Liquid Chromatography-Ultraviolet-Mass Spectrometry Analyses of Hydroethanolic Extracts of Three Wood Species and Their Antioxidant and Antifungal Activities

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Abstract

Degradation of wood and rot caused by wood-decaying fungi is a significant concern for countries such as Côte d'Ivoire, which has a substantial forest heritage. These pathogenic fungi have a negative effect on wood and other living organisms. Biological control agents could address environmental issues related to the large amount of wood waste in our environment and health issues linked to use of synthetic chemicals to combat wood-decaying fungi. This study examines the control of wood-destroying fungi *Coniophora puteana*, *Pleurotus ostreatus*, *Poria placenta*, *Pycnoporus sanguineus*, and *Trametes versicolor* using extracts from three durable woods of Côte d'Ivoire, *Mansonia altissima* (Bete), *Milicia excelsa* (Iroko), and *Nauclea diderrichii* (Badi). Wood sawdust comprises mixtures of sapwood and heartwood; for each wood species, evaluation of the hydroethanolic extracts obtained from sawdust with different sapwood : heartwood ratios is valuable. The studied sapwood–heartwood proportions were 5 percent : 95 percent, 15 percent : 85 percent, and 30 percent : 70 percent, with pure sapwood and pure heartwood extracts at 100 percent. Results showed that extracts from heartwood, sapwood, and sapwood–heartwood mixtures had fungicidal effects, with MFCs for Iroko of 1.25 mg mL^{-1} against *C. puteana*, *P. ostreatus*, and *P. placenta*. *Bete* extracts were more effective against *P. sanguineus* and *T. versicolor*, with minimum fungicidal concentrations of 4 mg mL^{-1} and 2.5 mg mL^{-1}, respectively. This study highlighted that the proportion of sapwood in sawdust (5%–30%), did not affect the fungicidal capacity or quality of the extracts. This research is of great significance for the large-scale valorization of wood sawdust and helps address a major environmental issue.

Côte d'Ivoire is rich in forest resources, particularly timber (IFFN 2021). Côte d'Ivoire has one of the largest forest massifs in West Africa, with around 4 million hectares of forest, according to the August 2023 progress report (Cuny et al. 2023). However, the intensification of forestry activities (e.g., tree felling, sawmilling) in the country has led to the production of a large amount of waste, which represents a major environmental challenge (MINEDD 2021). The main types of forest waste in Côte d'Ivoire are felling residues (e.g., trunks, branches, leaves, stumps), sawdust and shavings from sawing, bark, and other wood-processing waste (N'Guessan et al. 2023). These wastes have no major use for companies or local populations, and they are often burned, left on site, or simply buried, leading to air, soil, and water pollution that negatively affects the environment and biodiversity (ADEME 2016).

Efforts, such as the development of charcoal and fiberboard production or the use of residues as fuel, are being

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undertaken by the Ivorian government and research institutions to better valorize this waste (Organisation des Nations Unies pour l'Alimentation et l'Agriculture 2010). However, these efforts remain ineffective in the face of the amount of waste produced; therefore, in this context, alternative methods must be determined to ensure effective management of forestry waste in Côte d'Ivoire (N'Guessan et al. 2023). In this context, one alternative to traditional wood-waste management would be the valorization of the bioactive molecules they contain. Several scientific studies on the biological, toxicological, and chemical properties of Ivorian tree species have shown that they represent a critical reservoir of bioactive molecules with high economic potential (Annick et al. 2011; Bley-Atse et al. 2025). Several studies have shown that Ivorian woods such as samba (*Triplochiton scleroxylon*), fraké (*Terminalia superba*), and dabema (*Piptadeniastrum africanum*) contain phenolic and terpene compounds with promising fungicidal activities (Nadio et al. 2022). These wood extracts have demonstrated good effectiveness in inhibiting the growth of plant pathogenic fungi such as *Fusarium oxysporum f. sp. cubense*, *Aspergillus niger*, and *Candida albicans* (Tiendrebeogo et al. 2017).

With the aim of reducing environmental pollution caused by wood waste, promoting a circular economy, and decreasing the use of synthetic chemical compounds in our environment, the integration of an extractive sector downstream of forestry operations would be beneficial for the Ivorian economy and the environment in Côte d'Ivoire through the valorization of high value-added applications across various markets (N'Guessan et al. 2023; Bley-Atse et al. 2025). In some countries, for example, the "extractives chain" is an essential way of adding value to forest biomass; it can be used to design active ingredients for the cosmetics, phytopharmaceutical, wood preservation, and nutraceutical sectors (Thomas et al. 2023). The emergence of this sector relies primarily on the availability of naturally occurring bioactive molecules found in large quantities in the waste generated from forestry operations, which are characterized in tropical species by their diversity and high content (Annick et al. 2011; Broda 2020). However, extraction yields of these active compounds vary according to wood species, harvesting areas, and extraction methods used (Ouaar et al. 2022).

Species with high biological potential include *Milicia excelsa* (Iroko), *Mansonia altissima* (Bete), and *Nauclea diderrichii* (Badi; N'guessan et al. 2009; Seguena et al. 2013). These three types of trees were chosen because they contain extracts with strong bioactive potential (Thomas et al. 2023; Bley-Atse et al. 2025). For several years now, a significant amount of work has been performed on the valorization of extracts from Iroko, Bete, and Badi, studying their bioactive potential against various pests and their biotolerance (Adeoti et al. n.d.). This research has focused only on complex mixtures of molecules derived from leaves, roots, and bark (N'guessan et al. 2009; Seguena et al. 2013). However, the bulk of forest industry byproducts come from wood (heartwood and sapwood) and are complex mixtures of sapwood and heartwood (Seguena et al. 2013).

