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VARIABILITY OF THE CHEMICAL COMPOSITION OF THE WOOD AND BARK OF TWO TROPICAL HARDWOODS FROM GHANA

VARIABILNOST KEMIČNE SESTAVE LESA IN SKORJE DVEH TROPSKIH LISTNATIH DREVESNIH VRST IZ GANE

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Abstract / Izvleček

Abstract: The study aims to investigate the chemical properties of the wood and bark of two tropical tree species *Nesogordonia papaverifera* and *Holarrhena floribunda* from Ghana to increase the efficiency of their utilization. For this purpose, for each of the species five mature trees with similar diameters at breast height were selected. Lignin, cellulose, hemicellulose, and total extractive content were determined from the sapwood and heartwood and bark of stems and branches of both species. The tests were conducted using the Technical Association of the Pulp and Paper Industry (TAPPI) standards. The lignin, cellulose, hemicellulose, and total extractive content vary along different locations in the stems and branches in both species. The sapwood generally had higher cellulose and hemicellulose content, while the heartwood and bark had a greater amount of lignin and extractives. This may affect the lower durability of sapwood. This study shows that heartwood of both *Nesogordonia papaverifera* and *Holarrhena floribunda* can be considered a source of value-added compounds.

Keywords: structural components, total extractives, stem/branch wood, bark, *Nesogordonia papaverifera, Holarrhena floribunda*

Izvleček: Raziskana je bila kemi*čna* zgradba lesa in skorje dveh tropskih listavcev, *Nesogordonia papaverifera* in *Holarrhena floribunda* iz Gane za izboljšanje uporabe. V ta namen je bilo za raziskave izbranih pet odraslih dreves vsake vrste. Debla so imela podobne premere na prsni višini. Določena je bila vsebnost ekstraktivov, lignina, celuloze in hemiceluloz v beljavi in jedrovini ter skorji debel in vej. Testi so bili izvedeni v skladu s standardi tehničnega združenja za celulozo in papir (TAPPI). Vsebnost lignina, celuloze, hemiceluloz in celokupna vsebnost ekstraktivov je bila primerljiva v lesu debel in vej pri obeh vrstah. Vsebnost celuloze in hemiceluloz je bila pri obeh vrstah manjša v skorji kot v lesu. V beljavi smo zabeležili večjo vsebnost celuloze in hemiceluloz, v jedrovini in skorji pa večjo količino lignina in ekstraktivov. To utegne vplivati na slabšo odpornost beljave proti *škodljivcem*. Študija kaže, da sta jedrovina in skorja obeh vrst *Nesogordonia papaverifera* in *Holarrhena floribunda* lahko vir spojin z visoko dodano vrednostjo.

Ključne besede: strukturne komponente, celokupni ekstrakti, les debla/veje, skorja, *Nesogordonia papaverifera, Holarrhena floribunda*

1 INTRODUCTION
1 UVOD

In the context of tropical forest management, the branches, roots and bark of lesser-known tropical timber species are still underutilized and therefore continue to offer great potential for utilization. At present hundreds of potentially valuable trees are being left behind, often simply to be burnt in forest clearing operations (Boampong et al., 2015).

Nesogordonia papaverifera occurs in numerous forest types except the wet evergreen forests. It is distributed in West Africa and the Central Afri-

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can Republic, and is frequently found in Ghana. It is an evergreen tree on base-rich soils and comes from the family Malvaceae (formerly Sterculiaceae) (InsideWood, *Nesogordonia,* 2024) with the international trade name of kotibe, and local name of danta. The trees can be up to 30 m high with narrow sharp buttresses (Arevalo et al., 2020). The tree is harvested from the wild for local use as a medicine and source of wood materials. The heartwood is reddish-brown; it is sharply demarcated from the 5-8 cm wide band of lighter-coloured sapwood. The texture is fine and even, the grain narrowly interlocked, producing a striped figure, lustre is medium, it has no characteristic odour or taste, the wood is marked with dark streaks of scar tissue, and pin knots, it has a slightly greasy feel (Tamboura et al., 2005).

Another interesting tree species, *Holarrhena floribunda* comes from the family Apocynaceae. It has the synonyms *Holarrhena Africana* and *Holarrhena wulfsbergii*, while the vernacular names include the false rubber tree, conessi bark, kurchi bark (En) holarrhène, holarrhène du Sénégal (Fr), and sese (Gh). *Holarrhena floribunda* occurs from Senegal east to Sudan, and south to DR Congo and Cabinda (Angola). It sheds its leaves at the end of the dry season and new leaves appear at the beginning of the rainy season. The flowers appear shortly after the leaves; the flowering period is short. Fruits mature a few months after flowering but do not dehisce until 3–4 months later (Tamboura et al., 2005). *Holarrhena floribunda* coppices well and can survive bushfires by producing suckers from burned-down stumps. *Holarrhena floribunda* occurs in deciduous forests, open localities in dense forest, woodland, and savanna, on clay, sand, lateritic soils, or rocky outcrops, from sea level up to 1000 m altitude. *Holarrhena floribunda* is easily propagated by seed, suckers, or small-diameter cuttings. Fresh seed has a high germination rate but loses its viability after having been stored for a year (Tamboura et al., 2005).

