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Analysis of the Physical-Hydrical Behavior of Massouhoin Coconut Tree Wood in Togo

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Abstract: Wood is a very complex and anisotropic material whose properties are significantly influenced by its age and plantation areas. The purpose of this study is to determine the density distribution model of COCOS NUCIFERA (coconut tree) wood from Togo and to analyze its water behavior of physical and water properties 932 wood specimens are selected from a tree trunk from the locality of Massouhoin in Togo. These specimens were subjected to density and water absorption tests. The average density and absorption rate are respectively 0.372 and 44.95%. The average longitudinal swelling rate is 2.444 and 10.333% for radial swelling. The densities, absorption, and swelling rates of wood vary according to a polynomial law of degree two in the radial directions (from the periphery to the center) and longitudinal directions (from the base to the top of the trunk). Models are set up to deduce the properties (density, absorption, and swelling) in the different parts of the coconut tree trunk. The actors of the use of timber and service thus have models allowing them to deduce the properties of the wood for decision-making on the possible destinations of coconut tree wood according to the different parts of the trunk.

Keywords: Coconut Tree Wood, Density, Water Effect, Behavior Law

Introduction

Le bois est un matériau composite aux caractéristiques variables, très hétérogène, poreux et hygroscopique, notamment en termes de comportement mécanique, de teneur en eau, de retrait et de densité. En d'autres termes, les propriétés élastiques du bois dépendent de son état physique et de ses propriétés physiques (Guitard, 1987) (Samah *et al*., 2015).

Le bois de cocotier (Cocos nucifera L.), comme les bois ordinaires, pourrait être considéré comme l'une des matières premières alternatives dans la construction de bâtiments car il est largement disponible dans le monde entier (Fathi, 2014). De plus, les cocotiers sont des plantes monocotylédones constituées de tissus ligneux contenant des cellules fibreuses et parenchymateuses (COGENT, 2018) (Agridigitale, 2019). La plupart des propriétés des bois de cocotiers, comme celles des autres espèces monocotylédones, sont principalement influencées par les cellules fibreuses (Fathi, 2014; Meylan, 1978; Killmann, 1983). Les propriétés des bois de la zone périphérique et inférieure sont meilleures et varient en fonction des âges et des zones de plantation (Fathi, 2014; Meylan, 1978; Kloot, 1952; Gnanaharan and Dhamodaran, 1989).

Studies have determined the properties of coconut wood in southern Thailand for use as a raw material in the manufacture of cross-laminated timber (Srivaro *et al*., 2020). Its use is still quite limited in West African regions, particularly in Togo where it is generally cultivated in the maritime region for its fruits which are mainly used for food production (COGENT, 2018) (Agridigitale, 2019). Other studies conducted in Togo on coconut have mostly concerned the combustion potential of biochar produced from coconut shells (Kongnine *et al*., 2018). In-depth studies carried out on palm trees used in Togo have determined their mechanical and acoustic properties (Lolo and Ouedraogo, 2023; Samah *et al*., 2015). It is therefore noted that studies carried out on coconut wood in several countries do not provide laws and models of behavior of densities and water parameters. Also, no study has been carried out on determining the properties of coconut wood from Togo, while these parameters vary depending on the plantation areas. Thus, the use of coconut wood in construction is very limited due to the lack of knowledge of its water, thermal, and mechanical behavior. It is therefore essential to look into the analysis of the behavior of these woods. This study aims to determine the distribution model of the density of coconut wood from Togo collected in Massouhouin and to analyze its water absorption and swelling. The study will make it possible to provide stakeholders in the construction of buildings and public works in Togo with data enabling them to make decisions on the conditions of use of the different parts of coconut wood in Togo.

Materials and Methods

Materials

The material used for this study is given by:

- Precision electronic balance, capacity 160 g, reading 0,01g, glass protection chamber, weighing with tolerance range. Optimized ergonomic keyboard
- Digital reading caliper, capacity 150 mm, resolution 0.01 mm, RS232 data output, vernier locking screw, beak for internal measurements, Stainless steel material
- Plastic test tubes, graduated, capacity 2000 ml, precision 5 ml, Pyrex brand, type 3201/14WC

The raw material (coconut tree trunk) comes from Massouhouin, a district of the city of Lomé, capital of Togo (Fig. 1). The tree was cut at ground level. The total height of the trunk is 10 m with a diameter varying from 40 cm at the base and 21 cm at the top (Fig. 2). The trunk was then cut into ten (10) logs of 1 m each (Fig. 3c) using a chainsaw and dried in the open air for one (01) month.

