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Research paper

Physical, mechanical and acoustic characteristics of *Anogeissus leiocarpus, Manilkara multinervis* and *Cylicodiscus gabunensis* woods marketed in Benin in west Africa

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Abstract

Wood is a material used in construction, in instrument making, etc. In Benin, for heavy construction and construction on wetland, species with high technological characteristics are imported. But the performance of these imported species compared to local indigenous or exotic species remains to be verified. Thus, it is necessary to determine the basic technological properties of these species. It is within this framework that we have, on 500mm×20mm×20mm prismatic wood specimens of *Anogeissus leiocarpus, Manilkara multinervis and Cylicodiscus gabunensis*, used the acoustic method BING (Beam Identification by Non-destructive Grading) of CIRAD-Forêt to determine the density ρ, the moduli of Young's modulus E, shear modulus G and the internal friction tanδ and then evaluated the modulus of specific stiffness E/ρ. On other 20 mm edge cubic specimens, we evaluated the reference physical properties of density, infradensity, total shrinkage, radial shrinkage, tangential shrinkage and shrinkage anisotropy. It appears that the wood of *A. leiocarpus and M. multinervis* present better physico-mechanical characteristics than those of *C. gabunensis. A. leiocarpus* and *M. multinervis* are very dense woods with physico-mechanical characteristics better than those of most Benin's popular species. The average modulus of elasticity in bending of these two species is higher than 12000 MPa while that of *C. gabunensis* is 10713 MPa. In compression all these species have an average modulus of elasticity above 14100 MPa. *C. gabunensis* wood tested is light with a lower shrinkage anisotropy than the other two species studied and have excellent acoustic properties. Its average specific stiffness (14 GPa) is higher than that of the other two species studied (12 GPa). The good physical-mechanical and acoustic properties of these species show that they are good structural timbers with good potential for instrument making and acoustic insulation.

Keywords: *BING; Construction; Infradensity; Modulus of Elasticity; Shrinkage Anisotropy; Timber.*

1. Introduction

The multifunctionality of wood makes it a widely used material. In Benin, despite the exploitation of highly valued exotic and indigenous species, some locally available wood species are imported. Among the locally available wood species, some are beginning to be controlled, since the government measures aimed at restricting the marketing of certain threatened or overexploited local species [1]. This is the case for *Anogeissus leiocarpus*. Another species such as *Manilkara multinervis*, although existing according to the analytical flora of Benin [2], remains little known locally by timber professionals who import it. In addition to these two species of wood, a third is imported from Ghana and Nigeria, namely Cylicodiscus gabunensis. The fundamental reason for importing these species is that they have good technological aptitudes for heavy constructions with high stress and constructions in humid environments or in contact with the ground.
A. leiocarpus is a well-known forest species and is one of the most highly prized and commercialized wood species. It is a characteristic species of dense dry forests whose tree can reach 30 meters high; it is known in the local Fon language in Benin as hlihon or hili haye, in Yoruba/Nago: anyi ma, ayin [2]. *A. leiocarpus* is one of the wood species regularly exported from Benin. The export volume in 2018 is 32.5 m^3; 186.72 m^3 in 2017; 189.37 m^3 in 2016 and 1037 m^3 in 2015 against 1186.99 m^3 in 2013 [1]. In Ghana, it is known by the commercial name Kane.

Manilkara spp. is a species found in swampy areas. It is a food and medicinal species. Its wood is highly prized in carpentry and is used as framework in the realization of anti-noise wall, as framing wood in cabinet making and in the confection of floor. In Benin, three types of *Manilkara* are found: *Manilkara multinervis* (Baker ex Oliv.) Dubard, *Manilkara obovata* (Sabine & G.Don) J. H. Hemsl. and *Manilkara zapota* (L.) P. Royen producing a much appreciated fruit, wood and latex [2]. In Benin, *M. multinervis* occurs in riparian forests [3]. The wood of *M. multinervis*, imported from Ghana to Benin, is known in trade as Berekankum.

