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Physical and mechanical properties of *Holarrhena floribunda* and *Nesogordonia papaverifera* branch wood in Ghana

Kwaku Antwi[1*], Tobias Cremer[2] and Kwasi Frimpong-Mensah[1,3]

[1]Department of Construction and Wood Technology Education, Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Kumasi, Ghana.
[2]Department of Forest Utilization, Eberswalde University for Sustainable Development, Schicklerstr, Eberswalde, Germany.
[3]Department of Wood Science and Technology, Kwame Nkrumah University of Science and Technology, Kumasi-Ashanti, Ghana.

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The current study examines the physical and mechanical properties of branch wood from *Holarrhena floribunda* and *Nesogordonia papaverifera*, two of Ghana's least researched deciduous species. At an equilibrium moisture content of 12±2%, *H. floribunda* and *N. papaverifera* specimens had average density values of 467.53 and 720.80 kgm^{-3}, respectively. The overall tangential and radial shrinkage was 3.8 and 3.2%, respectively, while the radial shrinkage was 2.8 and 1.8%. For *H. floribunda* and *N. papaverifera*, the modulus of rupture was 80.2 and 122.3 N/mm^2, respectively, whereas the static modulus of elasticity was 8213.8 and 12902.8 N/mm^2. Shear strength parallel to grain was around 11.9 and 16.5 N/mm^2, whereas compression strength parallel to grain was approximately 36.6 and 52.3 N/mm^2. *H. floribunda* and *N. papaverifera* have Janka hardness values of 6.2 and 10.3 N/mm^2 tangentially, and 4.3 and 8.9 N/mm^2 radially, respectively. The qualities of the branch wood of *H. floribunda* and *N. papaverifera* were equivalent to those of their stem wood and other known wood species, indicating that they might be used in a variety of wood-related applications.

Key words: Branchwood, *Holarrhena floribunda, Nesogordonia papaverifera*, Ghana.

INTRODUCTION

In Ghana, *Holarrhena floribunda* and *Nesogordonia papaverifera*, often known as 'sese' and 'danta,' are semi-deciduous (New Koforidua) forest species found in the Ejisu - Juaben Municipality, in the Ashanti region of Ghana's middle belt. Trees were harvested in the wild (on a cocoa farm) in the same position inside the open forest of the area, which is located between the latitudes of 1° 15' N and 1° 45' N, and the longitudes of 6° 15' W and 7° 00 W. It covers a total area of 637.2 km^2 (EJMA, 2021). The Municipal Assembly has a bimodal rainfall pattern. March to July is the rainy season, with July being the wettest month. During the primary season, annual rainfall

*Corresponding author. E-mail: antwikwaku10@gmail.com/kantwi@aamusted.edu.gh. Tel: +233(0)208150964.

averages between 1200 and 1500 mm. With an average annual minor rainfall of 900-1120 mm, the minor rainfall season runs from September through November. From December to February, the weather is usually dry, hot, and dusty. In the Municipal area, the lowest annual temperatures are around 25°C in August and the highest are around 32°C in March. The relative humidity is moderate but high during the wet season. The terrain of the municipality is mostly undulating, with plains and hills ranging in elevation from 240 to 300 meters above sea level (EJMA, 2021). In a recent forest inventory by the International Tropical Timber Organization, an abundance of *H. floribunda* and *N. papaverifera* volume was observed in Ghana's forest reserves and farmlands (ITTO, 2019). *H. floribunda* and *N. papaverifera* are members of the Apocynaceae and Sterculiaceae families, respectively. From sea level to 1000 m above sea level, *H. floribunda* can be found in deciduous forest, open areas in dense forest, woodland, and savanna, on clay, sand lateritic soils, or rocky outcrops. *N. papaverifera* can reach a height of 120 feet, with a clean, straight, buttressed bole up to 60 feet long and trunk diameters of 2 to 3 feet. These trees are collected in the wild for use as medicine and as a supply of wood in the community.