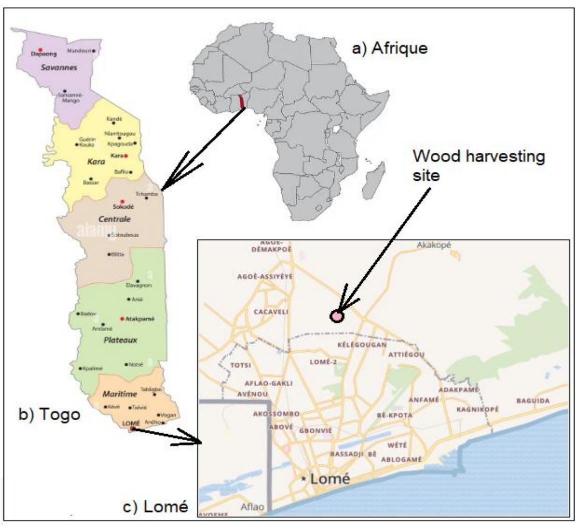

Fig. 1: Location of the sampling site (Massouhouin)

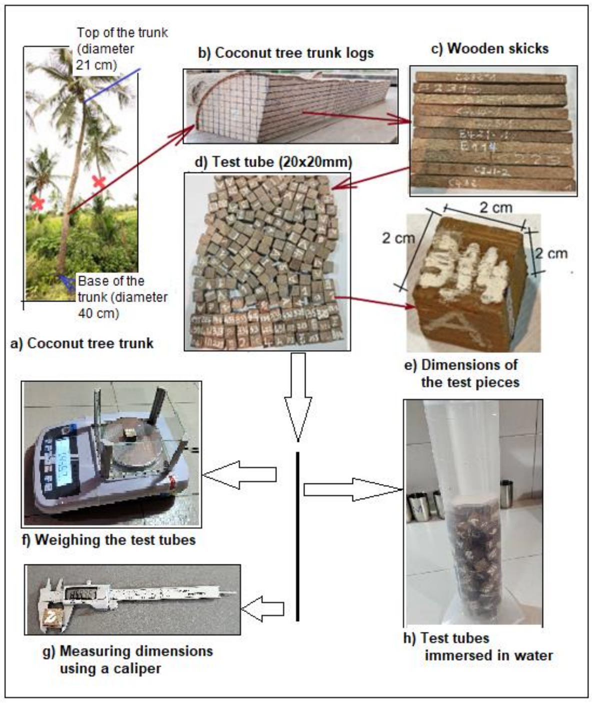

Fig. 2: Principle of sampling the Massouhoin coconut tree trunk

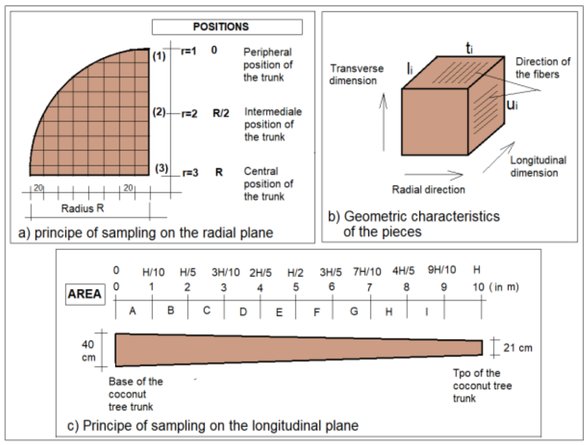

Fig. 3: Principle of sampling and geometric characteristics

Method

932 test pieces were taken from the trunk of the coconut tree distributed in zones identified by A-I positioned every 1 m along the entire length of the trunk from the base (foot of the tree) (Fig. 3c) and in three zones designated by "Peripheral (1)", "Intermediate (2)" and "Central (3)" (Fig. 3a). These test pieces of dimensions 20×20×20 (in mm) (Fig. 2e) are subjected to the determination of their density (B51-005, 1985). They are then immersed in water at 20°C for 24 h, and the mass and dimensions of each test piece are measured before and