C. gabunensis is a little exploited commercial species but quite present in Ghana and Nigeria [4-8]. *C. gabunensis*, also known as Okan, Denya and African green heart is a large tree native to tropical rainforests that can grow up to 60 m tall with a straight bole up to 24 m [9]. It is a wood whose sapwood color differs from that of the heartwood. The sapwood is light yellow, brighter than the heartwood which has a brown color [9]. This species is not described in the analytical flora of Benin and is not exploited in Benin [1]. Its wood is found in commerce under the name Denya or Okan depending on whether it is imported from Ghana or Nigeria.

In order to better benchmark Benin's wood species against these species, we physically and mechanically tested the wood species of *A. leiocarpus, M. multinervis* and *C. gabunensis* imported and marketed in Benin.

The objective of this work is therefore to evaluate the physical-mechanical and acoustic characteristics of these species in order to have a basis for assessing their good technological abilities.

The main characteristics determined are density, infradensity, total shrinkage, radial shrinkage, tangential shrinkage, shrinkage anisotropy, modulus of elasticity in compression, modulus of elasticity in bending, shear modulus, specific stiffness and internal friction.

2. Material and methods

The sample used consisted of 20 wood specimens of each of the species *A. leiocarpus, M. multinervis* and *C. gabunensis* purchased in Cotonou. Figure 1 shows some prismatic specimens of 2×2×50 cm cut for mechanical measurements. Cubic specimens of 2 cm edge length were also cut for the determination of physical characteristics (density and shrinkage) of the wood of these species.

The non-destructive mechanical characterization method using the BING (Beam Identification By Non-Destructive Grading) device of CIRAD-forest was used. Its principle was the subject of the work of [10]. It is based on the theory of beams and is based on the Bernoulli and Timoshenko models. It uses the frequency analysis of vibration signals by the Fast Fourier Transform (FFT) and is used in the work of Ahmed and Adamopoulos [11] and Hounlonon et al. [12, 13]. The parameters evaluated on the basis of BING data are among others the longitudinal elasticity modulus in compression and bending, the shear modulus, the internal friction and the specific rigidity modulus.

The determination of the physical parameters including shrinkage, density and infradensity or basal density followed the AFNOR standard as described by the forestry memento [14] and performed in works on standardized specimens without defects [13 ; 15-17].

The statistical results of the BING tests and calculations are presented in Table 1.

Fig. 1: Some Specimens of *M. multinervis* (Manilkara), *C. gabunensis* (DENYA) and *A. leiocarpus* (KANE) Wood Species.

3. Results and discussions

3.1. Physical-mechanical and acoustic properties of *A. leiocarpus, M. multinervis* and *C. gabunensis*

At the end of the tests carried out on each of the three species, we determined the average values and standard deviations of the physical, mechanical and acoustic parameters presented in Table 1.

From this table 1, *M. multinervis* (1002 kg.m^{-3}) has the highest anhydrous density followed by *A. leiocarpus* (890 kg.m^{-3}) and *C. gabunensis* (637 kg.m^{-3}). The observation remains the same for the flexural elasticity and shear moduli. The shrinkage anisotropy of *C. gabunensis* (1.21) is the lowest, followed by *A. leiocarpus* (1.89) and *M. multinervis* (2.63). *C. gabunensis*, with the highest specific stiffness (14 GPa) and lowest internal friction (1.03), has the best acoustic properties. The woods of *A. leiocarpus* and *M. multinervis* offer better physical and mechanical characteristics than those of *C. gabunensis* which, on the other hand, present good acoustic properties.

Table 1: Physical, Mechanical and Acoustic Properties of *A. leiocarpus, M. multinervis* and *C. gabunensis* Wood Species.