The bark is widely applied in West Africa, in decoction or macerated in palm wine, to treat dysentery and diarrhea. In Senegal, the roots are used for the same purposes and are further used to treat stomach complaints, including constipation and colic, to prevent spontaneous abortion, to treat sterility, and as a diuretic to treat venereal diseases (Arevalo et al., 2020). An infusion of the leaves is taken to treat diabetes and amenorrhea. In Sierra Leone, the leaves, mixed with kola nuts are eaten to treat gonorrhea. In Guinea Bissau, the fruit is used to prepare a remedy for dropsy. The latex is applied to snakebites. The stem bark and leaves are also widely used to treat fever, especially malaria. They are boiled and added to a bath, or taken orally.

In Côte d'Ivoire, a decoction of the bark is used as an enema or in baths to treat skin affections. The leaf sap is sprinkled on wounds as a haemostatic. The leaves, mashed with those of *Myrianthus arboreus* P. Beauv and fruits of *Capsicum* pepper in water, are applied as an enema against kidney pain. The latex has been used as arrow poison or fish poison (Arevalo et al., 2020). The 5-8 cm wide band of lighter-colored sapwood readily distinguishes the reddish-brown heartwood. The grain is narrowly interlocked, giving a stripe figure; the sheen is medium; there is no particular aroma or flavor; the wood is marked by dark scar tissue streaks; and it has a mild greasy feel (Arevalo et al., 2020). In Ghana, *H. floribunda* is primarily utilized for carving stools for kings, queen mothers, fetish priests, and other prominent members of society, and it is widely regarded as the best white wood available for these uses. *N. papaverifera* is also commonly employed in the manufacture of furniture and for other structural uses.

Commercial interest in *H. floribunda* and *N. papaverifera* wood for other technical uses has increased in recent years (eg, construction, window frames, and sculpture). In 2019, Ghana exported a total volume of 1898.57 m^3 of *N. papaverifera* for €379.876.48 (3,343,913.02 cedis) and finished curved products and sculptures of *H. floribunda* species for €976,430.88 (8,592,591.74 cedis) respectively (TEDB 2019). However, information on the physical and mechanical properties of these timbers' branch wood, which is required to improve their applications as a supplement to their stem wood, is scarce in the literature.

Branch wood is a valuable wood resource with a wide range of applications; it accounts for 25-32% of total wood volume and is a secondary resource with high-value applications such as chaise lounges, wall and floor mosaics, garden arbors, dining stools, beds, garment racks, curtain rods, and a variety of other applications that have yet to be fully explored (Dawkins and Philip, 2020). Overexploitation of most 'traditional' market species has resulted in some being endangered (such as *Milicia excelsa, Entandrophragma cylindricum, Khaya ivorensis*, and others) due to increased market demand, both locally and globally. Manufacturers and producers have no choice but to pay attention to the branch wood of established and lesser-known species that were previously ignored if they want to stay in business as traditional timber prices rise and quality and quantity decline (Dadzie et al., 2018).

The physical and mechanical qualities of *H. floribunda* and *N. papaverifera* branch wood from Ghana's semi-deciduous forest zone are the subject of this research. This could provide stakeholders in the wood products manufacturing industry with more valuable information. The research could also promote the use of forest tree branch wood as a substitute for the tree's stem wood, supporting sustainable forestry and ensuring that future generations will have forest trees that meet their needs. Based on the outcomes of this study, manufacturers and producers will be able to decide which parts of the tree can be used in the future to substitute commonly used timber species.

MATERIALS AND METHODS

Straight-grained mature heartwood and sapwood of *H. floribunda* and *N. papaverifera* with an average number of 8-10 annual rings cm^2 were taken from a semi-deciduous forest zone of Ghana in the wild (a cocoa farm). Small, transparent wood specimens were created for the various tests according to Table 1 after a 6-month gradual air-drying process. The specimens were subsequently dried for two weeks in an electronic drier (kiln) to a moisture level of 12%. Under oven-dry conditions, the density of the wood was measured according to ASTM D 2395 (2008) criteria. The basic density and moisture content were determined according to ASTM D 2395 (2008) and ASTM D4442 (2008) respectively. Same samples were used for both tests. Each strip was sawn to 20 mm x 20 mm sections and crosscut into 20 mm cubes. The mass of the samples was taken immediately after preparation using a VWR Science

Table 1. Information on testing of *H. floribunda* and *N. papaverifera* branch wood.

