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Intra-tree variability and quality of small-diameter trees from Ivorian secondary forests: The case of Mansonia altissima

Thomas Digbe*[1]*, B.F. Niamké*[1]*, B.A. Bley-Atse*[1]*, J.L.L. N'GUESSAN*[1]*, F. Adjé*[1]*, N.J.C. Yao*[1]*, D.K. René*[1]*, A.N. Armand*[2]*,
***A. Kouabenan*[3]*, T. Fabrice*[4]*, A.A. Augustin*[1]*, and N. Amussant*[5]**

[1]Institut national polytechnique Félix Houphouët-Boigny (INP-HB), Laboratoire des Procédés Industriels de Synthèse de l'Environnement et des Energie Nouvelles (LAPISEN), BP 1313 Yamoussoukro, Côte d'Ivoire

[2]Institut national polytechnique Félix Houphouët-Boigny (INP-HB), laboratoire de zoologie et d'entomologie agricole, Côte d'Ivoire

[3]Institut National Polytechnique Félix Houphouët Boigny, DFR Agriculture et Ressources Animales, Laboratoire de Phytopathologie et de Biologie Végétale, BP 1313, Yamoussoukro, Côte d'Ivoire

[4]Société de Développement Des Forêts, Abidjan, Côte d'Ivoire

[5]Centre de coopération internationale en recherche agronomique pour le développement (CIRAD), Ecologie des forêts de Guyane (ECOFOG), Guyane, France

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ABSTRACT: In Côte d'Ivoire, the rapid disappearance of the natural forest has led the forestry industry to procure small-diameter wood, mainly from secondary forests, whose properties are little known. In order to contribute to a better management of Ivorian forest species, this work aimed to analyze the properties (density and monnin hardness) of Bété, Mansonia altissima (A.Chev.), an emblematic species in Côte d'Ivoire. Density of wood and monnin hardness were determined under standards NF B51-005 and NF B51-013 respectively. Statistical analysis showed that Bété has a density of 681.8 ± SD kg/m3 and a monnin hardness of 3.77. These characteristics indicate that small-diameter wood from secondary forests can be used appropriately for a wide range of applications, just like wood from natural forests.

KEYWORDS: Wood density, monnin hardness, small-diameter wood, Mansonia altissima, secondary forest.

1 INTRODUCTION

Côte d'Ivoire is confronted with a crisis in the wood sector. This crisis is reflected in a limited supply of wood resources, which represents a serious problem for the forest-wood industry [1]. In recent years, to respond to the increasing needs of the wood industry, minimum exploitable diameters (MED) were revised downwards in 2006, following technical work carried out by the Direction de la Production et des Industries Forestières and discussed with the various syndicates' of economic operators in the forestry sector [2], then in 2018, 12 years later, another revision of standards for logging aimed at lowering minimum exploitable diameters was proposed, but the results could not be presented to the Council of Ministers due to fierce opposition from donors [3]. For them, the application of these results would promote ecological degradation of the forest. However, this trend of reductions in minimum exploitable diameters will certainly continue and gain momentum in the years to come. Yet less attention is being paid to the quality of small-diameter wood, which represents the most essential part of Côte d'Ivoire's forest resources. Indeed, the reduction in MED combined with difficult growing conditions (different from those in natural forests, due to soil degradation and decreased rainfall) can affect wood quality [4]. Soil degradation and decreased rainfall can also lead to intra-tree variability [5]. Thus, in the context of resource depletion, the new understanding of different tree tissues could increase the rational use of wood and reduce pressure on forest species, promoting the replenishment of forest stocks and thus maintaining the role of the forest in the country's economy. Due to the positive correlation between it and other physico-mechanical characteristics, wood density is an indicator frequently used to determine wood quality, in the case of species intended for high-value uses [6]. Also, monnin hardness is a particularly important property to know when woods are used for flooring (parquet, flooring and decking), but also for any other use in which the wood is subjected to knocking or punching [6]. In the light of the previously mentioned, the aim of this study is to investigate the intra-tree variability of the monnin hardness and density of small-diameter wood of Mansonia altissima (Bété wood).