		Anogeissus leiocarpus	*Manilkara multinervis*	*Cylicodiscus gabunensis*
Density (kg.m^{-3})	m	1005	1040	760
	e	78	34	69
Anhydrous density (kg.m^{-3})	m	890	1002	637

	e	99	8	14
Infradensity (kg.m^{-3})	m	800	913	599
	e	89	7	13
Total volume shrinkage (%)	m	10.01	8.90	5.98
	e	1.12	0.53	0.36
Tangential shrinkage R_T (%)	m	6.80	5.50	3.46
	e	0.87	0.29	0.26
Radial shrinkage R_R (%)	m	3.63	3.39	2.91
	e	0.34	0.15	0.34
Shrinkage anisotropy R_T /R_R	m	1.89	2.63	1.21
	e	0.31	0.05	0.18
Modulus of elasticity in compression (MPa)	m	14924	14364	14181
	e	1643	1390	1058
Modulus of elasticity in bending (MPa)	m	12190	12615	10713
	e	1016	1919	2224
Shear modulus (MPa)	m	1425	3353	946
	e	333	1313	316
Specific modulus of elasticity (GPa or MPa.kg^{-1}.m^{3})	m	12	12	14
	e	1	2	2
Internal friction tanδ	m	1.18	1.20	1.03
	e	0.25	0.25	0.47

m: Mean e: Standard Deviation

3.2. The properties of the studied species with regard to Benin species and other species of high technological value

In the open air, all wood species are very heavy, due to their density, except for *C. gabunensis* which is medium-heavy. In the anhydrous state, *A. leiocarpus* wood is heavy to very heavy; *M. multinervis* wood is very heavy while *C. gabunensis* wood is light [15].
Tali (*Erythrophleum suaveolens* or *Erythrophleum ivorense*), with good characteristics for wet construction, has a density of 910 kg.m^{-3} and a longitudinal modulus of elasticity of 19490 MPa [6]. Referring to Tali, *A. leiocarpus* as well as *C. gabunensis* would be less dense while *M. multinervis* is more dense. In the same sense, species that are fairly widely used in Benin, such as *Afzelia africana* (800 kg.m^{-3} [6]), *Tectona grandis* (800 kg.m^{-3}, [18]) and *Acacia auriculiformis* (825 kg.m^{-3} [12]), have lower overall densities than *A. leiocarpus* and *M. multinervis*. *C. gabunensis*, on the other hand, has a very low density compared to these highly exploited woods.
Due to the close correlation between density and mechanical properties, especially the modulus of elasticity [15], these wood species have remarkable technological characteristics, sometimes exceeding those of highly prized woods such as *T. grandis*.
The infradensity of the three species, with the exception of *C. gabunensis*, is largely above that of *A. auriculiformis* which has values between 496 and 705 kg.m^{-3} [17]. Tests have been carried out on highly prized timber species such as *A. leiocarpus* and *Pseudocedrela kotschyi* exploited in North Benin [16]. From these works, the infradensities of *A. leiocarpus* and *P. kotschyi* are respectively 911.0 and 824.86 kg.m^{-3}. These values found, especially that of *A. leiocarpus*, although slightly higher than that of the same species in our study, have a certain similarity. This similarity is also found when comparing the values of these two previous species [16] to that of *M. multinervis*. Compared to other popular species in Benin, *M. multinervis* and *A. leiocarpus* are still of a certain nobility, as their infradensity is much higher than that of popular species like A. africana, Pterocarpus erinaceus, Khaya senegalensis, Milicia excelsa, Gmelina arborea, *Diospyros mespiliformis*, *T. grandis*, *Isoberlinia doka* whose infradensities vary from 560.29 to 795.02 kg.m^{-3} [16]. The infradensity of *C. gabunensis* is in the range of that of *D. mespiliformis*, *T. grandis*, *I. doka* [16].
A very little known species, very little exploited as *Mimusops andongensis*, presents good characteristics [13]. *M. andongensis* wood has a modulus of (18470 ± 1828) MPa [13] higher than those of the three species studied with an average modulus lower than 15000 MPa. All these species are less rigid than *D. mespiliformis* (African ebony) whose heavy wood has a high modulus of (15500 ± 3500) MPa [6] and 17680 to 239200 MPa [19]. The famous pernambuco wood (*Caesalpinia echinata*) with its density of 1000 to 1019 kg.m^{-3} and its modulus of elasticity of 18619 to 28995 MPa [20] is stiffer than the three studied species. However, *A. leiocarpus* and *M. multinervis* have similar densities. The shear modulus of the three species studied remains low compared to that of *M. andongensis* [13].
Acoustically, all the species, the subject of our study, have a higher damping coefficient than *M. andongensis* and *D. mespiliformis* whose tanδ internal friction values are less than 10^{-2} [13]. *M. multinervis* and *A. leiocarpus* have an average specific stiffness of about 12 GPa while *C. gabunensis* has an average specific modulus of elasticity of about 14 GPa. *M. andongensis* has a specific stiffness of (18 ± 1) GPa [13], higher than that of the species studied and that of African ebony. African ebony has a stiffness of 17 GPa and an internal friction of 0.81 10^{-2} [6].
M. multinervis and *C. gabunensis* have low volume shrinkage of less than 9 % while *M. andongensis* has an average volume shrinkage of less than 13 % [13] as does *A. leiocarpus*. In terms of tangential deformations, the behavior of M. multinervis and C. gabunensis is similar to that of *M. andongensis* [13], which has a low shrinkage of less than 6.5 % lower than the average shrinkage of *A. leiocarpus* wood. For the radial linear shrinkage count, *M. multinervis* lower than the average shrinkage of *M. andongensis* [13] higher than those of *M. multinervis*, *A. leiocarpus* and *C. gabunensis* wood whose low shrinkage is less than 3.8 %. In our study, *A. leiocarpus* has a volume shrinkage of 10.01 % almost equal to that of *M. andongensis* [13] and higher than the volume shrinkage of *M. multinervis* (8.90 %) and *C. gabunensis* (5.98 %). The deformation propensity reflected by the shrinkage anisotropy of *C. gabunensis* is similar to that of *M. andongensis* [13] and lower than that of *A. leiocarpus* and *M. multinervis*.