Property	Number of specimens		Dimensions of specimen[a]	Standards
	HF	*NP*		
Density (kgm^{-3})	60	60	20×20×20	ASTM D 2395-07
Shrinkage and swelling (%)	60	60	10×20×20	DIN 52184
Modulus of elasticity (N/mm^2)	60	60	20×20×300	BS 373
Modulus of rupture (N/mm^2)	60	60	20×20×300	BS 373
Compression parallel to grain (N/mm^2)	60	60	20×20×60	BS 373
Shear parallel to grain (N/mm^2)	40	40	50×50×50	BS 373
Radial hardness (N/mm^2)	40	40	50×50×150	BS 373
Tangential hardness (N/mm^2)	40	40	20×20×150	BS 373

[a]Longitudinal × radial × tangential (mm × mm × mm). *HF* and *NP are Holarrhena floribunda* and *Nesogordonia papaverifera* respectively.

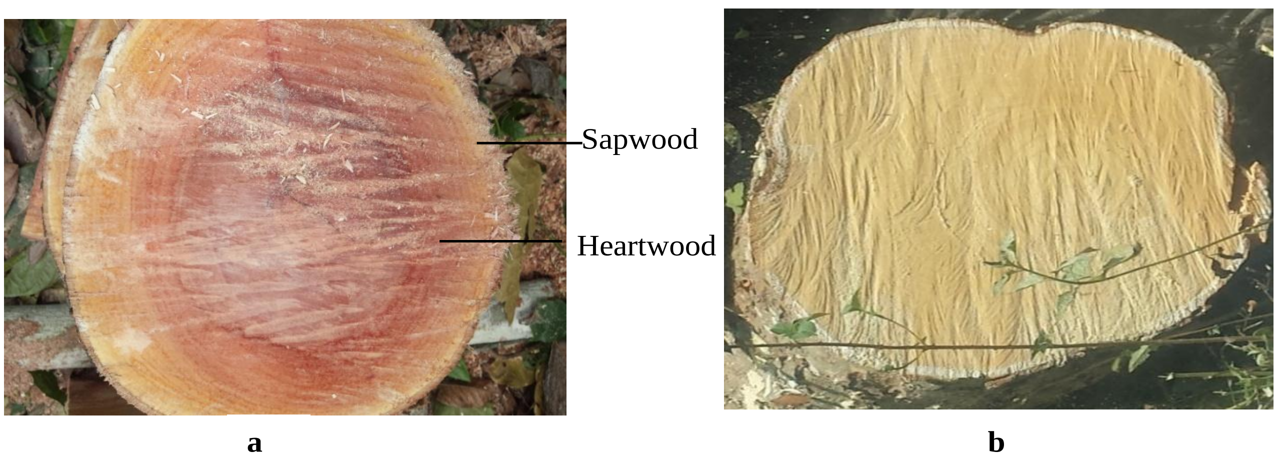

Figure 1. Cross-section of *H. floribunda* and *N. papaverifera* wood.

Education RS232 digital electronic balance (with precision 0.001g) to obtain the initial mass (W_1). The samples were then soaked in water for 24 h to obtain the swollen volume (V_1) which was determined by the immersion method. According to Archimedes' principle, the increase in the mass of water displaced by the submerged wood sample is numerically equal to the volume of water displaced. Afterward, the wood samples were oven-dried at 103 ± 2°C with intermittent weighing until constant mass, oven-dry mass (W_0) was attained (ASTM D 2395). The test was done under an ambient temperature condition of 20°C. The test duration was within 24 h. The basic density (BD) of the samples was then calculated from the formulae:

$$BD = W_0 / V_s \quad (1)$$

Where W_0 = Oven-dried mass; V_s = Swollen volume.