2 MATERIALS AND METHODS

2.1 DESCRIPTION OF THE STUDY AREA

The classified forest of Besso, our study area, is located in the administrative region of Mé in south-eastern Côte d'Ivoire (6°10' and 6° 30' North, 3° 35' and 3° 50' West) (figure 1). The choice of this study area was based on the characteristics of the forest (in line with the objectives of the study). Indeed, the classified forest of Besso is a secondary forest in full regeneration [7]. It is located at the top of the interfluves between the watersheds of the Comoé, Agnéby and Mé rivers, in a landscape of flat plateaus interspersed with broad, flat-bottomed valleys. Altitudes range from 110 to 209 m, with an average of 150 m [7]. Soils are medium to highly desaturated ferralitic. The climate of the forest is hot and humid, sub-equatorial, with four seasons (a long rainy season from April to June; a short dry season from July to August; a short rainy season from September to October, and a long dry season from November to March) [8]. Average annual rainfall varies between 1,350 and 1,400 mm. The average annual temperature is 26.5°C. In terms of botany, the forest belongs to the mesophilic sector of the Guinean domain, characterized by semi-deciduous dense rainforest [8].

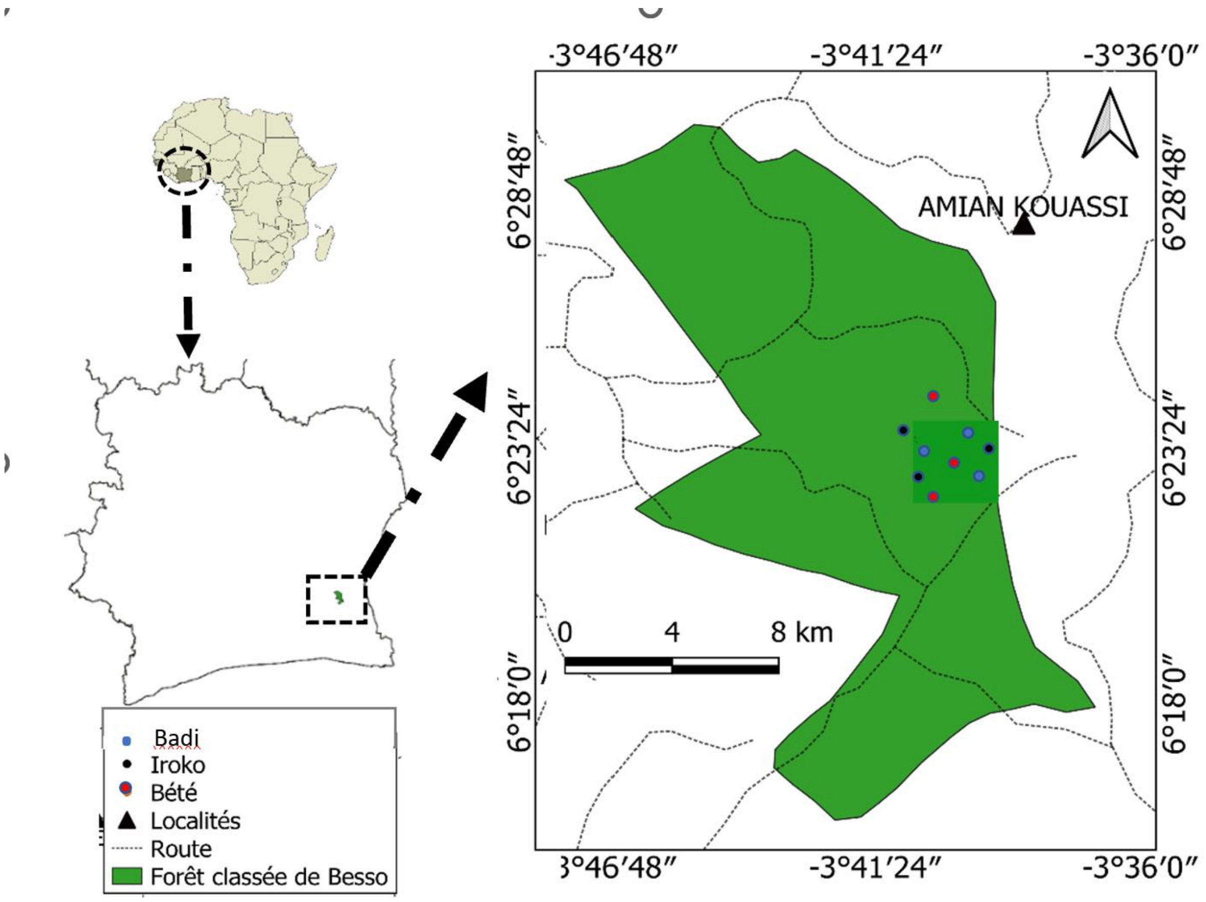

Fig. 1. Map of the classified forest of Besso

2.2 SELECTION AND COLLECTION OF PLANT MATERIAL

In order to avoid heterogeneity due to defects in tree conformation or health, only trees with straight trunks, high forks and no signs of disease were selected and then cut down. The dendrometric characteristics and geographical coordinates of the plants studied are given in Table 1.

Table 1. Measured dendrometric characteristics and geographical coordinates of the trees studied

Species	Diameter in cm	Height in m	Geographic coordinates	
			X (m)	Y (m)
Bété arbre 1	50	15	427566	704960
Bété arbre 2	50	16	425950	704719
Bété arbre 3	50	16	427712	706842

After the trees had been felled in the field, a 1.3 m long, 4 cm thick log was taken from each tree, 1.3 m above ground level, and transferred to the sawmill. Once at the sawmill, a 4 cm-high central plank was cut from each log, then cut into two equal lengths, first radially, then longitudinally, giving 4 half-planks (figure 2). After cutting, the boards were sent to CIRAD's BioWooEB research unit in Montpellier for physical-mechanical testing.