3.3. The properties of the studied species in comparison with those of the species of the same species in the literature

A. leiocarpus is a highly exploited species and is among the most exported wood species in Benin [1]. The study carried out in North Benin on this species found an infradensity of (911 ± 11) kg.m^{-3}, a shrinkage anisotropy of (1.26 ± 0.04), transverse linear shrinkages of (6.57 ± 0.14) % on the tangential plane, (6.18 ± 0.12) % on the radial plane and (14.71 ± 0.25) % as a volume shrinkage [16]. In Nigeria, in 2021, a study found for the same wood species a density of (1150 ± 50) kg.m^{-3}, a volume shrinkage of (9.17 ± 3.64) % and a modulus of elasticity of (17512 ± 8009) MPa [21]. In Sudan, *A. leiocarpus* has an anhydrous density of 861.0 kg.m^{-3}, an infradensity of 777.0 kg.m^{-3}, radial linear shrinkage 3.72 % of and tangential shrinkage of 8.23 % for a shrinkage anisotropy of 2.20 with an elastic modulus of 14,295.02 MPa [22]. A study conducted in 2018, on the same species, found a density of 1150 kg.m^{-3} and a modulus of elasticity of 10117 MPa [23]. In our present work, the infradensity found is (800 ± 89) kg.m^{-3}, density is (890 ± 99) kg.m^{-3}, modulus of elasticity is

(12190 ± 1016) MPa, tangential linear shrinkages of (6.80 ± 0.87) radial of (3.63 ± 0.34) %, volume shrinkage of (10.01 ± 1.12) % for a shrinkage anisotropy of (1.89 ± 0.31). These results show that the shrinkage of the tested wood is lower in all aspects than the wood of the same native Beninese species tested in 2013 [16] with similar volume shrinkage to the Nigerian study of 2021 [21] except that the shrinkage anisotropy is higher than in the 2013 Beninese work [16]. With its overall average shrinkage, this wood has a stiffness of the same order as the Nigerian wood of the same species from 2018 [23] and lower than the Nigerian wood from 2021 [21]. With the range of variation in our values, the physical-mechanical parameters evaluated in our work are similar to those found in Sudan [22]. Beyond these considerations, *A. leiocarpus* remains, due to its characteristics, a dense wood with good mechanical characteristics very useful in structural works, in the manufacture of furniture as well as in the construction of floorings as already concluded in the Sudanese works [22].