Both species are among the most important commercial tropical timber species in Ghana. In 2019, Ghana exported a total volume of 1,898 m^3 of *N. papaverifera* for €379,876 (3,343,913 cedis) and finished curved products and sculptures of *H. floribunda* species for €976,430 (8,592,591 cedis), respectively (TEDB, 2019). In spite of its economic value, little is known about chemical composition of its stem and branch wood and bark.

Previous investigations of *N. papaverifera* showed that the basic density of wood of different tree parts varied from 700 to 729 kg/m^3 (Antwi et al., 2022). Wood anatomy of the species is described in InsideWood (Wheeler et al., 2010; Wheeler, 2011; InsideWood*, Nesogordonia* 2024). The heartwood of the stems and branches was however rated very durable (Antwi et al., 2022) according to durability classifications (Eaton & Hale, 1993).

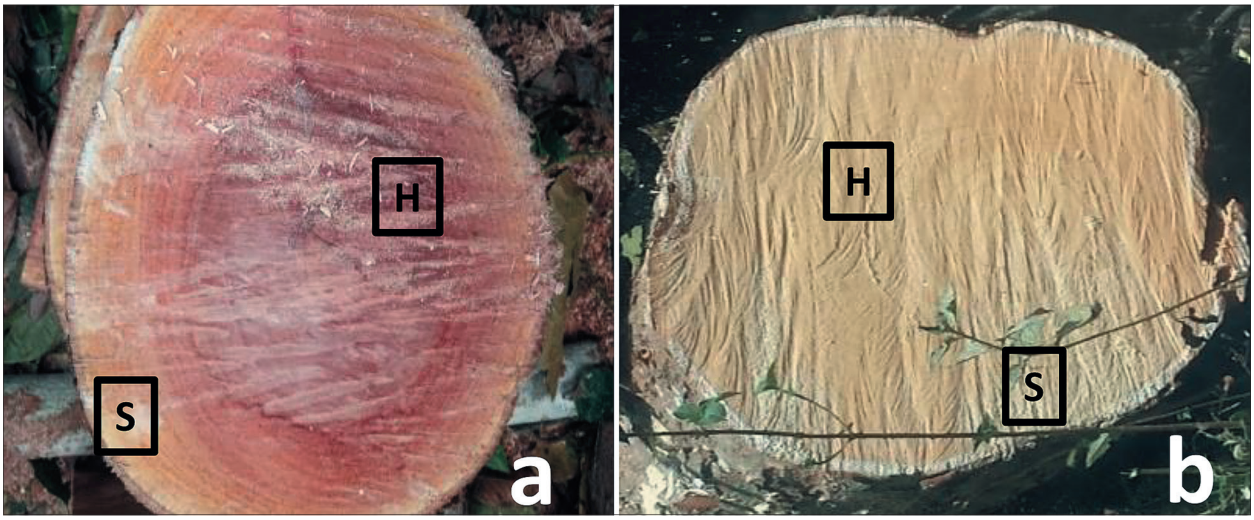

Figure 1. Cross sections of the stems of *Nesogordonia papaverifera* (a) and *Holarrhena floribunda* (b). S – sapwood, H – heartwood.

Slika 1. Prečni prerez debel *Nesogordonia papaverifera* (a) and *Holarrhena floribunda* (b). S – beljava, H – jedrovina.

The basic density of *H. floribunda* wood was found to vary from 456 to 479 kg/m³ (Antwi et al., 2022). The natural durability of *H. floribunda* heartwood of both stems and branches was rated moderately durable (Antwi et al., 2022) according to durability classifications (Eaton & Hale, 1993).

The wood of *N. papaverifera*, as shown in Figure 1a, is suitable for shaving into wood wool for packing fruit, carvings, combs, axe handles, and small utensils (Arevalo et al., 2020). *N. papaverifera* is also mostly used in furniture production and other structural purposes. However, not much has been studied with regard to the chemical composition characteristics across the components and tissues of stem wood, branch wood, and bark of this timber species.

In Ghana *H. floribunda*, as shown in Figure 1b, is mostly used for carving stools for kings, queen mothers, fetish priests, and other prominent persons in society, and is considered to be the best white wood available for these purposes. The wood anatomy of the species is described in InsideWood (InsideWood, *Holarrhena*, 2024).

The objective of this study is to determine the chemical components such as cellulose, hemicellulose, lignin, and total extractives of *N. papaverifera* and *H. floribunda* stem and branch wood and bark.

2 MATERIALS AND METHODS
2 MATERIALI IN METODE
2.1 MATERIALS
2.1 MATERIALI

Five mature trees each of *Nesogordonia papaverifera* (danta) and *Holarrhena floribunda* (sese) were acquired from New Koforidua, in the Ejisu – Juaben Municipality of the Ashanti region within the middle belt of Ghana to provide wood samples for the chemical composition of the structural and non-structural components of the wood and bark of the selected species, mainly because of the availability and accessibility of the trees. The trees were obtained from a cocoa farm in the same locality within the open forest of the area, which lies within latitudes 1° 15'N and 1° 45'N and longitude 6° 15'W and 7° 00'W. It occupies a land area of 637 km² (Ghana Statistical Service, 2021).