This study focuses on the use and recovery of sawdust and shavings produced by secondary wood-processing companies (joineries). The waste from these woods, such as certain Ivorian wood species, contains natural compounds with interesting properties, including antioxidant, fungicidal, anticancerous, antimicrobial, insect attractant, herbivore repellent (N'Guessan et al. 2023; Bley-Atse et al. 2025). The valorization of these wood-waste extracts as natural fungicides presents an economic and environmental interest for Côte d'Ivoire. Several studies focus on the potential of wood bioactive molecules as preservatives for nondurable woods); authors have demonstrated that extracts from those Ivorian species were useful for transferring durability to nondurable woods exposed to severe environmental conditions (Bopenga 2020; Calovi et al. 2024). Therefore, this study investigated the antioxidant and antifungal activity of extracts from heartwood, sapwood, and mixtures (sapwood : heartwood of 5%:95%, 15%:85%, 30%:70%) of *M. excelsa* (Iroko), *M. altissima* (Bete), and *N. Diderrichii* (Badi) against five wood-eating fungi (i.e., *Coniophora puteana*, *Pleurotus ostreatus*, *Poria placenta*, *Pycnoporus sanguineus*, and *Trametes versicolor.*

Materials and Methods

The study focuses on hydroethanolic extracts (1:1, v/v) from heartwood, sapwood, and heartwood–sapwood mixtures of three sustainable Ivorian tree species: *M. excelsa* (Iroko), *M. altissima* (Bete), and *N. diderrichii* (Badi). The trees (three trees per species) were sampled in the Besso classified forest, located in southeastern Côte d'Ivoire (06°14′ to 06°30′N, 003°37′ to 003°48′W). The sampling procedure followed the French standard NF B51-003 of September 1985, which involves the felling and processing of sampled trees to assess the properties of their wood.

After felling, in the field, a 1-m log was collected from each tree at a height of 1.3 m above the ground and then transported to the sawmill. At the sawmill, two central planks were sawn from each log for further studies.

Five wood-decaying fungi were used in the study: *P. ostreatus*, *P. sanguineus* (L.:Fr.), and *T. versicolor* ([Linnaeus] L. Quélet, strain CTB 863 A), which cause white rot (or fibrous decay), as well as *P. placenta* ([Fries] Cooke, sensu J. Eriksson, strain FPRL 280) and *C. puteana* ([Schumacher ex Fries] Karsten, strain BAM Ebw. 15), which are responsible for brown rot (or cubic decay). All fungal strains were provided by the Centre de Coopération Internationale en Recherche Agronomique pour le Développement in Montpellier.

Sample preparation

After felling the trees, wood samples were taken from the heartwood and sapwood of each log. The samples were then crushed, ground separately with a Retsch SM100 mill (Retsch Group, Haan, Germany) and sieved using a 0.5-mm mesh sieve. After grinding, the samples were placed in a climatic chamber set to 20°C at 70 percent relative humidity for 2 weeks, and the moisture content of the sawdust was determined. The average moisture content of the samples was measured in triplicate for each species. A mass of shavings ($M1 = 20$ g) was placed in an oven at 103°C ± 2°C, then weighed to constant mass to determine the dry mass ($M2$). The moisture content of the samples was determined according to the equation:

$$H = \frac{M1 - M2}{M1} \times 100 \quad (1)$$

where

$H =$ sample humidity in percent,
$M1 =$ wet mass of samples in g, and
$M2 =$ dry mass of samples in g.

Extraction

This work promotes sustainable development by reducing the environmental effect of the chemical industry while maintaining quality of life and meeting society's needs, so a green, sustainable, and ecological extraction solvent, ethanol–water (1:1, v/v) was chosen. Cold maceration was used as the extraction method. To achieve this, 20 g of wood shavings ($M1$) were placed in a 500-mL flask, then 200 mL of an ethanol–water solvent mixture (1:1, v/v, 96% ethanol and distilled water) were introduced, followed by 2 hours of magnetic stirring. Extracts were obtained after filtration on a whatman filter (grade 4 CHR) and evaporation using a rotavapor (Buchi, France) and an oven at 65°C. The dry extract ($M3$) obtained was stored in a dark place at 5°C. The average extractives content (T) was determined from a triplicate per species according to the equation:

$$T = \frac{M3}{M1} \times 100 \quad (2)$$

where

$T =$ extractives content (%),
$M1 =$ wet sample mass (g), and
$M3 =$ mass of dry extract obtained after evaporation (g).

Quantitative analysis of extractives

We highlighted the presence or absence of certain chemical groups known for their biological activities using tests in which a coloration or precipitate specific to the major chemical families appeared, in accordance with the techniques described in the work of Bekro et al. (2008). Three repetitions were completed for each test, and the results were interpreted as follows:

Presence denoted with +; absence denoted with −.

Polyphenol detection was performed according to the method described by Bekro et al. (2008). A few drops of 2 percent alcoholic ferric chloride solution were added to 2 mL of extract (5 mg mL^{-1}, ethanol–water, 1:1 [v/v]) for each of the essences studied. The appearance of a dark, blue-black, or green color indicates the presence of phenolic compounds.

The detection of catecholic tannins was completed according to the method described by Bekro et al. (2008). The 5 mL of extract (5 mg mL^{-1}, ethanol–water) was added to 15 mL of STIASNY reagent (10 mL 30% formalin plus 5 mL concentrated HCl). The mixture was kept in a water bath at 80°C for 30 minutes then cooled. Precipitates were observed, indicating the presence of catecholic tannins (Julkunen-Tiitto 1985). The solution containing catecholic tannins was filtered through a whatman filter (grade 4 CHR), and the filtrate collected was saturated with sodium acetate. Three drops of 2 percent ferric chloride were added to this mixture. The appearance of an intense blue-black coloration indicates the presence of gallic tannins (Bekro et al. 2008).

Flavonoids were detected in a tube containing 3 mL of extract solution (5 mg g mL^{-1} ethanol–water), to which a few drops of 10 percent NaOH solution were added. A yellow-orange color indicates the presence of flavonoids (Le Thi et al. 2021).

For saponins, 5 mg g mL^{-1} (ethanol–water) wood extract is dissolved in a test tube containing 10 mL of distilled water. The tube is shaken vigorously lengthwise for 30 to 45 seconds, then left to stand for 15 minutes. The height of the foam is measured. The persistence of foam over 1 cm in height indicates the presence of saponins (Tampang et al. 2024).