M. multinervis remains very absent from the literature on technological properties. The only works on the species concern its natural resistance to insects [24; 25]. Thus we referred to other types of *Manilkara* treated in the literature. *Manilkara* spp. has a Young's modulus of (17271 ± 2253) MPa and a shear modulus of (254 ± 85) MPa [26]; a density of 1058 to 1140 kg.m^{-3}, a modulus of 16758 to 25650 MPa [20]; a density of 900 to 1150 kg.m^{-3} [27]. *Manilkara huberi* wood, used in guitar making in Brazil, has a modulus of elasticity of 10800 to 19600 MPa and a density ranging from 870 to 950 kg.m^{-3} [28]. In our study, *M. multinervis* has a density of (1002 ± 8) kg.m^{-3} and a modulus of elasticity of (12615 ± 1919) MPa. This species is therefore dense in the range of the famous pernambuco wood (*Caesalpinia echinata*) and ebony. Referring to the properties of ebony wood used in the manufacture of the guitar [19] or the properties of pernambuco wood (*C. echinata*) used in the manufacture of bows of stringed instruments [20] and taking into account its properties, *M. multinervis* can be, with adequate sizing, used in structural works as in the manufacture of musical instruments. Information on these other physical properties is not available in the literature. However, its low transverse linear and volume shrinkage presages a very good dimensional stability predisposing it to various uses including exterior construction, sleepers, flooring (heavy floor construction), shipbuilding and marine works [4 ; 6], due to its good natural durability. Its good characteristics have certainly been noted by the inhabitants of the lake villages of Benin who have adopted it in the construction of pilings.

C. gabunensis presents characteristics below the values of Hédin [29] who, on a semi-dry wood, found a density of 1100 kg.m^{-3}; of the Tropix 7 database of Cirad-Forêt which has a density at 12% humidity of 910 ± 100 kg.m^{-3} [6] and of the 950 kg.m^{-3} found in Ghana [4]. The open air densities of the sapwood and heartwood range from 770-890 kg.m^{-3} and 1160-1230 kg.m^{-3} respectively [9]. Compared to Tropix 7 values, wood from this species also has low transverse linear shrinkages with a shrinkage anisotropy of (1.21 ± 0.18) which is still lower than the 1.4 of Tropix 7 [6]. However, the volume shrinkage coefficient of our study (5.98 ± 0.36) % is much higher than the volume shrinkage of (0.61 ± 0.10) % of Tropix 7 [6] for the same species. The same is true for the mechanical parameters, where Tropix 7 found a modulus of elasticity of (22260 ± 3348) MPa [6]. In Ghana, a modulus of elasticity of 16600 MPa was found [4] while in our study we found a value of (10713 ± 2224) MPa. The large difference in values found for this species can be explained by the age of the tree or by other parameters such as the ecology or heredity of the tree [30] or by the difference in measurement techniques. *C. gabunensis* is a wood species used in construction in Benin [29] and can also be used in hydraulic works in the maritime environment, in sculpture, in heavy carpentry, as a crossbeam, in the construction of bridges, as posts, parquet and flooring or in the manufacture of turned articles [6]. It is a wood recommended for flooring in intensive use such as factories and warehouses [9]. Thus, imported from tropical Africa, the wood of *C. gabunensis*, is increasingly used, in South Korea, for terraces and wooden floors [9]. *C. gabunensis* is a moderately to poorly stable wood species [4; 6].

The acoustic properties of these species coupled with their shrinkability predispose the three wood species tested to instrument making and sound insulation.

4. Conclusions

From the study of the wood species of *A. leiocarpus*, *M. multinervis* and *C. gabunensis*, it appears that the physico-mechanical characteristics of *A. leiocarpus*, *M. multinervis* are better than those of the most exploited species in Benin. *C. gabunensis* has better acoustic characteristics than the other species studied and some Benin species. However, the wood of *M. andongensis*, a new species in the process of technological appropriation, has better properties than all the species studied. Also, locally harvested *A. leiocarpus* wood appears better than imported wood. Good prospects would allow a better appreciation of the availability of good performing species in order to open up promising channels.

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