after their immersions (B51-004, 1985). The density, the Water Absorption rate (T_A), The radial (T_r) and longitudinal (T_l) swelling rate (B51-002, 1942) (B51-003, 1985), are determined by expressions (1-4):

$$\rho = \frac{m}{V} \tag{1a}$$

$$d = \frac{\rho}{\rho_e} \tag{1b}$$

$$V = l_i \times t_i \times u_i \tag{1c}$$

$$T_A = \frac{m_i - m_0}{m_0} \times 100 \tag{2}$$

$$T_r = \frac{t_i - t_0}{t_0} \times 100 \tag{3}$$

$$T_l = \frac{l_i - l_0}{l_0} \times 100 \tag{4}$$

With:

V and m, respectively volume and mass of the specimen; ρ and ρ_e, density respectively of the specimen and of the water; m_o and m_i, the mass of the specimen respectively before and after immersion (g); t_o, the radial dimension (perpendicular to the fibers in the radial direction) of the specimen before immersion and t_i, that after (mm) (Fig. 3b); l_o and l_i, longitudinal dimension (parallel to the fibers) of the specimen respectively before and after immersion (mm) (Fig. 3b); u_o, transverse dimension (perpendicular to the fibers in the direction perpendicular to the radial direction) of the specimen before immersion and u_i, that after (mm) (Fig. 3b).

Results

Densities of Coconut Wood

Transverse/Radial Evolution of Densities

The densities decrease from the periphery (1) To the center (3) (Fig. 4) for the entire trunk of the tree (Figs. 4-5a). The highest density is recorded at the foot of the trunk (zone A) with a variation of 0.928-1.200. The average density varies from about 0.433-0.273 from the Periphery (1) To the Center (3) Of the trunk (Fig. 5b). The lowest density, located in zone I, varies from 0.022-0.074 (Table 1).

From the base to the top of the trunk, the densities vary from the periphery to the center of the coconut trunk following a decreasing and concave parabolic function; except for the specimens taken at the top (Point J) for which the decreasing parabolic function is convex (Fig. 5a). The equations which illustrate these behaviors are given by Eqs. (5a-i):

$$d_A = -0.0685\, r^2 + 0.1379\, r + 1.1304\ with\ R^2 = 1 \tag{5a}$$

$$d_B = -0.0916\, r^2 + 0.2346\, r + 0.7038\ with\ R^2 = 1 \tag{5b}$$

$$d_C = -0.0925\, r^2 + 0.2543\, r + 0.4358\ with\ R^2 = 1 \tag{5c}$$

$$d_D = -0.0832\, r^2 + 0.2369\, r + 0.2680\ with\ R^2 = 1 \tag{5d}$$

$$d_E = -0.0703\, r^2 + 0.2045\, r + 0.1634\ with\ R^2 = \tag{5e}$$

$$d_F = -0.0571\, r^2 + 0.1687\, r + 0.0984\ with\ R^2 = 1 \tag{5f}$$

$$d_G = -0.0451\, r^2 + 0.1350\, r + 0.0584\ with\ R^2 = 1 \tag{5g}$$

$$d_H = -0{,}0350\, r^2 + 0{,}1057\, r + 0{,}0339\ with\ R^2 = 1 \tag{5h}$$

$$d_I = +0.0257\, r^2 - 0.1284\, r + 0.1765\ with\ R^2 = 1 \tag{5i}$$

The smoothing curve of the variation of the average density from the periphery (1) To the center (3) of the wood trunk is given by Eq. (6) (Fig. 5b):

$$d = -0.0575\, r^2 + 0.1499\, r + 0.341\ with\ R^2 = 1 \tag{6}$$

With r, the radial position of the specimen (Periphery (r = 1), Intermediate (r = 2), and central (r = 3)) (Fig. 3b) and dj, the densities at the different zones (A-I).