The green moisture content (GMC) of the samples was then calculated from formulae:

$$GMC = \frac{(W_1 - W_0)}{W_0} \times 100 \quad (2)$$

Where W_1 = Initial mass; W_0 = Oven-dried mass

The shrinkage and swelling values (radial and tangential) were calculated using standard methodology after measuring the dimensions of the specimens under green and oven-dry conditions (DIN 52184, 2005). The 3-point loading (that is, central loading) system on an 'Instron' Universal Testing Machine was used to perform static bending tests for the determination of modulus of elasticity (MOE) and modulus of rupture (MOR) (BS 373(1957) requirements). According to BS 373 (1957) requirements, axial compression strength, shear strength parallel to the grain, and Janka hardness in the axial and transverse directions was measured. Heartwood and sapwood were well distinguished in *N. papaverifera* species; however, heartwood and sapwood were not clearly distinguished in *H. floribunda* species (Figure 1).

Data analyses

Using descriptive statistics, the data were numerically summarized. The findings of the various parameters determined are represented by the mean and standard deviation. The Single Factor Turkey Multiple Comparison Test was used to determine the statistical significance of each pair of means, as well as variance in quantitative physical and mechanical characteristics. To assess whether the two treatment pairs were significantly different, the

Table 2. Physical and mechanical properties of *H. floribunda* and *N. papaverifera* branchwood and literature values.

Property	*HF* branch wood[a]	*NP* branch wood[a]	Literature values[b]		
			HF stem wood	*NP* stem wood	*CM* stem wood
Wood density (kgm^{-3})					
Oven-dry	467.53 ± 70.87	720.80 ± 77.52	457.40 ± 70.46	711.98 ± 76.48	648 ± 72.04
Shrinkage (%)					
Radial	2.0 ± 0.5	1.8 ± 0.3	1.9 ± 0.2	1.7 ± 0.2	1.7 ± 0.3
Tangential	3.8 ± 0.7	3.2 ± 0.5	3.6 ± 0.6	3.0 ± 0.4	3.0 ± 0.5
Ratio T/R shrinkage	1.9 ± 0.2	1.8 ± 0.2	1.9 ± 0.4	1.8 ± 0.2	1.8 ± 0.2
Swelling (%)					
Radial	2.4 ± 0.6	2.0 ± 0.5	2.2 ± 0.5	1.9 ± 0.2	2.2 ± 0.4
Tangential	4.0 ± 0.8	3.8 ± 0.7	3.8 ± 07	3.7 ± 0.7	3.6 ± 0.6
Static bending					
MOE (N/mm^2)	8213.83 ± 116.23	12902.80 ± 133.04	8654.96 ± 108.30	12489.63 ± 232.38	9868.78 ± 0.92
MOR (N/mm^2)	80.15 ± 1.10	122.28 ± 2.18	80.72 ± 1.00	121.92 ± 1.94	104 ± 0.68
Compression (N/mm^2)	36.55 ± 0.44	52.28 ± 0.72	37.30 ± 0.42	54.00 ± 0.54	38.46 ± 0.35
Shear (N/mm^2)	11.87 ± 0.12	16.54 ± 0.60	12.44 ± 0.17	16.30 ± 0.16	9.50 ± 0.11
Janka Hardness (N/mm^2)					
Radial	4.33 ± 0.14	8.92 ± 0.21	5.08 ± 0.16	8.57 ± 0.28	6.75 ± 0.32
Tangential	6.21 ± 0.43	10.29 ± 0.37	5.77 ± 0.23	9.04 ± 0.29	8.34 ± 0.65

HF= *H. floribunda*; *NP*= *N. papaverifera*; *CM*= *Celtis mildbraedii* (essa); [a]mean±SD; [b]data from literature (Antwi 2018, Dadzie et al., 2018). MOE= modulus of elasticity; MOR=modulus of rupture.

Tukey HSD post-hoc tests were utilized.

RESULTS AND DISCUSSION

The physical and mechanical properties of *H. floribunda* and *N. papaverifera* branch wood, as well as stem wood properties and available literature values, are presented in Table 2. It should be emphasized that the literature figures are unknown whether they apply to heartwood or sapwood. As a result, they can only make a relative comparison to the results of this study. *H. floribunda* 467.53 kg/m^3 and *N. papaverifera* 720.80 kg/m^3 had comparable density values (oven-dry), and *H. floribunda* shrinkage (radial 2.0%, tangential 3.8%) and *N. papaverifera* shrinkage (radial 1.8%, tangential 3.2%) were likewise equivalent to their stem wood qualities and literature values.