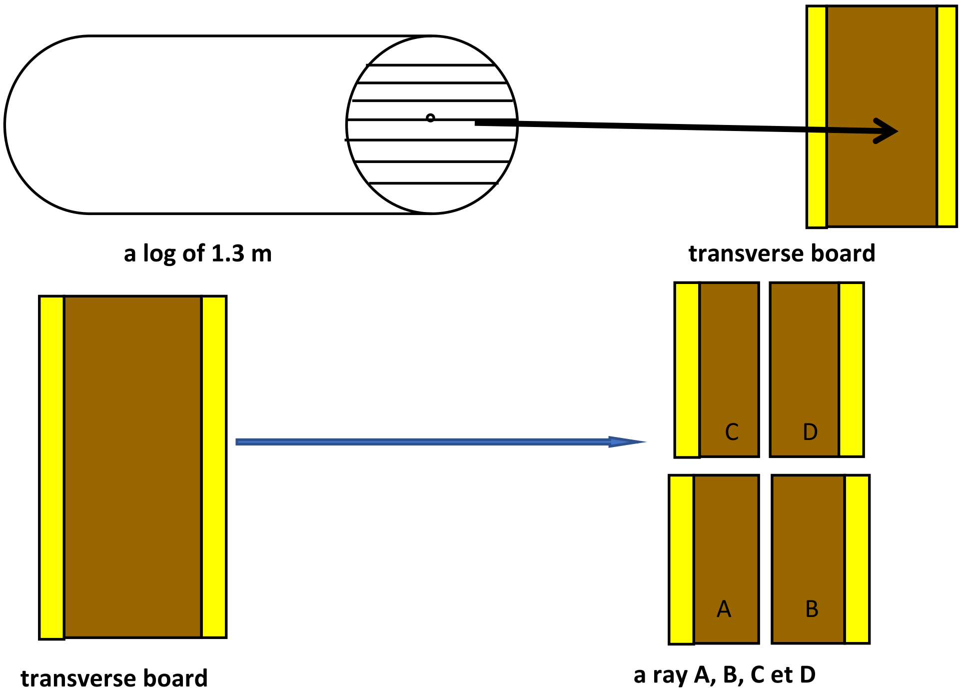

Fig. 2. Sampling design for plots

2.3 PREPARATION OF TEST SPECIMENS

At CIRAD Montpellier, the sample wood boards were first placed in a climatic chamber set at 20 ± 2°C and 65 ± 5% relative humidity, for 3 weeks to reduce the wood humidity to 12%. The cross-sections of the trays were marked to identify the position of the specimen blanks intended for testing. Marking was carried out in such a way as to respect the correct orientation of the specimen cross-sections in both radial and tangential directions (figure 3). The study of intra-tree variability in mechanical and physical properties was carried out from the bark to the pith, taking into account 4 radial positions: sapwood, outer heartwood, middle heartwood and inner heartwood. The blanks were then cut at these 4 radial positions and stored at 20 ± 2°C and 65 ± 5% relative humidity for 3 weeks. These conditions ensured a wood moisture content of around 12% (reference moisture content for physical and mechanical analyses).

After this stabilization period, a 20 x 20mm oriented bar (2 tangential faces, 2 radial faces) was taken from each blank (Figure 3). Each bar was cut to produce test specimens of dimensions 20 x 20 x 100 mm3, L, R, T. Once machined (Fig. 3), the specimens were sanded with sandpaper to ensure that the surface was free of irregularities. 96 specimens (4 radial positions x 3 shafts x 2 boards x 4 specimens) were used.