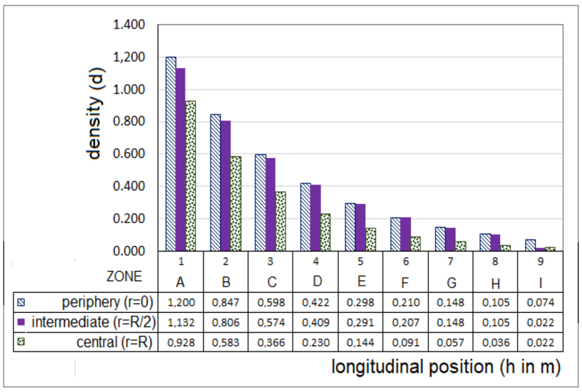

Fig. 4: Longitudinal/transverse variation of wood density

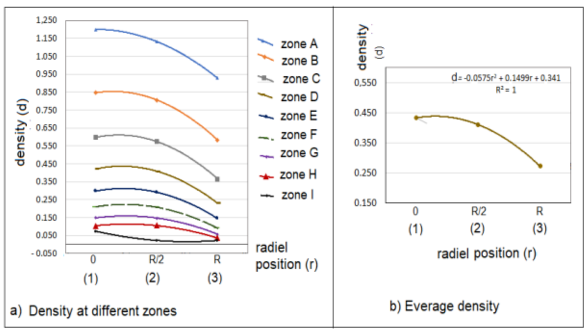

Fig. 5: Variation of wood densities

Table 1: Physical properties of coconut wood

	Longitudinal position on the trunk			Density (d) at transverse positions				Water behavior		
N°	Code	m	n	Perip (r = 1)	Inter (r = 2)	Cent (r = 3)	Moy	T_A (%)	T_l (%)	T_r (%)
1	A	1	107	1.200	1.132	0.928	1.087	36.333	1.333	1.667
2	B	2	149	0.847	0.806	0.583	0.745	34.000	1.000	2.333
3	C	3	148	0.598	0.574	0.366	0.513	34.333	1.000	3.333
4	D	4	116	0.422	0.409	0.230	0.354	36.333	1.333	4.333
5	E	5	128	0.298	0.291	0.144	0.244	39.667	1.667	6.000
6	F	6	120	0.210	0.207	0.091	0.169	45.000	2.333	9.333
7	G	7	68	0.148	0.148	0.057	0.118	51.667	3.000	13.667
8	H	8	68	0.105	0105	0.036	0.082	60.000	4.333	22.000
9	I	9	28	0.074	0.022	0.022	0.040	67.222	6.000	30.333
				0.433	0.411	0.273	0.372	44.951	2.444	10.333

Legend: T_A: Absorption rate (%); T_l: Longitudinal swelling (%); T_r: Radial swelling (%); m: Meter
Perip: Periphery (1); Inter: Intermediate (2); Cent: Central (3); Moy: Average; n: Number of samples

Longitudinal Evolution of Densities

The densities show a decreasing evolution in a parabolic shape, from the base to the top of coconut woods whatever the profile, namely the Peripheral zone (1) (d_p), the Intermediate zone (2) (d_i), and the Central zone (3) (d_c)) whose equations are given respectively by (7a-c) (Fig. 6a):

$$d_p = 0.0181\, h^2 - 0.3082\, h + 1.3797 \; with \; R^2 = 0.9902 \qquad (7a)$$

$$d_i = 0.0214\, h^2 - 0.3452\, h + 1.4833 \; with \; R^2 = 0.9934 \qquad (7b)$$

$$d_c = 0.0209\, h^2 - 0.3099\, h + 1.1618 \; with \; R^2 = 0.9829 \qquad (7c)$$

The average density varies from 1.087 at the base to 0.040 at the top of the wood (Table 1). This evolution from the base to the top will be due to the maturity of the wood which is more important at its base. The evolution of the average density, of exponential form is given by Eq. (8) (Fig. 6b):

$$d = 1.6954\, e^{-0.394\, h} \; with \; R^2 = 0.9991 \qquad (8)$$

With h, the longitudinal position of the test piece is taken from the base of the trunk (in m).