For alkaloid detection, 4 mL of each extract solution (5 mg mL^{-1} ethanol–water) is evaporated to dryness by heating in a water bath in a capsule. The residue is taken up in 4 mL alcohol at 60°C. The alcoholic solution is divided into two test tubes. In the first tube, two drops of Bourchardat reagent (iodine–iodide reagent) are added. Observation of a reddish-brown precipitate indicates the presence of alkaloids. In the other tube, two drops of Dragendorff reagent (aqueous solution of potassium iodobismuth) are added. The appearance of a precipitate or an orange coloration indicates the presence of alkaloids.

For sterols and polyterpenes, 0.1 g of dry extract of each essence is dissolved in 1 mL of acetic anhydride in a hot capsule, then transferred to a test tube containing 0.5 mL concentrated sulfuric acid (H_2SO_4). The appearance of a violet coloration, turning blue and then green, reveals the presence of sterols and triterpenes.

Determination of phytochemical compounds in extracts

Determination of total polyphenols.—The total polyphenol content of extracts was determined using the Folin-Ciocalteu method described by Wood et al. (2002). A volume of 30 µL of hydroalcoholic extract (1 mg mL^{-1}) or extract fraction were added to 2.5 mL of Folin-Ciocalteu reagent diluted 1:10. The resulting mixture was kept for 2 minutes in the dark at room temperature (27°C ± 3°C), after which 2 mL of 75 g L^{-1} sodium carbonate solution was added. The resulting solution is then incubated at 50°C for 15 minutes. Absorbance readings are taken using an ultraviolet (UV)-visible spectrophotometer at a wavelength of 760 nm against a blank comprising 5 mL of Folin-Ciocalteu reagent diluted 1:10 and 4 mL of 75 g L^{-1} sodium carbonate solution. Gallic acid was used as the reference standard for establishing the calibration curve and quantifying total polyphenol content, which was expressed as mg gallic acid equivalent (GAE) per g extract. Tests were completed in triplicate for each sample. The total polyphenol content of the extract and fractions were determined from the calibration curve plotted using gallic acid as the standard.

Determination of flavonoids.—The method of Marinova et al. (2005) was used for the determination of total flavonoids. Volumes of a 0.75-mL 5 percent (w/v) sodium nitrite solution and 0.75-mL 10 percent (w/v) aluminum chloride solution are added to 2.5 mL of hydroalcoholic extract solution (1 mg mL^{-1}) or 1/500 (w/v) fraction. After 5 minutes of incubation at 25°C ± 5°C, the mixture was completed with 5 mL of 1 M sodium hydroxide solution. The volume obtained is adjusted to 25 mL, then shaken vigorously. Absorbance was recorded at 510 nm against a blank comprising 0.75-mL 5 percent (w/v) sodium nitrite solution, 0.75-mL 10 percent (w/v) aluminum chloride solution, and 5-mL 1 M sodium hydroxide solution. Quercetin was used as the standard for establishing the calibration curve and for quantifying total flavonoid content, expressed as mg quercetin equivalent (EQ) per g extract. Tests were performed in triplicate for each sample. The flavonoid content of the hydroalcoholic extract and fractions was determined from the calibration curve plotted using quercetin as the standard.

Determination of condensed tannins.—Condensed tannin content is determined using the method described by Julkunen-Tiitto (1985): 50 µL of each fraction or hydroalcoholic extract is added to 1,500 µL of 4 percent vanillin solution in methanol. The resulting mixture is vigorously shaken, and 750 µL of concentrated hydrochloric acid is added. The resulting mixture is left to react at room temperature for 20 minutes. Absorbance was measured at a wavelength of 550 nm against a blank comprising the 4 percent vanillin solution in methanol. Tests were completed in triplicate for each sample. A stock solution of tannic acid was used as the standard for establishing the calibration curve and for quantifying condensed tannin content, expressed in mg equivalents of tannic acid (EAT) per g of dry matter. Tests were completed in triplicate for each sample. The condensed tannin content of the extract and fractions was determined from the calibration curve plotted using the stock tannic acid solution as standard.

Antioxidant activity of extracts

ABTS+ method.—This method is based on the ability of the compounds to reduce the 2,2′-azinobis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS+) radical cation. The test was performed according to the method described by Teow et al. (2007). ABTS+ radical cation was produced by reaction of 8 mM ABTS (87.7 mg in 20 mL distilled water) and 3 mM potassium persulfate (0.0162 g in 20 mL distilled water) in a 1:1 (v/v) ratio. The mixture was then incubated in the dark at room temperature for 16 to 20 hours. This ABTS+ solution was diluted with methanol to obtain a solution with an absorbance of 0.7 ± 0.02 at 734 nm. Thus, 3.9 mL of this diluted $ABTS^+$ solution was added to 100 µL of the extract solution to be tested. After stirring, the mixture was incubated for 6 minutes in the dark (T = 30°C ± 2°C). The residual absorbance of the $ABTS^+$ radical was then measured at 734 nm with a UV-visible spectrophotometer and should be between 20 and 80 percent of the absorbance of the blank. Tests were performed on triplicates, and results were expressed in µmol Trolox equivalent (ET) per liter of extract by the equation:

$$I(\%) = \frac{A_0\ (\text{Control absorbance}) - A\ (\text{Absorbance of extract})}{A_0\ (\text{Control absorbance})} \times 100 \quad (3)$$

where

control absorbance = diluted ABTS absorbance,
absorbance of extract = diluted ABTS absorbance + sample, and

the antioxidant activity of the various extracts is as follows:

$$\text{Antioxidant concentration or activity } [\mu\text{MeqTrolox L}^{-1}] = \frac{I(\%)*Fd}{49.9} \quad (4)$$

where

$I(\%)$ = percentage of inhibition of the $ABTS^+$ radical and
Fd = dilution factor.

The extract concentration before dilution = 1 mg mL^{-1}.