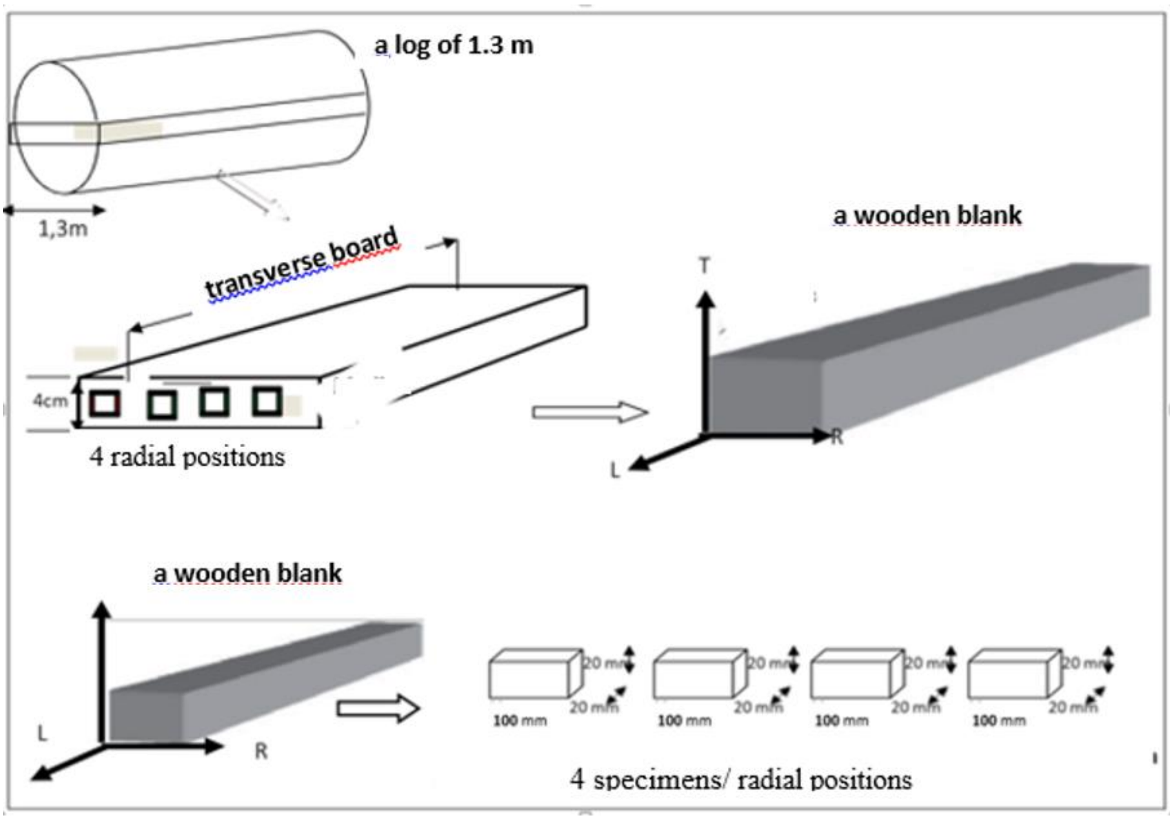

Fig. 3. Specimen sampling schedule

2.4 MEASUREMENT OF WOOD DENSITY AT 12% MOISTURE CONTENT

The nominal density of the wood, expressed in kg/m3, was determined on each test specimen in accordance with standard NF B 51-005. In addition, for each test specimen, the density (D) was obtained by calculating the ratio between the mass of the specimen at 12% moisture content (M12) and its volume at 12% moisture content (V12) according to the following equation:

D12 = M12/V12

where M12 = specimen mass at 12% moisture and V12 = volume at 12% moisture.

The mass of each test specimen was determined using a 0.01 g precision balance, and the dimensions (length, width and thickness) used to calculate its volume were measured using an electronic caliper accurate to 0.01 mm.

2.5 MONNIN HARDNESS MEASUREMENT

Monnin hardness is measured in accordance with French standard NF B51-013 (AFNOR, 1988). In order to do this, the penetration resistance of a metal cylinder of a given radius on the radial face of the wood is determined (applied along a generatrix, under a continuous force up to the maximum load of 1960N). A sheet of carbon paper interposed between the cylinder and the test piece provides a visible imprint, corresponding to the penetration of the cylinder on the radial face of the test piece (Figure 4). For each specimen, the deflection t, in mm, is calculated according to the following formula:

$t = 15 - 1/2 \sqrt{((900) - a^2)}$ where a is the width of the indentation, in mm