In this study, the sampling approach by Bao et al. (2001) was adopted. Trees with similar diameters at breast height were selected for harvesting for both *N. papaverifera* and *H. floribunda* species. The trees were first identified by a technical officer from the Forestry Commission, Juaso District. Fresh and dry leaves and seeds from the trees were collected and sent to the laboratory at the Forest Research Institute of Ghana for the confirmation of the field species identification using the field guide to the forest trees of Ghana by Arevalo et al. (2020). Trees were purposefully selected based on their availability in the farmland, the diameter range of 40-45 cm at the breast height, and the overall straightness of the trunk. Samples were critically examined to ensure that they were free from both natural and artificial defects. Samples were taken specifically from the three portions of the species tissues (the heartwood, the sapwood, and the wood bark) and the tree component (the stem and the branch wood) for their chemical characteristics, as illustrated in Figure 2. *N. papaverifera* exhibited a clear distinction between heartwood and sapwood, but in the case of *H. floribunda* there is no clear distinction between heartwood and sapwood, as shown in Figures 1a and 1b. As a result, the surface of the billets was carefully measured and sawn to ensure the inclusion of heartwood and sapwood portions. The discs of each selected portion were divided into four (i.e. North, South, East, and West) and sawn into three planks (1-3) from the pith portion of the billet to the bark portion to represent the heartwood and sapwood part of the tree after comparing the sawn planks results.

A disc of about 50 cm represents the stem and for a branch, 75 cm from the knot, a disc of 50 cm was extracted from the two branches of each tree

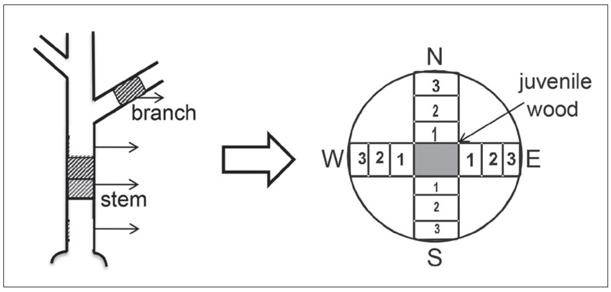

Figure 2. Schematic illustrations, showing how the wood and bark samples were collected from the stem and branches of the trees studied.

Slika 2. Shema, ki prikazuje način vzorčenja lesa in skorje iz debel in vej preučevanih dreves.

to obtain varied diameters of branch wood for the total extractive, hemicellulose, cellulose, and lignin study, as illustrated in Figure 2. This criterion was adopted to ensure the straightness of the branch disc and possibly avoid the inclusion of obvious tension wood.

2.2 CHEMICAL ANALYSIS OF WOOD AND BARK
2.2 KEMIJSKA ANALIZA LESA IN SKORJE

2.2.1 Content of total extractives
2.2.1 Vsebnost celokupnih ekstraktivov

The total extractives were determined in three successive steps: extraction with acetone, extraction with alcohol, and hot water extraction, according to the TAPPI standards. The dried samples were ground into a powder with a Wiley mill to pass a 40-mesh (425µm) sieve and retained in a 60-mesh (250µm) sieve. The extraction was performed using a Soxhlet extractor. After the extraction, the wood samples were air-dried before the determination of their chemical components (TAPPI T207cm-2011).

2.2.2 Lignin content
2.2.2 Vsebnost lignina

Lignin was determined by weighing 1g of extractive-free sample into a conical flask. Fifteen milliliters of cold sulfuric acid (72%) was then added slowly while stirring, and mixed well. The reaction proceeded for two hours with frequent stirring in a water bath maintained at 18-20°C. After two hours the specimen was transferred by washing it with 560ml of distilled water into a 1,000 ml flask, diluting the concentration of the sulfuric acid to 3%. A condenser was attached to the flask and the insoluble material was allowed to settle. The contents of the flask were filtered by vacuum suction into a fritted-glass crucible of known weight. The residue was washed with 500ml of hot tap water and then oven-dried at 103°C. The crucible was then cooled in a desiccator and weighed until a constant weight was obtained (TAPPI T222cm-2011).

2.2.3 Cellulose content
2.2.3 Vsebnost celuloze

Cellulose was determined by weighing 1.5g of the hemicellulose into a 250ml Erlenmeyer flask with a small watch glass cover. The flask was placed into a water bath at 25°C and 100ml of 17.5% NaOH solution was added with thorough stirring. After 30 minutes of stirring, 100ml of water was added and stirring was continued for another 30 minutes. The Erlenmeyer flask was removed and filtered with a fritted-glass crucible of known weight. The residue was washed with 25ml of 9.45% NaOH solution and then with 40ml of 10% acetic acid, and finally washed free of acid with plenty of water. The residue was oven-dried in an oven at 103°C, cooled in a desiccator, and weighed until a constant weight was reached (TAPPI T203cm-2011).

2.2.4 Hemicellulose content
2.2.4 Vsebnost hemiceluloz

Hemicellulose content was determined by weighing 2g of extractive-free sample in a 250ml conical flask with a small watch glass cover. The sample was then treated with 180ml of distilled water, 8.6g of sodium acetate, 6.0ml of acetic acid, and 6.6g of sodium chlorite. The sample was covered and placed in a hot-water bath for 3 hours. The samples were filtered into a coarse porosity-fitted glass of known weight and washed free of CIO_2 with distilled water. The crucible was oven-dried at 103°C, cooled in a desiccator, and weighed until a constant weight was reached.

2.3 STATISTICAL PROCEDURES
2.3 STATISTIČNA OBDELAVA PODATKOV

The data were checked for statistical significance using Origin statistical software (Version 9.0 Pro. software). A descriptive statistical tool was used to summarize the data numerically. The Tukey Multiple Comparison Test was used to test the statistical significance of each pair of means and the variation in the quantitative structural elements and total extractive. The Tukey HSD post-hoc tests were done to identify which of the pairs of treatments are significantly different from each other.