DPPH method.—A 100-µM solution of 2,2-diphényl 1-picrylhydrazyl (DPPH) in methanol was prepared. Seven concentrations of extract from 0 to 200 μg^{-1} mL^{-1} were then prepared. Then, 3.9 mL of DPPH was added to 100 µL of extract. After stirring, the reaction mixture was incubated for 15 minutes in the dark at room temperature.

The absorbance of the radical is measured at 517 nm using a spectrophotometer against a blank comprising 2 mL methanol. The percentage reduction of the DPPH free radical was expressed by the following equation:

$$I(\%)\frac{A_0 - A}{A_0} \times 100 \quad (5)$$

where

A_0 = absorbance of the $ABTS^+$ control solution and
A = absorbance of the sample containing the antioxidant extract.

Control absorbance is the absorbance of control (DPPH solution without extract), and sample absorbance is the absorbance of DPPH in the presence of extract.

The inhibitory concentration $(IC)_{50}$ value is the concentration that ensures a 50 percentage reduction in DPPH, determined graphically for each extract from the curve of percentage reduction versus concentration (Samarth et al. 2008).

Antifungal activity

The efficacy threshold was determined for each extract on the five lignivorous fungi—*C. puteana*, *P. ostreatus*, *P. placenta*, *P. sanguineus*, and *T. versicolor*—under laboratory conditions using the ELISA (Enzyme-Linked Immunosorbent Assay) plate method. The method involves inoculating a disc of each fungus obtained with a sterile cork borer into each well of the ELISA plate in the presence of extracts at different concentrations and allowing incubation for 72 hours. Each of the extracts from sapwood, heartwood, and the mixture (sapwood–heartwood) of the three species studied were prepared by dissolving 25 mg of dry extract in

1 mL of ethanol–water solvent (1:1, v/v). Stock solutions with a concentration of 25 mg mL^{-1} were obtained. Two types of culture medium were prepared. The first was malt medium, prepared by adding 40 g of malt to 1 liter of water, shaking and autoclaving at 120° for 25 minutes. From this medium and the stock solutions, 10 concentrations covering a range from 1.25 mg mL^{-1} to 12 mg mL^{-1} were prepared on the ELISA plate in a laminar flow hood next to a flame, then inoculated with mycelium from the three fungi and left to incubate for 72 hours.

The wells of the ELISA plate have a volume of 200 µL. To validate the assay, it was ensured that the presence of alcohol in the medium did not affect fungal growth. Ethanol is generally used as a disinfectant at concentrations ranging from 60 to 90 percent. In our study, with the different dilutions made, ethanol showed no fungicidal or fungistatic activity. A test solution was prepared by replacing the volume of extract with the same volume of ethanol–water mixture (1:1, v/v). The virulence of the strain was also checked by using a negative control to monitor mycelial growth on extract- and alcohol-free medium. A positive control was prepared with tebuconazole (known for its antifungal properties), as described for the extracts. After 72 hours of incubation, the mycelia were removed and inoculated into petri dishes containing the second medium. They were prepared 24 hours before by adding 40 g L^{-1} malt and 20 g L^{-1} agar to 1-liter water and then mixed, shaken, and autoclaved at 120°C for 25 minutes; the mycelia were then poured into petri dishes. The test is completed when mycelium growth covers the entire surface of the culture medium for the negative control.

At the end of the test, the minimum fungicidal concentration (MFC) of the extracts was determined as the smallest concentration leading to total inhibition of mycelial growth, and the IC_{50} of the extracts was determined as the concentration leading to 50 percent inhibition of fungal growth.

Results and Discussion

Statistical tests were performed at the 5 percent probability level, and data were processed and analyzed using R version 4.3.0 and R studio version 4.3.3.

Extractive content of wood samples

The moisture content of the wood samples was determined; the average was 10.65 percent. The moisture contents ranged from 10 to 11 percent for all sawdust samples. The extraction yields using ethanol–water (1:1, v/v) as solvent for sapwood–hardwood mixtures were 6.7 percent ± 0.2, 5.4 percent ± 0.9, and 4.7 percent ± 0.1, respectively, for Badi, Iroko, and Bete (Table 1). The same order was found for the average extractives content of the sapwood and heartwood of these three woods species. Badi wood, both sapwood and heartwood, had the highest extractives content. The data obtained are in accordance with those observed in the literature (Mounguengui et al. 2015).

Note that some discrepancies occur with data obtained by certain authors (Huang et al. 2009). Indeed, when studying the extractives content of heartwood from certain tropical species, Huang et al. (2009) obtained higher contents of extractives. This difference is due to two major factors. On one hand, the difference in extraction solvent and the extraction method used are generally the first cause of divergence in the results obtained. This is the case for the results obtained on Iroko by Nagawa et al. (2015), who obtained extractive contents of 10 percent, 7.6 percent, and 2.1 percent, respectively, for methanol, acetone, and dichloromethane. The part of the tree studied is the other cause of divergence in the results obtained. This study focused on heartwood, sapwood, and mixtures of sapwood–heartwood, and the extractive content was found to be lower than that of many other authors because these studies are generally performed only on heartwood, which contains far more extractives than sapwood. In addition to the nature of the extraction solvent and the part of the tree studied, the diversity of geographical sites, the age of the trees sampled, and the duration of extraction can also lead to divergent results (Marinova et al. 2005).

Phytochemical screening of extracts

The results of phytochemical screening of ethanol–water extracts (1:1, v/v) showed the presence of polyphenols, flavonoids, alkaloids, and cachectic tannins in all wood species (sapwood–heartwood). The results did not detect quinones, saponins, or polyterpenes in heartwood of any of the species studied; however, some studies have highlighted the presence of quinones and polyterpènes in Badi, Bete, and Iroko (Edoun Ebouel et al. 2020; Table 2). This difference may be due to the different solvents used.