Density Evolution Model

The parabolic form of Eqs. (5a-i) describing the behavior of the density radially (Fig. 5a) makes it possible to illustrate the variations in the densities (d) of the trunk (from the peripheral to the center of the trunk) by a polynomial function of degree two whose form is given by Eq. (9):

$$d = a\, r^2 + b\, r + c \qquad (9)$$

With:

r, the radial position of the point considered in relation to the periphery of the trunk (Periphery (r = 1), Intermediate (r = 2) and central (r = 3)) (Fig. 4a-c), parameters of the position of the point considered in relation to the base of the coconut tree trunk.

From the different density equations given in Fig. (5a), the evolutions and expressions of three parameters (a, b, and c) are given in Fig. (7) and Eq. (10a-c), with h designating the distance (in m) in relation to the base of the coconut tree trunk:

$$a = 0.003\, h^2 - 0.0193\, h - 0.0574 \; with \; R^2 = 0.9408 \qquad (10a)$$

$$b = 0.0306\, h^2 - 0.4188\, h + 1.4651 \; with \; R^2 = 0.9884 \qquad (10b)$$

$$c = -0.0124\, h^2 + 0.0946\, h + 0.0693 \; with \; R^2 = 0.9091 \qquad (10c)$$

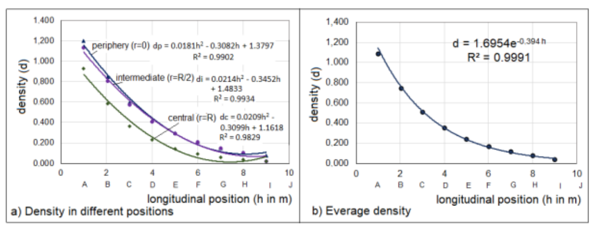

Fig. 6: Longitudinal variation of average wood density

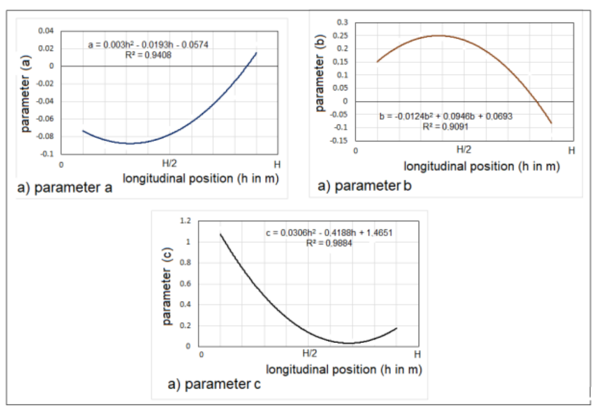

Fig. 7: Parameters a, b, and c of the transverse/radial variation of wood density

The evolution of the density from the base to the top of the coconut tree trunk, having the parabolic shape for each of the zones (Peripheral (1), Intermediate (2) and Central (3)) (Fig. 6a and Eqs. (7a-c)), can be illustrated in the form of polynomials of degree two given by Eq. (11):

$$d = g\,h^2 + f\,h + e \tag{11}$$

With:

h, the longitudinal position of the point considered, taken from the base of the trunk (in *m*).

g, f, and e, parameters depending on the position of the point considered relative to the periphery of the trunk of the wood whose expressions are obtained from the density Eqs. (7a-7c) are given by Fig. (8) and Eq. (12a-c) with h designating the position relative to the periphery of the trunk of the coconut tree:

$$g = -0.0028\,r^2 + 0.0112\,r + 0.0097\ with\ R^2 = 1 \tag{12a}$$

$$f = 0.2179\,r^2 - 0.8716\,r + 2.0334\ with\ R^2 = 1 \tag{12b}$$

$$e = 0.0017\,r^2 + 0.0068\,r \pm 0.3031\ with\ R^2 = 1 \tag{12c}$$

Water Absorption and Swelling

The average water absorption rates (T_A) range from 8.556-113.815% from the periphery (1) To the center (2) and from 36.33-67.22% from the base (zone A) to the top (zone I) for the entire trunk length (Fig. 9).