3 RESULTS AND DISCUSSION
3 REZULTATI IN RAZPRAVA

3.1 VARIABILITY OF THE CONTENT OF STRUCTURAL COMPONENTS AND EXTRACTIVES IN WOOD AND BARK
3.1 VARIABILNOST V VSEBNOSTIH STRUKTURNIH KOMPONENT IN EKSTRAKTIVOV V LESU IN SKORJI

3.1.1 Total extractives
3.1.1 Količine ekstraktivnih snovi

The cold-water-soluble samples of both stem and branch contained a more extractives than the hot-water-soluble samples. Ethanol soluble matter was slightly higher than the acetone soluble matter. The mean total extractives of bark, heartwood, and sapwood for the stem and branch of the species are shown in Table 1. For *N. papaverifera,* the stem wood recorded a total of 8.19% and 6.85% for the branch wood. *H. floribunda* recorded a total of 7.23% for the stem and 6.34% for the branch wood. For the radial variation, the bark contained higher extractives followed by the heartwood and sapwood. These differences in extractive content between the tissues have been known and scientifically proven for more than four decades. For the tree chemical components, the stem contained a higher content than the branch in both species but the differences are not significant.

The results show that the bark and heartwood contain a greater amount of extractives than the sapwood. This pattern was the consequence of the radial distribution of dichloromethane soluble, which had a peak concentration at the heartwood-sapwood transition (6.0%) and decreased to very small values in the outer sapwood (1.0%), as reported by Mayer et al. (2006). Polar compounds (ethanol and water-soluble) increased in sapwood and the largest concentrations were found closest to the bark. The differences between the bark, sapwood, and heartwood samples of the species studied are associated with the metabolic activities observed in the transition zone related to heartwood formation, with enzymatic hydrolysis of triglycerides and an increase in fatty acids during the process of parenchyma cell death (Piqueras et al., 2020). This type of radial variation of extractives has already been reported in other species, for example, Vek et al. (2020) investigated the amounts of hydrophilic extractives in bark and wood samples of black locust stem (*Robinia pseudoacacia L.*) and found that the concentrations of extractives were highest in the outermost samples of heartwood. Significantly less hydrophilic compounds were extracted from bark and sapwood samples. They reported that heartwood of black locust can be considered a source of value-adding compounds. The investigation showed significant variability in the content of extractives in the radial direction and less pronounced variability in the axial direction. Dünisch et al. (2010) reported that, based on extractive content, the formation of juvenile wood in black locust is restricted to the first 10–20 years of cambial growth. In mature heartwood, high contents of phenolic compounds and flavonoids were present, localized in high concentrations in the cell walls and cell lumen of axial parenchyma and vessels. In juvenile wood, the content of these extractives is significantly lower.

This pattern explains the variation in natural durability in the selected species where heartwood is more durable than sapwood. The results that show the bark and heartwood contain a greater amount of extractives than the sapwood (Kai, 1991).

The quantity of total extractives in wood is highly variable and can range from 3-30% by weight depending on the tree species (Desch & Dinwoodie, 2016), as was observed by this study. Roger (2012) noted that they usually range from 2–10% by dry weight and up to 40% in some timbers, the percentage extractives reported in Table 2 were higher in the stem wood than branch wood of the species, consistent with the report by Samariha and Kiaei (2011) for *Ailanthus altissima*. The higher extractive content may offer the heartwood of stem wood and branch wood better durability with regard to fungus infestation, and minimize the severity of attack by destructive organisms (e.g. termites), as reported by Quartey (2009). However, the sapwood portions of the studied species would have greater pulp yield, but less natural durability than their comparable heartwood portions. Moreover, the higher extractive content may be attributed to the attack of the tree by the shoot borer, which resulted in the large production of extraneous material to protect itself against the attack.

Table 1. Content of extractives in stem and branches as well as in different tissue categories (heartwood, sapwood and bark) of *Nesogordonia papaverifera* and *Holarrhena floribunda.*
Preglednica 1. Vsebnost ekstraktivov v deblu in vejah ter v različnih kategorijah tkiv (jedrovina, beljava in skorja) *Nesogordonia papaverifera* in *Holarrhena floribunda.*