Monnin hardness N is equal to the inverse of penetration deflection. N = 1/t

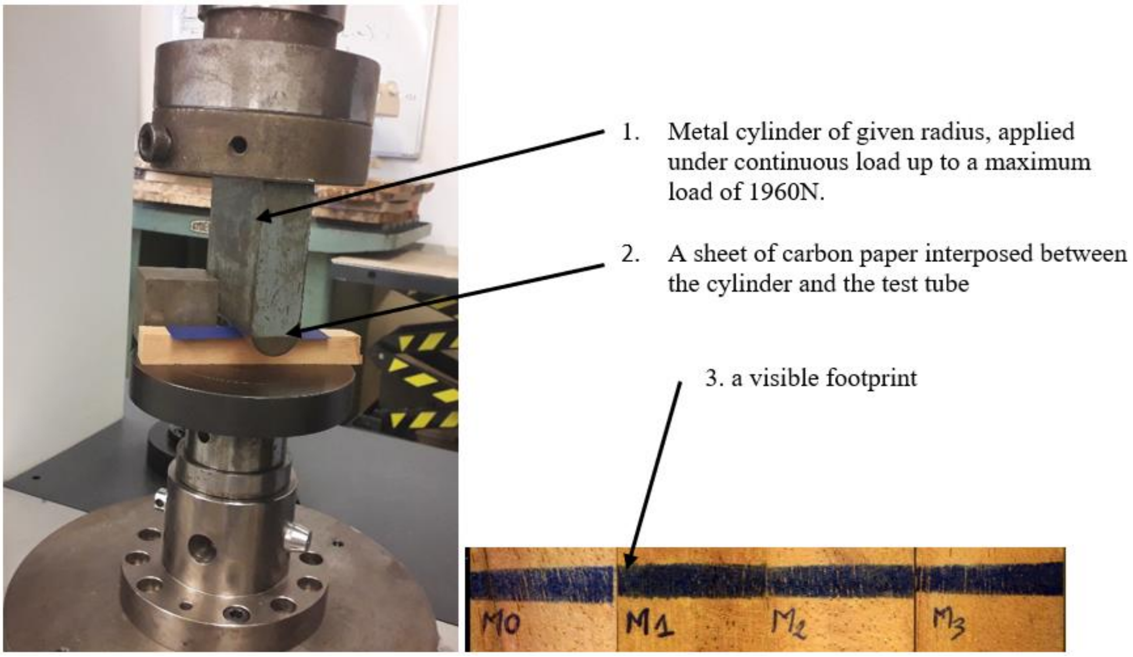

Fig. 4. Monnin hardness test in accordance with the standard NF B51-013

3 RESULTS AND DISCUSSION

3.1 WOOD DENSITY

The results of the statistical analysis show that Bété has a density of 681.8 kg/m3, which is in line with the findings of [9], [10]. Based on these observations, Bété can be considered as a medium-heavy wood, with reference to the wood qualification grid proposed in the Tropical Wood Atlas [9]. Indeed, medium-heavy woods cover densities between 650 kg/m3 and 800 kg/m3.

In this work, taking into account the variation in wood density from the pith to the bark enabled a finer characterization of the variation of this property within the tree. This approach can facilitate the study of the effects of climate variation, known to affect wood characteristics [11]. According to these authors, the radial variation in density of tropical species is linked to a mechanism of adaptation to environmental conditions, where the tree modifies its growth according to the seasons and available resources. In the present study, analysis of wood density from pith to bark shows similar patterns of variation. In fact, no significant variation at the 5% confidence level (p = 0.09) was observed between the different tissues of the tree (inner heartwood, intermediate heartwood, outer heartwood and sapwood). Furthermore, in terms of classification, the different tree tissues all belong to the same density class (mid-hardwood) (Table 2). This homogeneity of wood density is not only a desired characteristic for the industry, but is also an indicator of the trees' resistance to environmental stresses such as drought episodes. Moreover, during its development, the tree is subjected to various constraints linked to its environment [12]. In response to these constraints, the functional performance of wood is adjusted by property variations [12]. However, intra-tree variability in wood mechanical properties could be