H. floribunda had an average MOE of 8213.83 N/mm^2 and *N. papaverifera* had an average MOE of 12902.80 N/mm^2, which is comparable to literature values. The average MOR value of *N. papaverifera* branch wood (122.28 2.18 N/mm^2) compares favorably to most heavy construction species such as wawabima (127 N/mm^2), essa (104 N/mm^2), dahoma (109 N/mm^2), and Albizia (102 N/mm^2) (Dadzie et al., 2018). The mean values (80.15 1.10 N/ mm^2) obtained for *H. floribunda* branch wood were lower than those obtained for these heavy construction species but were comparable to some medium-class wood species such as ofram (*Terminalia superba*), iroko (*Chlorophora spp*), and emeri (*Terminalia ivorensis*), which can be used for medium to light constructional works.

H. floribunda branch wood had a compression strength of 36.93 N/mm^2 and *N. papaverifera* had a compression value of 53.14 N/mm^2. These values are comparable to Antwi's (2018) stem wood values. According to the ASTM D 143-83 standard (2008), practically all specimens showed an overall compression failure of the "shearing kind." The compressive strengths of *N. papaverifera* (53.14 N/mm^2) and *H. floribunda* (36.93 N/mm^2) have been classed as medium according to Olorunisola (2017) categorization.

Shear strength values obtained for *N. papaverifera* branch wood (16.54 0.60 N/mm^2) compare favorably to those obtained for stem wood and most heavy construction species such as odum (*Milicia exelsa*) 14.10 N/mm^2, denya (*Cyclidiscus gabunensis*) 11.10 N/mm^2, dahoma (*Piptadeniastrum africanum*) 17.60 N/mm^2, asanfena (*Aningeria altis*) (Desch and Dinwoodie, 2016). However, as compared to *N. papaverifera* trees, the shear strength values for *H. floribunda* branch wood (11.87 0.12 N/mm^2) were lower but remained comparable to most known species appropriate for structural and non-structural uses.

Finally, the Janka hardness found to be 4.33 ± 0.14 N/mm^2 and 8.92 ± 0.21 N/mm^2 in the radial direction and 6.21 ± 0.43 N/mm^2 and 10.29 ± 0.37 N/mm^2 in the tangential direction for *H. floribunda and N. papaverifera* branch wood were comparable to the literature values reported by Antwi (2018) and Dadzie et al. (2018). The resistance of *N. papaverifera* to indentation was relatively high for branch portions and medium for *H. floribunda*.

Conclusion

N. papaverifera and *H. floribunda* branch wood were equivalent to its stem wood and other species. The shrinkage and swelling qualities of its stem wood and other species were comparable. In both species, the modulus of elasticity values of branch wood compares favorably to stem wood. Most heavy construction species, such as wawabima, essa, dahoma, and Albizia, have a lower modulus of rupture mean values than *N. papaverifera*. *H. floribunda*, on the other hand, has lower mean values than these heavy construction species, but it can still be used for light building. *H. floribunda* and *N. papaverifera* stem and branch shear resistance showed no significant differences, and the values obtained for *N. papaverifera* trees compare favorably to most heavy construction species such as odum (*Milicia exelsa*), denya (*Cyclidiscus gabunensis*), dahoma (*Piptadeniastrum africanum*), asanfena (*Aningeria altissima*), and *H. floribunda* (*Terminalia ivorensis*). The branch section of *N. papaverifera* had a high resistance to indentation, while *H. floribunda* had a medium resistance.

N. papaverifera branch wood is suitable for exterior and interior usage, even when untreated, due to its exceptional strength in resisting failure. For external usage, however, *H. floribunda* must be treated. The species (stem and branch wood) investigated have a high potential for industrial usage, and their qualities would be suited for a variety of wood-related applications.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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