Species	Tree component	Species tissue	Mass fraction of extractives (%) in:			
			Coldwater	Hot water	ASM	ESM
Nesogordonia papaverifera	Stem	Bark	17.50 (2.84)	14.65 (1.30)	4.09 (0.59)	5.87 (1.00)
		Sapwood	9.09 (0.67)	7.43 (1.82)	1.95 (1.24)	2.93 (0.61)
		Heartwood	15.86 (2.01)	11.40 (1.78)	3.87 (0.69)	3.74 (0.43)
		Average	14.15 (1.84)	11.16 (1.63)	3.30 (0.84)	4.18 (0.68)
						8.19
	Branch	Bark	14.85 (3.06)	13.46 (2.05)	2.69 (0.89)	3.27 (1.05)
		Sapwood	8.06 (1.86)	7.22 (1.64)	1.40 (0.52)	1.59 (0.24)
		Heartwood	12.34 (2.89)	11.87 (1.94)	2.80 (0.83)	2.78 (0.72)
		Average	11.75 (2.60)	10.85 (1.87)	2.29 (0.74)	2.54 (0.67)
						6.85
Holarrhena floribunda	Stem	Bark	15.56 (2.02)	13.23 (3.09)	4.23 (1.16)	6.12 (1.64)
		Sapwood	7.39 (1.74)	5.74 (1.13)	1.08 (0.78)	1.88 (0.48)
		Heartwood	12.79 (2.43)	11.59 (2.21)	3.92 (0.64)	3.37 (1.56)
		Average	11.91 (2.06)	10.18 (2.14)	3.07 (0.86)	3.79 (1.22)
						7.23
	Branch	Bark	14.77 (2.51)	12.74 (2.49)	2.55 (0.90)	4.30 (1.81)
		Sapwood	7.01 (2.17)	5.15 (0.96)	0.51 (0.31)	0.72 (0.44)
		Heartwood	12.08 (0.91)	11.87 (1.89)	2.22 (0.46)	2.25 (0.39)
		Average	11.28 (1.86)	9.92 (1.77)	1.76 (0.55)	2.42 (0.88)
						6.34

~Standard deviations in parentheses. ASM=Acetone soluble matter, ESM=Ethanol soluble matter

3.1.2 Lignin
3.1.2 Lignin

Lignin content in the heartwood of *N. papaverifera* and *H. floribunda* stem wood and branch wood was comparable to that in the bark tissue, but much lower lignin content was found in the sapwood of both species. A significant difference ($p<0.05$) exists between the bark and sapwood and heartwood. The stem wood contained higher values than the branch wood, but the differences were not significant. However, for *H. floribunda* species, the branch wood contained a slightly higher value than the stem wood but the difference is not significant at a 5% level of probability, as shown in Table 2.

The stem wood contained higher lignin than the branch wood for both selected timber species. Similar to what Samariha and Kiaei (2011) reported, there was a greater percentage of lignin in the stem wood compared to the branch wood of *Ailanthus altissima*. This study also confirms an earlier report by Ververis et al. (2004) which found that the content of chemical components, and especially lignin, in wood depends on tissue maturity, and the literature says there is a general tendency for a decrease in lignin as we move from the base of the tree to the top (Mitsuhashi, 2007). This corresponds to a greater lignin percentage in the stem than the branch from this study, in which the stem is expected to have older tissues such as fibres, parenchyma, and vessels than the branch. Again, Mitsuhashi (2007) noted that the amount of lignin in wood usually decreases from the heartwood to the sapwood and from the base of the tree to the crown. The lignin content observed in this study was greater in heartwood than sapwood, supporting Miranda et al. (2007) and Sitsofe (2016), who reported lower lignin content in the sapwoods of *Eucalyptus globulus*, *Eucalyptus nitens*, *Terminalia ivorensis,* and *Vachellia robusta.* However, the bark has more lignin followed by the heartwood and the sapwood portions in this study. This was expected since mature tissues (at the base) accumulate higher amounts of metabolic products than the younger parts at the top, as reported by Mitsuhashi (2007).

3.1.3 Cellulose
3.1.3 Celuloza

The cellulose content in the sapwood of *N. papaverifera* and *H. floribunda* stem wood and branch wood was comparable to that in the bark tissue, although a much lower cellulose content was found in the heartwood of the species. A significant difference ($p<0.05$) exists between the sapwood and heartwood, and the bark and the heartwood. The branch wood contained higher values than the stem wood, but the differences were not significant ($p<0.05$), as shown in Table 2.

The branch-sap/heartwood portion of the species contained a higher cellulose content than the stem sap/heart portion. This agrees with Magel (2000), which found that there is a greater cellulose percentage for sapwood than the heartwood. Comparing this result with earlier reports by Mitsuhashi (2007) and Raniati (2016), the data from the current study fall within the reported range. According to the rating system designated by Nieschlag et al. (1960), plant material with 34% and higher alpha-cellulose content can be characterized as promising for pulp and paper manufacture from a chemical composition point of view. As the principal food for termites, wood structures that contain excessive alpha-cellulose and moisture content are avidly consumed and destroyed by these insects (Peralta et al., 2003). With regard to their cellulose contents, the stem and branch sapwood of both *N. papaverifera* and *H. floribunda* could be suitable for the production of pulp and paper. The amount of cellulose and excessive moisture content at the sap portions within the two species could be factors that attract bio-degradation (i.e. termites) to attack the sapwood portion, making this less durable than the heartwood portion, as observed in our previous study on the termite resistance of stem and branch wood of these species (Antwi et al., 2020)

3.1.4 Hemicellulose content
3.1.4 Vsebnost hemiceluloz

The hemicellulose content in the sapwood of *N. papaverifera* stem wood and branch wood was comparable to that in the bark tissue, although much lower hemicellulose content was found in the heartwood of the species. A significant difference ($p<0.05$) exists between the sapwood and heartwood, and the bark and heartwood. The branch wood contained more hemicellulose than the stem wood, but the differences were not significant ($p<0.05$), as shown in Table 2.