The polarity of a solvent plays a crucial role in determining the chemical composition of extractives from plant materials, including wood. Polar solvents (e.g., water, methanol, ethanol) dissolve polar compounds such as sugars, phenolic compounds, tannins, and alkaloids, but nonpolar solvents (e.g., hexane, chloroform, toluene) are more effective for extracting nonpolar compounds such as lipids, waxes, essential oils, and hydrocarbons (Santos et al. 2022; Zhou et al. 2022). This difference is confirmed by various studies that highlight the difference between extracts obtained using different solvents of different polarity, such as acetone, dichloromethane, methanol, and water (D'Auria et al. 2021). These studies have shown that extractive composition varies from one solvent to another; however, numerous studies have highlighted the effectiveness of most of the families of compounds identified in this study as antifungals or antioxidants.

LC-UV-MS of wood extracts

The comparison of the chromatograms of the different woods shows that some of the extracts present in the heartwood were also found in the sapwood, particularly in Beté and Iroko woods (Fig. 1). The presence of additional signals other than those identified in this study indicates the existence of other unidentified compounds. The intensity of the chemical compound signals decreases as we move from the heartwood to the sapwood. A more detailed characterization of the chemical compounds present in the extracts was conducted to explore their potential valorization. The analysis results are presented in Tables 3, 4, and 5. The choice of negative ionization mode in the mass spectrometry (MS) component enhanced the detection and identification of target compounds, which were further analyzed using the UV detector. Indeed, some of the compounds identified in this

Table 1.—Extractives content of different wood compartments. Values followed by the same letter do not differ significantly, according to Duncan's test.

Woods	Extractive content (%)				
	Heartwood (100%)	Mixture (H:S,[a] 5%)	Mixture (H:S, 15%)	Mixture (H:S, 30%)	Sapwood (100%)
Bete	6.1 ± 0.6^{e}	5.4 ± 0.2^{d}	4.5 ± 0.2^{c}	3.9 ± 0.1^{b}	2.5 ± 0.4^{a}
Badi	6.9 ± 0.1^{fg}	6.8 ± 0.1^{fg}	6.6 ± 0.2^{efg}	6.6 ± 0.2^{efg}	7.2 ± 0.1^{g}
Iroko	6.4 ± 0.7^{ef}	6.1 ± 0.2^{e}	5.5 ± 0.1^{d}	4.3 ± 0.3^{bc}	2.7 ± 0.5^{a}

[a] H:S, % = heartwood : sapwood, percentage of sapwood in the mixture.

liquid chromatography (LC)-MS analysis (chlorophorine and oxyresveratrol) exhibit interesting antioxidant and antifungal properties. Oxyresveratrol, a stilbene related to resveratrol, is particularly effective in neutralizing free radicals, thus protecting cells from oxidative stress. Its antioxidant properties are superior to those of resveratrol because of its additional hydroxyl groups. Chlorophorine, extracted from the wood of *M. excelsa* (Iroko), possesses notable antifungal properties, inhibiting the growth of several lignivorous fungi responsible for wood degradation (Thiriloshani and Bharti 2013). This antifungal activity is attributed to its ability to disrupt the fungal cell membranes, contributing to the preservation of wood under stress conditions. In addition to its antifungal properties, chlorophorine also provides antioxidant protection.

Total polyphenol content

Statistical analysis of the content of polyphenol showed that the highest levels were recorded in Iroko, followed by Badi and Bete. In all three wood species, as the sapwood content of the sawdust mixture increases, the polyphenol content tends to decrease (Table 6). However, from 5 to 30 percent of sapwood in the sawdust mixture, the three studied species show no significant intra-tree differences for polyphenol levels. The results here are different from those found in the literature. Indeed, Bley-Atse et al. (2025) studies different tropical wood species and found a lower result comparison when using hydroethanolic as the extraction solvent. Similarly, Huang et al. (2009), studying the polyphenol content of 10 Congolese essences, obtained polyphenol contents of 164 mg EQ AG g^{-1} for Badi (extract obtained with a mixture of toluene and ethanol [1/2, v/v]). The differences observed between these authors can be explained by the nature of the extraction solvent, wood age, and geographical location of the woods.

Flavonoid content of extracts

Flavonoid content expressed as mg EQ per gram extract is shown in Table 7. The total flavonoid content obtained in Bete heartwood (63.33 ± 12.67 mg EQ g^{-1}) is statistically lower than that of white Iroko (120 ± 17.2 mg EQ g^{-1}) and Badi (108.83 ± 22.5 mg Qg^{-1}). Flavonoid content decreases as the percentage of sapwood in the sawdust mixture increases because sapwood is less rich in flavonoids than heartwood in these woods, so increasing the percentage of sapwood in the mixture decreases flavonoid content. The scientific literature is abundant with information regarding the total flavonoid content of leaves, roots, and bark of the species studied, but few data on the total flavonoid content of heartwood, sapwood, and sapwood–hardwood mixtures are available (Adebayo et al. 2019). However, this study found that, in comparison with the values obtained in the literature for bark and leaves, 25 to 40 mg EQ g^{-1} occurs in Iroko bark and 30 to 50 mg EQ g^{-1} occurs in Iroko leaves. The work of Bley-Atse et al. (2025) on the same studied woods shows that the flavonoid contents of sapwood and heartwood were 110.0 ± 0.1 and 96.8 ± 0.1 for *N. diderrichii*, 116.4 ± 0 and 197 ± 1.1 for *M. altissima*, and 0.2 ± 0 and 0.2 ± 0 for *M. excelsa.* Results for flavonoid content in wood in this study are different; the differences could be attributed to variations in environmental conditions, tree age, sampling methods, analytical techniques, or genetic differences within the species.

Catechic tannin content

Catechic tannin content is expressed in mg equivalents of tannic acid per gram of dry extract (Table 8). Catechic tannins play a protective role in wood, repelling insects and fungi (Saad et al. 2012; El-Aswad et al. 2023). Their ability to interact with other substances gives them antioxidant and

Table 2.—Results of phytochemical screening of extracts.