Like water absorption, radial (T_r) and longitudinal (T_l) swellings decrease from the periphery to the interior with radial swelling rates from 5.22-19.333% and longitudinal swelling rates from 1-5.222% (Fig. 10a-c). On the longitudinal plane, from the bottom (zone A) to the top (zone I) of the wood, the radial (T_r) and longitudinal (T_l) swelling rates are globally increasing respectively from 1.667-30.333 and 1.333-6% (Fig. 10b-d). This is normal behavior, in fact, the heavier a material is (high density), the harder it is and the more resistance it provides to liquid infiltration and consequently, it deforms less (low swelling rate on the peripheries). The smoothing curves that illustrate these behaviors of the water absorption rate (T_A in %), the radial (T_r in %) and longitudinal (T_l in %) swelling rates are parabolic functions given by Eqs. (13-15).

$$T_A = 0.7506\,h^2 - 3.4245\,h + 38.304\ with\ R^2 = 0.9969 \tag{13}$$

$$T_r = 0.6255\,h^2 - 2.9332\,h + 5.1905\ with\ R^2 = 0.9894 \tag{14}$$

$$T_l = 0.1245\,h^2 - 0.6835\,h + 1.9206\ with\ R^2 = 0.9951 \tag{15}$$

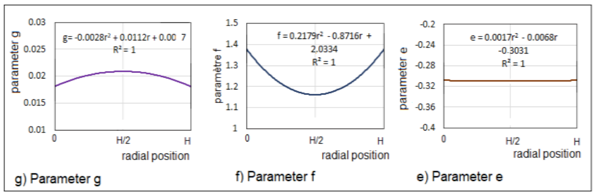

Fig. 8: Variation in average wood density

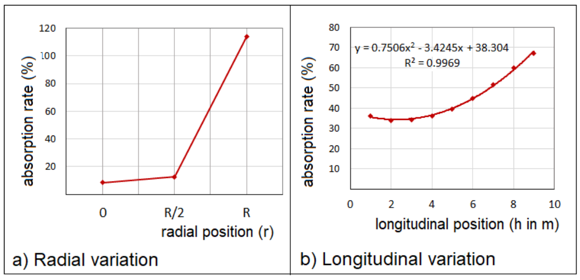

Fig. 9: Average variation of water absorption rate per coconut tree

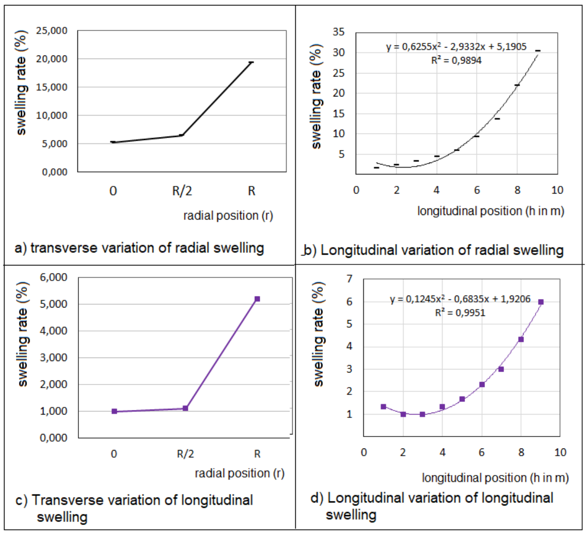

Fig 10: Average variation of coconut tree swelling

Correlation between Water Parameters of Coconut Wood and its Density

The properties (water absorption rate, radial and longitudinal swelling rate) of coconut wood are low for high densities (Fig. 11); these behaviors are given by Eqs. (16-18) which are decreasing power functions.

$$T_A = 31.699\,d^{-0.222} = 31.699\,e^{-0.222\ln d}\ with\ R^2 = 0.9258 \tag{16}$$

$$T_l = 0.895\,d^{-0.562} = 0.895\,e^{-0.562\ln d}\ with\ R^2 = 0.9650 \tag{17}$$

$$T_r = 1.777\,d^{-0.925} = 1.777\,e^{-0.925\ln d}\ with\ R^2 = 0.9583 \tag{18}$$