The hemicellulose content for the stem and branch wood portions shows that the branch wood contained a higher percentage of hemicellulose than the stem wood portions for both species, similar to the findings of an earlier report by Magel (2000) which stated that there is more hemicellulose in branch wood than stem wood. In the species tissues in the radial direction, the sapwood had a greater amount of hemicellulose than the heartwood. This also supports Magel (2000), who found that heartwood has less hemicellulose content than sapwood. Mitsuhashi (2007) observed that hemicellulose in softwoods ranges from 25-30% and in hardwoods from 30-35%, and the results are within the range (28-34%) identified by Mitsuhashi (2007) for hardwoods. Bowyer et al. (2003) reported that the amount and type of hemicellulose within timber species depend on the kind of wood and the position along the stem, and this was observed within the branch and the stem of the two-timber species included in this study.

Table 2. Chemical analysis of tree components (stem and branch) and tissues (heartwood, sapwood, bark) of *Nesogordonia papaverifera* and *Holarrhena floribunda.*
Preglednica 2. Kemijska analiza drevesnih komponent (debla in vej) in tkiv (jedrovina, beljava, skorja) *Nesogordonia papaverifera* in *Holarrhena floribunda.*

Species	Tree part	Chemical compound (%)	Tissues			
			Bark	Sapwood	Heartwood	Average
Nesogordonia papaverifera	Stem	Lignin	30.45**a** (2.07)	25.85**b** (1.84)	32.95**a** (4.76)	29.75 (5.23)
		Cellulose	31.62**a** (3.67)	32.82**a** (4.94)	27.71**b** (2.38)	30.71 (3.43)
		Hemicelluloses	32.67**a** (3.67)	33.23**a** (4.94)	28.17**b** (3.24)	31.35 (2.63)
	Branch	Lignin	29.87**a** (1.09)	26.85**b** (2.54)	31.90**a** (3.42)	29.54 (2.06)
		Cellulose	33.60**a** (5.31)	33.84**a** (3.26)	28.14**b** (3.26)	31.86 (3.83)
		Hemicelluloses	34.15**a** (5.42)	33.10**a** (3.82)	28.00**b** (4.06)	31.75 (5.26)
Holarrhena floribunda	Stem	Lignin	31.64**a** (4.86)	25.20**b** (3.03)	31.00**a** (3.08)	29.28 (2.16)
		Cellulose	31.60**a** (2.96)	34.00**a** (2.44)	29.40**b** (5.32)	31.33 (3.35)
		Hemicelluloses	32.95**a** (2.96)	34.43**a** (3.54)	29.10**b** (5.31)	32.16 (4.35)
	Branch	Lignin	32.00**a** (3.89)	26.40**b** (2.61)	30.62**a** (2.35)	29.67 (2.53)
		Cellulose	32.85**a** (2.70)	33.25**a** (3.35)	27.95**b** (1.02)	31.35 (3.90)
		Hemicelluloses	34.19**a** (2.70)	34.95**a** (5.02)	28.78**b** (2.47)	32.64 (4.16)

~Mean values in different letters (**a** and **b**) indicate a significant difference (P<0.05)
~Standard deviations in parentheses

4 CONCLUSIONS
4 SKLEPI

Generally, the chemical characteristics of the branch wood of the species studied are comparable with their stem wood and other most known species used for structural applications in Ghana. The cellulose and hemicellulose contents were higher in sapwood than in heartwood and in branch wood than in stem wood. However, the lignin and extractive content of both species was higher in heartwood than in sapwood and in stem wood than in branch wood. The content of cellulose and hemicelluloses was lower in bark than in wood.

The lignin, cellulose, hemicellulose, and total extractive content are comparable in stem wood and branch wood in both species, *N. papaverifera* (danta) and *H. floribunda,* like in the well-known wood species such as *Leuceana leucocephala* and *Moringa perigrina* woods that are used in the production of pulp for the paper industry in Ghana. The content of cellulose and hemicellulose was lower in bark than in wood in both species.

For radial variation, the sapwood recorded a greater value of cellulose and hemicellulose content than the heartwood. However, the heartwood and bark recorded a greater amount of lignin and total extractive content than the sapwood.

While the biomass of the Ghanaian tree species studied here is usually described as less utilizable, this report shows that the wood and bark of these species are useful and could be a source of valuable bioactive phytochemicals, but this needs further investigation.

5 SUMMARY
5 POVZETEK

Določili smo kemično zgradbo in količino ekstraktivov v deblih, vejah in skorji dveh tropskih listavcev *Nesogordonia papaverifera* (kotibe, danta) in *Holarrhena floribunda* (holarhena, sese) iz Gane. Določili smo količino ekstraktivov, lignina, celuloze in hemiceluloz.

Pet zrelih dreves vsake od obeh vrst smo posekali v območju New Koforidua v občini Ejisu-Juaben v regiji Ashanti v srednjem pasu Gane na kmetiji kakava in v odprtem gozdu območja, približne koordinate 1°15'J do 1°45'J, 6°15'Z in 7°00 Z.

Vzorčili smo v skladu z metodologijo, ki so jo uporabili Bao in sodelavci (2001). Drevesa so imela podobne premere v prsni višini. Drevesa je prvi določil tehnični uradnik iz komisije za gozdove okrožja Juaso. Sveže in suhe liste in semena z dreves so zbrali in poslali v laboratorij na Inštitutu za gozdne raziskave Gane za potrditev identifikacije drevesnih vrst z uporabo terenskega vodnika po gozdnih drevesih Gane (Arevala et al., 2020). Drevesa so bila izbrana glede na njihovo razpoložljivost na kmetijskem zemljišču, razponi premerov so bili 40–45 cm v prsni višini. Pri vzorčenju smo izbrali ravna debla. Vzorci so bili pregledani, da bi zagotovili, da so brez napak. Odvzeti so bili iz beljave in jedrovine debla in vej.