Woods	Phytochemical screening of extracts					
	Badi		Bete		Iroko	
	Heartwood[a]	Sapwood	Heartwood	Sapwood	Heartwood	Sapwood
Polyphenols	+	+	+	+	+	+
Flavonoids	+	+	+	+	+	+
Alkaloids	+	+	+	+	+	+
Cate tannins	+	+	+	+	+	+
Gallic tannin	−	−	−	−	−	−
Polypterpenes	−	−	−	−	−	−
Saponins	−	−	−	−	−	−
Quinones	−	−	−	−	−	−

[a] + = presence; − = absence.

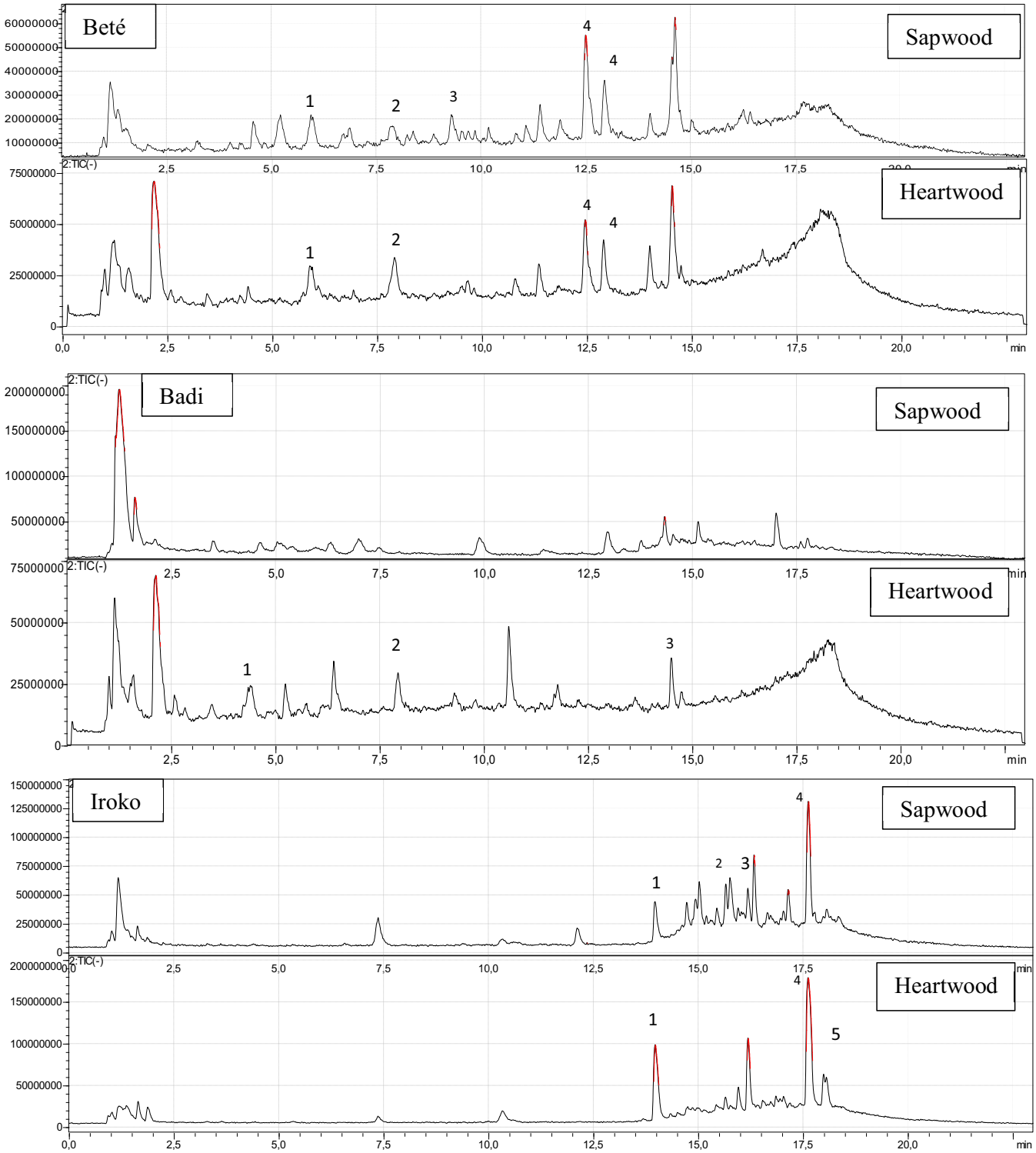

Figure 1.—Comparison of ultraviolet chromatograms of sapwood and heartwood extracts.

antimicrobial properties, which are valuable in the fight against wood-destroying fungi (El-Aswad et al. 2023). Duncan's statistical test shows that Badi sapwood has the highest catecholic tannin values, followed by Iroko heartwood at 1,430.0 ± 52.4 and 1,349.0 ± 7.0 mg tannin acid equivalent g^{-1} of dry extract, respectively. For Bete wood, extracts from sapwood and sapwood–heartwood mixtures showed the lowest values.

Antioxidant activity

ABTS+ method.—Assessment of antioxidant activity using the ABTS test shows that overall, extracts from the different species studied all have antioxidant potential. Badi heartwood extract showed the highest antioxidant activity (3.86 ± 0.16), followed by Bete (3.46 ± 0.12) and Iroko (2.37 ± 0.10; Table 9). The high content of total polyphenols

Table 3.—Identified compounds in the extracts of sapwood and heartwood of Mansonia altissima.

Identified compounds	RT[a] (min)	[M-H]$^-$	λ (nm)	Sapwood (%)	Heartwood (%)
Sorbitol	6.1	181	360	1	3
1-methyl-2-phenylbenzimidazole	7.9	207	357	2	8
Acide stearidonique	9.3	275	220	5	-
1,2-Hexadecanediol	12.5	257	230	30	18

[a] RT = Retention Time; M-H = Mass-Hydrogen.

Table 4.—Identified compounds in the extracts of sapwood and heartwood of Nauclea diderrichii.