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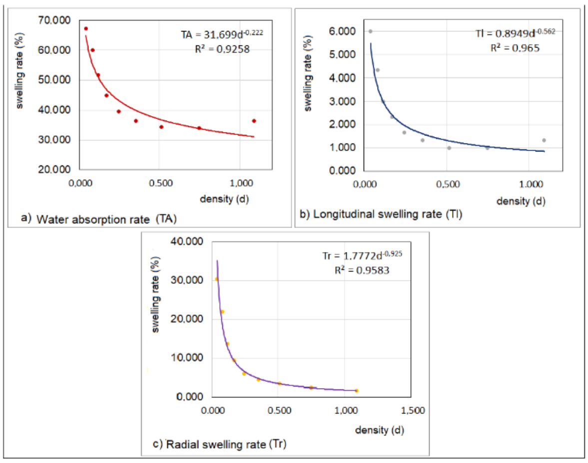

Fig. 11: Correlations between density and water parameters of coconut wood

Discussion

The properties (densities, water absorption, and swelling) of coconut wood vary transversely (from the periphery to the center) and longitudinally (from the bottom to the top of the tree) with an average density of 0.372 and max of 1.087, an average water absorption rate of 44.951%, longitudinal swelling rates of 2.444 and radial of 10.333.

The variation in the water absorption rate would depend on the porosity of the wood tissues when moving from the periphery to the interior and from the base to the top of the trunk, which is inversely related to the density of the coconut tree. The coconut tree is a fibrous material, the low longitudinal swelling rate (T_l) compared to the radial one (T_r) is due to the fibers which oppose the longitudinal deformation. The maximum density of 1.087 is consistent with that of coconut trees taken in Thailand (which have respective densities of 1.110 and 1.059. The variation in the radial swelling rate at the bottom of the 65-year-old trunk studied is similar to that of the work done on a 60-year-old trunk (Srivaro *et al*., 2020).

An analysis of the interactions between the properties of coconut wood taken in Togo showed that the densities follow decreasing polynomial laws of degree two in the radial direction (from the periphery to the center) and longitudinal direction (from the base to the top) of the coconut trunk (Fig. 5). On the other hand, the water absorption and swelling rates are consistent with increasing polynomial laws of degree two (Figs. 9-10). Thus, the denser the wood, the lower its absorption rate and the less it swells. This behavior is confirmed by the correlations given in Fig. (11) and Eqs. (16-18).

The variations in properties become less and less weak from the periphery to the center when moving from the base to the top of the trunk; This would be due to the immaturity of the trunk in its upper part (top) (Fig. 5).

Models developed and given by Eqs. (9-12) and Figs. (7-8), illustrate the behavior of the density of wood at any point (from the base to the top and from the periphery to the center) of the coconut trunk. The densities can therefore be determined at any part of the trunk; Thus the water absorption and swelling rates can be deduced from Eqs. (16-18). The actors of the use of timber can therefore make decisions on the exploitation of the different parts of the coconut trunks according to their densities, water absorption, and swelling. Water absorption rates can be deduced from Eqs. (16-18). It is therefore possible to deduce the possibilities of using coconut wood as construction and service timber according to its properties.

Conclusion

This study, which aimed to enhance the exploitation of coconut wood, involved carrying out density and water absorption tests on wood samples taken from Massouhoin, a locality in Togo. The results showed that coconut wood is denser from the periphery to the inside and from the base to the top of the tree trunk; The variation in its water absorption rate, and radial and longitudinal swelling is inverse to that of the density according to power functions. Laws are established to deduce the properties (density, water absorption, and swelling rates) at any point of the coconut trunk to enable construction stakeholders to make decisions. A study of the mechanical and shrinkage properties will determine the sustainable characteristics.

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Author's Contributions

Essey Agbédidi Kossi: Research and preparation of samples, performance of tests, analysis of results, and writing of the manuscript.

Amey Kossi Bollanigni: Plan research work, analyze results, and write manuscripts.

Drovou Soviwadan: Participation in the processing of test results.

Lolo Komlan: Participation in the analysis of the test results.

Kassegne Komlan Assogba: Coordination of research work.

Ethics

There are no ethical worries or concerns regarding this study.

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