Iz debla smo odvzeli hlodiče dolžine približno 50 cm in iz vej kolute približno 75 cm od nastavka prve in druge veje vsakega drevesa. Vzorčili smo tako, da so bili hlodiči čim bolj ravni, s čim manj tenzijskega lesa in drugih napak. Vsi testi so bili izvedeni v skladu z navodili standardiziranega tehničnega združenja za celulozo in papir (TAPPI), razen za topnost lesa v alkoholu in benzenu. Pri določanju količine ekstraktivov je prišlo do manjše spremembe. Namesto alkohola in benzena je bil zaradi varnosti uporabljen aceton.

Za določitev osnovne statistike in statističnih razlik smo podatke obdelali s statističnim programom Origin (različica 9.0 Pro.).

Ugotovljenih je bilo več v hladni vodi topnih ekstraktivnih snovi kot tistih, topnih v vroči vodi. Snovi, topnih v etanolu, je bilo nekoliko več kot snovi, topnih v acetonu. Topilo diklorometan je bilo uporabljeno za določanje sterolov, maščobnih kislin in voskov, v skladu s standardom TAPPI T204cm-97 za komponente lesa debel in vej za obe vrsti. Povprečni celokupni ekstraktivi skorje, jedrovine in beljave so prikazani v preglednici 1. Skorja je imela največ ekstraktivnih snovi, sledile so količine v jedrovini in nato v beljavi. V deblih je bilo pri obeh vrstah več ekstraktivnih snovi kot v vejah, vendar razlike niso bile statistično značilne.

Les vej je imel višji odstotek hemiceluloz kot deblo in skorja. Vsebnost celuloze je bila višja v beljavi in nižja v jedrovini. Les vej je imel več celuloze kot les debla, vendar razlike niso bile statistično značilne ($p<0,05$). Vsebnost lignina je bila višja v jedrovini in nižja v beljavi obeh vrst. Les debla je imel več lignina kot les vej, vendar razlike niso bile statistično značilne. Izvlečki skorje in jedrovine vrste *N. papaverifera* se lahko uporabljajo za zaščito lesa beljave nekaterih drugih drevesnih vrst.

Ker se šteje, da je biomasa preučevanih lesnih vrst iz Gane slabo uporabna, ta študija kaže, da sta les in skorja obeh vrst uporabna in bi lahko bila vir dragocenih bioaktivnih fitokemikalij, vendar je ta potencial treba dodatno raziskati.

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REFERENCES
VIRI

Albert, L., Hofmann, T., Nemeth, Z., I., Retfalvi, T., Koloszar, J., Verga, S., & Csepregi, I. (2005). Radial variation of total phenol content in beech (*Fagus sylvatica* L.) Wood with and without heartwood. European Journal of Wood and Wood Products, 61(3), 227–230. DOI: https://doi.org/10.1007/s00107-003-0381-x

Antwi, K., Cremer, T., Amoah, M., & Frimpong-Mensah, K. (2020). Termite resistance of stem and branch wood of two tropical hardwood species in Ghana, Society of Wood Science and Technology 63rd conference, Slovenia. URL: https://www.swst.org/wp/meeting/2020-international-convention-slovenia/ (11.12.2023)

Antwi, K., Cremer, T., & Frimpong-Mensah, K. (2022). Variations of stem and branch wood properties of *Nesogordonia papaverifera* in Ghana. Journal of Plant Sciences, 10(1), 32–41. DOI: https://doi.org/10.11648/j.jps.20221001.15

Arevalo, R., Ebanyaenle, E., Ebeheakey, A. A., Abban Bonsu, K., Lambog, O., Soares, R., & Wiedenhoeft, A., C. (2020). Field identification manual for Ghanaian timbers. United States Department of Agriculture. General Technical Report

FPL-GTR-277. URL: https://www.fs.usda.gov/treesearch/pubs/60264 (11.12.2023)

Bao, F. C., Jiang, Z. H., Jiang, X. M., Lu, X. X., Luo, X. Q., & Zhang, S. Y. (2001). Differences in wood properties between juvenile wood and mature wood in 10 species grown in China. Wood Science and Technology, 35, 363–375.

Boampong, E., Effah, B., Antwi, K., Boadi Asante, A., & Nti, A., J. (2015). Factors influencing the choice of timber for furniture and joinery production in Ghana. European Journal of Engineering and Technology, 3(5), 12–16.

Bowyer, L. J., Shmulsky, R., & Haygreen, G. J. (2003). Forest products and wood science: an introduction. (4th ed.). Iowa: Blackwell Publishing Company, 103–319.

Desch, H. E., & Dinwoodie, J. M. (2016). Timber structures, properties, conversion, seasoning, and use (7th eds). Published by Macmillan International, 27–56.

Dünisch, O., Richter, H. G., & Koch, G. (2010). Wood properties of juvenile and mature heartwood in *Robinia pseudoacacia* L. Wood Science Technology, 44, 301–313. DOI: https://doi.org/10.1007/s00226-009-0275-0

Eaton, R. A., & Hale, M. D. C. (1993). Wood decay, pests, and protection. 546. Cambridge: Chapman and Hall, University Printing house.