Identified compounds	RT[a] (min)	[M-H]$^-$	λ (nm)	Sapwood (%)	Heartwood (%)
Acide myristoléique	4.4	226	199	-	9
1-methyl-2-phenylbenzimidazole	7.9	207	356	-	7
Galactinol	14.5	341	280	-	7

[a] RT = Retention Time; M-H = Mass-Hydrogen; - = unidentified compounds.

Table 5.—Identified compounds in the extracts of sapwood and heartwood of Milicia excelsa.

Identified compounds	RT[a] (min)	[M-H]$^-$	λ (nm)	Sapwood (%)	Heartwood (%)
Oxyresveratrol	13.9	243	320	8	24
Heptadecandiol	15.6	271	199	3	-
Acide arachidique	16.3	311	200	11	-
Chlorophorine	17.6	379	333	24	45
Acide rosmarinique	17.9	363	329	-	12

[a] RT = Retention Time; M-H = Mass-Hydrogen; -= unidentified compounds.

is thought to be behind the antioxidant activity observed in these species (Huang et al. 2009). This high antioxidant activity represents a promising avenue for the valorization of sawdust from these species. Similar results were obtained by Liu et al. (2011) on Iroko leaf extract and Bete and Badi bark, who concluded that the natural antioxidant substances found in these species are part of the therapeutic arsenal in the fight against numerous pathogens.

DPPH method.—The IC_{50} was determined as the extract concentration at which 50 percent of DPPH free radicals are trapped (IC_{50}). These values are obtained from trend curves for which the linear regression coefficient (R^2) of the Y function (the percentage of DPPH inhibition) as a function of extract concentration is close to 1. It appears that antioxidant activity varies according to the wood compartment considered. Sapwood extracts have the highest antioxidant activity because of their lower IC_{50}, followed by sapwood–hardwood blends, whereas pure heartwood has the lowest antioxidant activity (Table 10).

Antifungal effectiveness of extracts

The assay validation test shows that the solvent used is perfectly safe at the various concentrations studied and that the fungus is virulent (optimal growth of the fungus on the negative control medium after 5 days). The MFCs obtained with tebuconazole (positive control) are 200 μg mL^{-1}, 15 μg mL^{-1}, 15 μg mL^{-1}, 10 μg mL^{-1}, and 15 μg mL^{-1}, respectively, for the fungi *C. puteana*, *P. ostreatus*, *P. placenta*, *P. sanguineus*, and *T. versicolor*. Concentrations inhibiting fungal growth by 50 percent (IC_{50}) were 145 μg mL^{-1}, 5 μg mL^{-1}, 12 μg mL^{-1}, 3.5 μg mL^{-1}, and 2.5 μg mL^{-1}, respectively, for the fungi *C. puteana*, *P. ostreatus*, *P. placenta*, *P. sanguineus*, and *T. versicolor* (Table 11). However, the work of Woo et al. (2010) suggests that *T. versicolor* (L. ex Fr. Quel.) may have degraded up to 54 percent of tebuconazole at low concentrations when used as a preservative in end-of-life wood. Indeed, the low fungicidal concentrations obtained could be explained by the difference between controlled laboratory conditions and real-world applications, where tebuconazole may undergo alterations.

Effectiveness of extracts on C. puteana.—Results on the fungicidal effectiveness of extracts showed that Iroko extracts could be successful against this fungus, with MFCs = 1.25 mg mL^{-1} for extracts of 100 percent heartwood, sapwood–hardwood mixtures, and MFC = 5 mg mL^{-1} for extracts of 100 percent sapwood. For these fungi, the different sapwood : heartwood ratios, ranging from 5 to 30 percent, had no effect on the MFC of the wood extracts, which remained at 1.25 mg mL^{-1}, 2.5 mg mL^{-1}, and 5 mg mL^{-1} for Iroko, Bete, and Badi, respectively. However, a variation was observed in the concentration inhibiting 50 percent of fungal activity (IC_{50}), depending on the sapwood : heartwood ratio studied, without however having a significant effect on the latter as the level of sapwood in the sample increased. For Badi, sapwood and heartwood had the same MFC, which would underline the high activity of Badi sapwood extracts. Sapwood extracts from these woods have fungicidal activity on *C. puteana*, underlining the value of valorizing sapwood extracts (Table 11). Numerous studies have described the antifungal activity of wood extracts. In fact, the low or high fungicidal activity (obtained by some authors) could be due to the type of compounds extracted by the solvent on one hand and the method used to assess fungicidal activity on the other. Note that antifungal test results in the literature are generally based on extracts of wood duramen and not on sapwood or sapwood–duramen mixtures.

Table 6.—Total polyphenol content of wood compartment extracts. Values followed by the same letter do not differ significantly, according to Duncan's test.

Woods	Polyphenol total content (mg GAE[a] g^{-1} of dry extract)				
	Heartwood (100%)	Mixture (H:S, 5%)	Mixture (H:S, 15%)	Mixture (H:S, 30%)	Sapwood (100%)
Bete	246.0 ± 21.2^{cd}	201.7 ± 11.4^{bc}	215.0 ± 15.0^{bc}	215.0 ± 5.0^{bc}	170.0 ± 10.0^{b}
Badi	248.3 ± 17.6^{cd}	210.0 ± 0.8^{bc}	216.7 ± 5.8^{bc}	206.7 ± 15.3^{bc}	123.3 ± 5.8^{a}
Iroko	549.0 ± 20.1^{f}	502.3 ± 45.2^{e}	481.3 ± 35.0^{e}	474.3 ± 5.1^{e}	286.7 ± 64.0^{d}

[a] GAE = gallic acid equivalent; H:S, % = heartwood : sapwood, percentage of sapwood in the mixture.

Table 7.—Total flavonoid content of wood compartment extracts. Values followed by the same letter do not differ significantly, according to Duncan's test.