associated with the genetic and/or heliophilic character of trees. Indeed, a study by [12] showed that the physical and mechanical properties of wood decrease from the bark towards the pith of the wood. This type of variation is considered a characteristic of heliophilic trees and is interpreted as an adaptation of the tree to a growth mode that initially favors significant height growth in the absence of rigid, dense wood [13]. Then, in a second phase, the latter favors the rigidification and perpetuation of the tree structure through the establishment of denser wood in the absence of lower height growth [13].

Table 2. Intra-tree variability of Bété wood density

Radial positions	Mean (kg/m³)	Density class
Sapwood	681,75 ± 102,58	semi-heavy
Outer heartwood	677,11 ± 86,90	semi-heavy
Middle heartwood	679,81 ± 108,72	semi-heavy
Inner heartwood	689,00 ± 106,88	semi-heavy

3.2 MONNIN HARDNESS

To study the mechanical properties of Bété, we used monnin hardness, one of the most important mechanical characteristics of wood. The results showed that the Monnin hardness of Bété is 3.77, which classifies it among medium-hard woods with reference to the wood qualification grid proposed in the Tropical Wood Atlas [9]. Indeed, hardwoods cover the hardness class between 3 and 6. The values obtained in this study are in line with those found in the literature [9]. Thus, this study attests to the fact that reducing the minimum exploitable diameter of Bété does not result in a loss of wood quality. A similar study focusing on tree age and carried out on plantation teak concluded that the quality of young trees (13 to 21 years old) were not necessarily inferior to those observed in older trees (55 to 65 years old) and that reducing the rotation age of fast-growing teak was without risk (Hounlonon et al., 2017). Another study carried out on the mechanical properties of teak wood from fast-growing plantations of different ages showed that density, modulus of rupture, modulus of elasticity and natural durability were essentially the same [14].