Ghana Statistical Service (2021). The district analytical report for Ejisu-Juaben Municipal in the Ashanti region. URL: https://statsghana.gov.gh/2021phc/ (15.12.2023)

Inside Wood, *Holarrhena floribunda*. URL: https://insidewood.lib.ncsu.edu/description?7 (20.2.2024).

Inside Wood, *Nesogordonia papaverifera*. URL: https://insidewood.lib.ncsu.edu/description?10 (20.2.2024).

Kai, Y. (1991). Chemistry of extractives. In wood and cellulosic chemistry, D. N. S. Hon and N. Shiraishi, eds. (New York: Marcel Dekker, Inc.), 215-255.

Magel, E. A. (2000). Biochemistry and physiology of heartwood formation. 363-379: cited in Taylor, A. M., Gartner, B. L. and Morrell, J. J. (2002). Heartwood formation and natural durability. A review. Wood Fiber Science, 34(4), 587–611.

Mayer, I., Koch, G., & Puls, J. (2006). Topochemical investigations of wood extractives and their influence on color changes in American black cherry (*Prunus serotina* Borkh). Holzforschung, 60, 589–598. DOI: https://doi.org/10.1515/HF.2006.100

Miranda, I., Gominho, J., Lourenco, A., & Pereira, H. (2007). In Abdel-Aal, M. A., Nasser, R. A. and Al-Meferrej, H. A. (2011). Comparative study on tension and opposite woods of some species grown and under Saudi Arabia condition. Middle-East Journal of Scientific Research, 7(4), 490-496.

Mitsuhashi, G. J. M. (2007). Limiting copper loss from treated wood in or near aquatic environment. Master's thesis. Oregon State University. URL: https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/qz20sv42h (15.12.2023)

Nieschlag, H. J., Nelson, G. H., & Wolff, I. A. (1960). A search for new fiber crops. Tappi Journal*,* 44(7), 515–516.

Peralta, R. C. G., Menezes, E. B., Carvalho, A. G., & Menezes, E. L. A. (2003). Feeding preferences of subterranean termites for forest species associated or not to wood-decaying fungi. Floresta e Ambiente 10,(2), 5–63.

Piqueras, S., Füchtner, S., Rocha de Oliveira, R., Gómez-Sánchez, A., Jelavić, S., Keplinger, T., De Juan, A., Garbrecht, T. L. (2020). Understanding the formation of heartwood in larch using synchrotron infrared imaging combined with multivariate analysis and atomic force microscope infrared spectroscopy. Frontiers in Plant Science, 10 art. 1701. DOI: https://doi.org/10.3389/fpls.2019.01701

Quartey, A. G. (2009). Relationships between some anatomical, physical, and durability properties of the wood of some lesser utilized Ghanaian hardwoods. Doctoral thesis. Faculty of Renewable Natural Resources, Kwame Nkrumah University of Science and Technology Library, Kumasi.

Roger, M. R. (2012). Cell wall chemistry. Handbook of wood chemistry and wood composites. 2nd Edition, Boca Raton: Taylor and Francis. DOI: https://doi.org/10.1201/b12487

Samariha, A., & Kiaei, M. (2011). Chemical composition properties of stem and branch in *Ailanthus altissima* wood. Middle-East Journal of Scientific Research, 8(5), 967–970.

Sitsofe, K. M. (2016). The natural durability, anatomy, and chemical composition of the stem and branch woods of two commercial hardwood timbers. Doctoral thesis. Faculty of Renewable Natural Resources, Kwame Nkrumah University of Science and Technology Library, Kumasi.

Tamboura, H. H., Bayala, B., Lompo, M., Guissou, I. P., & Sawadogo, L., (2005). Ecological distribution, morphological characteristics and acute toxicity of aqueous extracts of *Holarrhena floribunda* (G. Don) Durand & Schinz, *Leptadenia hastata* (Pers.) Decne and *Cassia sieberiana* DC. Used by veterinary healers in Burkina Faso. African Journal of Traditional, Complementary and Alternative Medicines, 2(1), 13–24.

TAPPI T264 cm (2009). Standardized Technical Association of the Pulp and Paper: Preparation of wood for chemical analysis. Committee of the Process and Product Quality Division, TAPPI, Atlanta, GA, USA.

TEDB (2019). Report on the export of timber and wood productions. Research and Statistics, Timber Industry Development Division of Forestry Research Institute of Ghana. URL: https://fcghana.org/?p=2808 (15.12.2023)

Vek, V., Poljanšek, I., & Oven, P. (2020) Variability in content of hydrophilic extractives and individual phenolic compounds in black locust stem. European Journal of Wood and Wood Products, 78, 501–511. DOI: https://doi.org/10.1007/s00107-020-01523-y

Ververis, C., Georghiou, K., Christodoulakis, N., Santas, P., & Santas, R. (2004). Fiber dimensions, lignin, and cellulose content of various plant materials and their suitability for paper production. Industrial Crops and Products, 19, 245–254. DOI: https://doi.org/10.1016/j.indcrop.2003.10.006

Wheeler, E. A. (2011). InsideWood – A web resource for hardwood identification. IAWA Journal 32(2), 199–211.

Wheeler, E. A., Gasson, P. E., & Baas, P. (2020). Using the InsideWood web site: potentials and pitfalls. IAWA Journal, 41(4), 412–462. DOI: https://doi.org/10.1163/22941932-bja10032