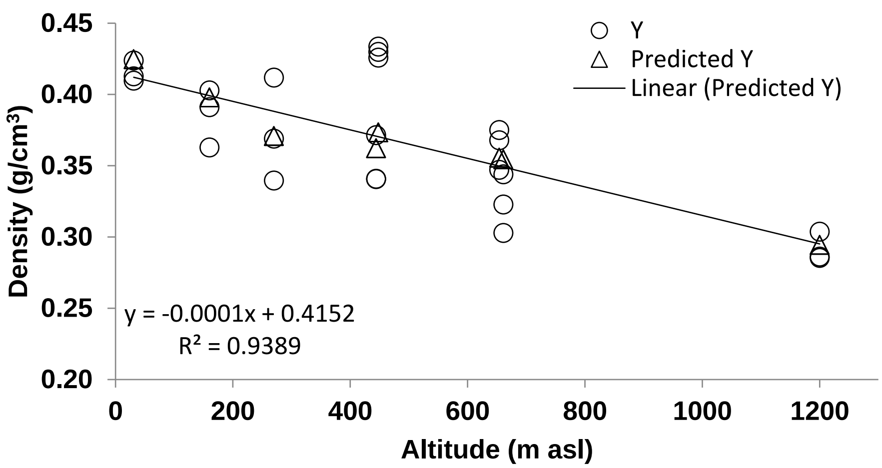

Fig. 6. Relationship between altitude and density of jabon wood

Altitude is one of the significant physiographic factors affecting plant development and growth, as functional characteristics can vary greatly depending on altitude (Keleş 2020). Growth rates can decrease with altitude due to reduced soil and air temperatures, increased wind exposure, shorter growing seasons, and reduced nutrient supply (Coomes and Allen 2007). Diameter growth rates decreased with increasing altitude, and this was associated with a shortening of the growing season and a decrease in average summer temperatures (Wardle 1984).

Based on the distribution of soil types in the study sites (Table 3), it is known that high wood density was obtained from the Cianjur location with Eutric Fluvisol (FLe) soil type. Fluvisols are young soils with weak horizon differentiation; they have mostly AC-profiles and are predominantly brown (aerated soils) and/or grey (waterlogged soils) in color (Msanya *et al*. 2003). Meanwhile, low-density wood was obtained from the Sumedang location (Tanjungsari) with Haplic Andosol (ANh) soil type.

Andosols are highly porous, dark-colored soils developed from parent material of volcanic origin, such as volcanic ash, tuff, and pumice (FAO 2009). Based on the research location, several locations with Andosol soil types tend to produce low wood density of wood.

CONCLUSIONS

1. The results from 8 locations in West Java showed that the highest density average of white jabon (*Neolamarckia cadamba* Roxb. Bosser) wood 0.43 ± 0.004 $g.cm^{-3}$ was produced from Cianjur, and the lowest density average of 0.29 ± 0.010 $g.cm^{-3}$ was from Tanjungsari Sumedang.
2. The highest modulus of rupture (MOR) average 641 ± 40 $kg.cm^{-2}$ was produced from Cianjur and the lowest density average of 361 ± 41 $kg.cm^{-2}$ from Tasikmalaya.
3. The results of analysis of variance (ANOVA) show that density, MOR, and modulus of elasticity (MOE) were significantly different between locations. The highest average 58,910 ± 1,007 $kg.cm^{-2}$ in MOE was obtained from Tangerang, and the lowest 31,117 ± 2,410 $kg.cm^{-2}$ was from Tasikmalaya. In general, white jabon (*Neolamarckia cadamba* Roxb. Bosser) wood with high density has high MOR and MOE values as well.
4. The range of wood strength class of white jabon (*Neolamarckia cadamba* (Roxb.) Bosser) in West Java and Banten was class III to IV-V.
5. Due to high variations in wood characteristics, wood must be used with caution because not all wood is of the same quality. Before its use, it is better to know the specific characteristics, especially its density. Environmental factors, such as precipitation and altitude, affect the density of wood. Separately, rainfall has a low effect and a negative relationship to jabon wood density, while altitude has a high influence and a negative relationship to jabon wood density. Andosol soil types tend to produce low wood density of wood.