Table 3 shows the mean values obtained for the 4 radial positions (inner heartwood, middle heartwood, outer heartwood and sapwood). The pattern of variation in hardness is similar to that of density. Indeed, no significant variation at the 5% confidence level (p = 0.12) was observed between the different tree tissues (inner, intermediate and outer heartwood and sapwood).

Table 3. Intra-tree variability in beech heartwood hardness

Radial positions	Mean	monnin hardness Class
Sapwood	3,832 ± 0,752	Semi-hard
Outer heartwood	3,763 ± 0,708	Semi-hard
Middle heartwood	3,856 ± 0,772	Semi-hard
Inner heartwood	3,746 ± 0,762	Semi-hard

3.3 RELATIONSHIP BETWEEN DENSITY AND MONNIN HARDNESS

The aim of this section was to predict wood quality (monnin hardness) on the basis of density, an easily measurable indicator. Figure 5 shows a close relationship between density and monnin hardness. The study revealed that density and Monnin hardness were positively correlated, with a coefficient of determination of 0.74 (P = 0.0001). It is therefore possible to predict the monnin hardness of wood from its density. Similar results were obtained [6] on Pterocarpus erinaceus. The study of relationships between wood properties also makes it possible to identify some characteristics whose determination in the laboratory can be relatively laborious and require substantial equipment, but which can be estimated with sufficient reliability from basic properties obtained quickly in routine testing, such as wood density.

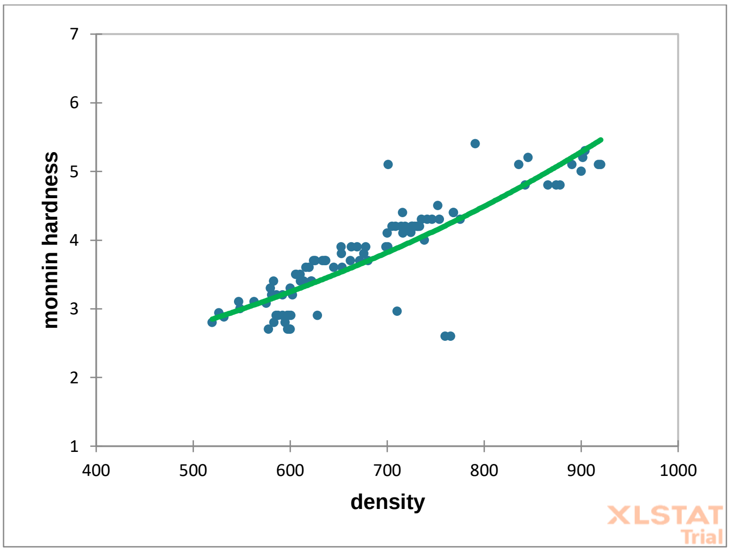

Fig. 5. Correlations between density and monnin hardness of Bété wood

4 CONCLUSION

The aim of this study was to investigate the intra-tree variability of the mechanical and physical properties (hardness and density) of Mansonia altissima wood, whose diameters fluctuate around the EMD. The mechanical and physical properties of Bete were studied using small-diameter trees from secondary forests. The results obtained for the density and monnin hardness classify Bété as a wood with average physical and mechanical characteristics. In view of these results, we can conclude that small-diameter wood (diameter fluctuating around the minimum exploitable diameter) can be reserved for the same uses as large-diameter wood. However, as the results were obtained on a small number of samples (3 trees/species), it is important to validate the initial conclusions of this work on a larger sample.

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