REFERENCES CITED

Abdulah, L., Mindawati, N., Kosasih, A. S., and Darwo. (2013). "Early growth evaluation of *Neolamarckia cadamba* Roxb at private forest (in Indonesian)," *Jurnal Penelitian Hutan Tanaman* 10(3, September 2013), 119-128. DOI: 10.20886/jpht.2013.10.3.119-127

BS 373 (1957). "Testing small clear specimens of timber," British Standard Institution, BSI, London, England.

Cienciala, E., Radek, R., Hana, S., Jan, A., Jiri, K., Iva, H., Petr, S., Filip O., Jan, T., and Goran, S. (2016). "Discerning environmental factors affecting current tree growth in Central Europe," *Science of The Total Environment* 573, 541-554. DOI: 10.1016/j.scitotenv.2016.08.115

CGIAR. (2020). "MarkSim DSSAT weather file generator," (http://gisweb.ciat.cgiar.org/marksimgcm/), Accessed 27 Feb 2020.

Coomes, D. A., and Allen, R. B. (2007). "Effects of size, competition and altitude on tree growth," *Journal of Ecology* 95(5), 1084-1097. DOI: 10.1111/j.1365-2745.2007.01280.x

Dias, A., Gaspar, M. J., Carvalho, A. *et al.* (2018). "Within- and between-tree variation of wood density components in *Pinus nigra* at six sites in Portugal," *Annals of Forest Science* 75, 58, 1-19. DOI: 10.1007/s13595-018-0734-6

FAO (2009). *Harmonized World Soil Database*, version 1.1, FAO, Rome, Italy, and IIASA, Laxenburg, Austria.

Fitter, A. H., and Hay, R. K. (1987). *Environmental Physiology of Plants*, Academic Press, Harcourt Brace Javanovich, London, England.

Fritts, H. C. (1976). *Tree Ring and Climate*, Academic Press, New York, NY, USA.

Gindl, W., Teischinger, A., Schwann Inger, M., and Hinterstoisser, B. (2001). "The relationship between near infrared spectra of radial wood surfaces and wood mechanical properties," *Journal of Near Infrared Spectroscopy*. 9, 255-261. DOI: 10.1255/jnirs.311

Hadi, Y. S., Rahayu, I. S., and Danu, S. (2013). "Physical and mechanical properties of methyl methacrylate impregnated jabon wood," *Journal of the Indian Academy of Wood Science* 10(2), 77-80. DOI: 10.1007/s13196-013-0098-3

Izekor, D. N., Fuwape, J. A., and Oluyege, A. O. (2010). "Effects of density on variations in the mechanical properties of plantation grown *Tectona grandis* wood," *Archives of Applied Science Research*, 2(6), 113-120.

Junaedi, A., Mindawati, N., and Rochmayanto, Y. (2021). "Early growth of jabon (*Anthocephalus cadamba* Miq) in a drained peatland of Pelalawan, Riau," *Indonesian Journal of Forestry Research* Vol. 8 No. 1, April 2021, 59-72. DOI: 10.20886/ijfr.2021.8.1.59-72

Keleş, Ö. S. (2020). "The effect of altitude on the growth and development of trojan fir (*Abies nordmanniana* subsp. *equi-trojani* [Asch. & Sint. ex Boiss] Coode & Cullen) Saplings," *Cerne 26*, 381-392. DOI: 10.1590/01047760202026032734

Kiaei, M., and Samariha, A. (2011). "Relationship between altitude index and wood properties of *Pinus eldarica* Medw (case study in North of Iran)," *Gazi University Journal of Science* 24(4), 911-918.

Krisnawati, H., Kallio, M., and dan Kanninen, M. (2011). *Anthocephalus cadamba Miq*.: *Ekology, Silviculture dan Productivity*, Center for International Forestry Research (CIFOR), Bogor, Indonesia.

Lestari, A. S. R. D., Hadi, Y. S., Hermawan, D., and Santoso, A. (2018). "Physical and mechanical properties of glued laminated lumber of pine (*Pinus merkusii*) and jabon (*Anthocephalus cadamba*)," *Journal of The Korean Wood Science and Technology* 46(2), 143-148. DOI: 10.5658/WOOD.2018.46.2.143

Martawijaya, A., Kartasujana, I., Kadir, K., and Prawira, S. A. (1981). *Indonesian Wood Atlas Volume I*, Forest Products Research Institute, Bogor, Indonesia.

Martawijaya, A., Kartasujana, I., Mandang,Y. I., Kadir, K., and Prawira, S. A. (1989). *Indonesian Wood Atlas Volume II*, Forest Products Research Institute, Bogor, Indonesia.

Mindawati, N., Mansur, I., and Setio, P. (2015). *Breeding and Seeding Technology White Jabon (Neolamarckia Cadamba (Roxb.) Bosser*), Forda Press, Bogor Indonesia.

Msanya, B. M., Kaaya, A. K., Araki, S., Otsuka, H., and Nyadzi, G. I. (2003). "Pedological characteristics, general fertility and classification of some benchmark soils of Morogoro District, Tanzania," *African Journal of Science and Technology* 4(2), 101-112. DOI: 10.4314/ajst.v4i2.15309

Nakai, K., Ishizuka, M., Timothy, S. O. J., Jasper, M., Lyatura, N. M., Shau, V., and Yoshimura, T. (2019). "Environmental factors and wood qualities of African blackwood, *Dalbergia melanoxylon*, in Tanzanian Miombo natural forest," *Journal of Wood Science* 65, article 39. DOI: 10.1186/s10086-019-1818-0

Nicholls, J. W. P., and Wright, J. P. (2011). “The effect of environmental factors on wood characteristics, 3. The influence of climate and site on young *Pinus radiata* material,” *Canadian Journal of Forest Research* 6(1), 13-121. DOI: 10.1139/x76-014

Rahman, W. M. N. W. A., Yunus, N. Y. M., Kasim, J., and Tamat, N. S. M. (2018). "Effects of tree portion and radial position on physical and chemical properties of Kelampayan (*Neolamarckia cadamba*) wood," *BioResources* 13(2), 4536-4549. DOI: 10.15376/biores.13.2.4536-4549

Ramananantoandro, T., Ramanakoto, M. F., Rajoelison, G. L., Randriamboavonjy, J. C., and Rafidimanantsoa, H. P. (2016). “Influence of tree species, tree diameter and soil types on wood density and its radial variation in a mid-altitude rainforest in Madagascar,” *Annals of Forest Science* 73, 1113-1124. DOI: 10.1007/s13595-016-0576-z

Russo, D., Marziliano, P. A., Macrì, G., Zimbalatti, G., Tognetti, R., and Lombardi, F. (2020). “Tree growth and wood quality in pure *vs.* mixed-species stands of European beech and Calabrian pine in Mediterranean mountain forests,” *Forests* 11(1), article 6. DOI: 10.3390/f"11010006

Suhaya, Y., Akyas, A. M., Supriatun, T., and Wahyudi, I. (2015). “Variation of Surian woods *(Toona sinensis* Roem.*)* characteristics in West Java, Indonesia (1WP-O01),” in: *Proceeding of IAWPS 2015 International Symposium on Wood Science and Technology*, Tokyo, Japan, pp. 35-40.

Wahyudi. (2012). “Growth and yield analysis of jabon plantation (*Anthocephallus cadamba*) (in Indonesian),” *Jurnal Perennial* 8(1), 19-24. DOI: 10.24259/perennial.v8i1.210

Wardle, J. (1984). *The New Zealand Beeches: Ecology, Utilisation and Management*. New Zealand Forest Service, New Zealand.

Zhang, S., Belien, E., Ren, H., Rossi, S., and Huang, J. G. (2020). “Wood anatomy of boreal species in a warming world: A review,” *iForest* 13, 130-138. DOI: 10.3832/ifor3230-013 (Online 2020-04-09)

Zhang, Z., Papaik, M. J., Wang, X.-G., Hao, Z.-Q., Ye, J., Lin, F., and Yuan, Z.-Q. (2017). “The effect of tree size, neighborhood competition and environment on tree growth in an old-growth temperate forest,” *Journal of Plant Ecology* 10(6), 970-980. DOI: 10.1093/jpe/rtw126

Zhou, Y., Lei, Z., Zhou, F., Han, Y., Yu, D., and Zhang, Y. (2019). “Impact of climate factors on height growth of *Pinus sylvestris* var. *mongolica*,” *PLoS One* 14(3), Article ID e0213509. DOI: 10.1371/journal.pone.0213509

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