Woods	Flavonoid total content (mg QE[a] g^{-1} of dry extract)				
	Heartwood (100%)	Mixture (H:S, 5%)	Mixture (H:S, 15%)	Mixture (H:S, 30%)	Sapwood (100%)
Bete	122.0 ± 2.6[f]	97.0 ± 2.0[d]	81.7 ± 3.5[c]	60.7 ± 4.7[b]	32.3 ± 6.8[a]
Badi	112.7 ± 2.5[e]	95.7 ± 3.1[d]	76.7 ± 1.5[c]	62.7 ± 2.5[b]	35.0 ± 5.0[a]
Iroko	190 ± 4.6[j]	171.7 ± 6.5[i]	149.3 ± 4.5[h]	133.7 ± 5.5[g]	90.0 ± 8.9[d]

[a] QE = quercetin equivalent; H:S, % = heartwood : sapwood, percentage of sapwood in the mixture.

Table 8.—Catechic tannin content of wood compartment extracts. Values followed by the same letter do not differ significantly, according to Duncan's test.

Woods	Tannin total content (mg TAE[a] g^{-1} of dry extract)				
	Heartwood (100%)	Mixture (H:S, 5%)	Mixture (H:S, 15%)	Mixture (H:S, 30%)	Sapwood (100%)
Bete	955.3 ± 23.6[d]	841.3 ± 9.9[bc]	818.0 ± 15.7[b]	724.3 ± 66.9[a]	651.3 ± 14.2[a]
Badi	905.3 ± 67.3[cd]	960.7 ± 36.0[d]	1068.3 ± 49.4[e]	1,164.3 ± 123.2[fg]	1,430.0 ± 52.4[i]
Iroko	1,349.0 ± 7.0[h]	1,241.3 ± 3.2[g]	1,105.7 ± 7.1[ef]	1,053.0 ± 27.6[e]	876.3 ± 11.4[bcd]

[a] TAE = tanic acid equivalent; H:S, % = heartwood : sapwood, percentage of sapwood in the mixture.

Table 9.—Antioxidant activity by ABTS+ method. Values followed by the same letter do not differ significantly, according to Duncan's test.

Woods	Antioxidant activity (μMéqTrolox L^{-1})				
	Heartwood (100%)	Mixture (H:S,[a] 5%)	Mixture (H:S, 15%)	Mixture (H:S, 30%)	Sapwood (100%)
Bete	3.46 ± 0.12[h]	3.25 ± 0.11[g]	3.05 ± 0.09[f]	2.88 ± 0.04[ef]	2.35 ± 0.15[d]
Badi	3.86 ± 0.16[i]	3.70 ± 0.05[i]	3.27 ± 0.10[g]	2.73 ± 0.21[e]	2.52 ± 0.08[d]
Iroko	2.37 ± 0.10[d]	2.16 ± 0.05[c]	1.98 ± 0.11[c]	1.54 ± 0.12[b]	1.22 ± 0.09[a]

[a] ABTS = 2,2′-azinobis-3-ethylbenzothiazoline-6-sulfonic acid; H:S, % = heartwood : sapwood, percentage of sapwood in the mixture.

Table 10.—Antioxidant activity by DPPH method. Values followed by the same letter do not differ significantly, according to Duncan's test.

Woods	Antioxidant activity (μg mL^{-1})					
	Heartwood (100%)	Mixture (H:S,[a] 5%)	Mixture (H:S, 15%)	Mixture (H:S, 30%)	Sapwood (100%)	Ascorbic acide
Bete	4.56 ± 0.12[e]	4.45 ± 0.10[e]	4.45 ± 0.09[e]	3.88 ± 0.04[d]	3.45 ± 0.13[bc]	
Badi	4.93 ± 0.06[f]	4.90 ± 0.05[f]	4.65 ± 0.12[e]	4.53 ± 0.21[e]	4.50 ± 0.08[e]	1.14 ± 0.10
Iroko	3.97 ± 0.13[d]	3.86 ± 0.05[d]	3.57 ± 0.10[c]	3.34 ± 0.12[b]	3.02 ± 0.09[a]	

[a] DPPH = 2,2-diphényl 1-picrylhydrazyl; H:S, % = heartwood : sapwood, percentage of sapwood in the mixture.

Results obtained in the present study are fully comparable with those obtained by many authors on other fungi, such as Niamké et al. (2011) on *Tectona grandis*, with minimal inhibiting concentration = 5.6 mg mL^{-1}, and Thomas et al. (2023) who for these three woods found MFCs of 6, 8, and 8, respectively, for Bete, Badi, and Iroko heartwood extracts. This difference could be attributed to the various compounds present in the hydroethanolic extracts of these woods (e.g., sorbitol, galactinol, oxyresveratrol, chlorophorine), which exhibit marked antifungal and antioxidant activities.

Efficacy of extracts on P. ostreatus.—Iroko extracts were the most effective against this fungus, with MFCs of 1.25 mg mL^{-1} for 100 percent heartwood and sapwood–hardwood mixtures and MFC = 5 mg mL^{-1} for 100 percent sapwood extracts. For these fungi, increasing the sapwood content in our sawdust from 5 to 30 percent had no effect on the MFC of these woods, which were 1.25 mg mL^{-1}, 2.5 mg mL^{-1}, and 5 mg mL^{-1}, respectively, for Iroko, Bete, and Badi, but the effect was felt at the level of IC for 50 percent of fungal activity (IC_{50}). For Badi, sapwood and heartwood had the same MFC, underlining the high activity of Badi sapwood extracts. For Bete, we observed a change in the MFC of the heartwood (100%) as the ratio changed (95%:5%, heartwood : sapwood; Table 11). This variation could be explained by the low content of extractable compounds (e.g., polyphenols, flavonoids, tannins) in Bete sapwood.

Efficacy of extracts on P. placenta.—Extracts from the duramen of these three woods proved fungicidal at certain concentrations, i.e., 1.25, 5, and 10 mg mL^{-1}, respectively, for white Iroko, Bete, and Badi. Sapwood extracts for Badi had no fungicidal activity but were fungistatic at the

Table 11.—Woods extract concentration against fungi.

Fungi	Woods	Extract concentration against fungi (mg mL^{-1}) Heartwood (100%)	Mixture (H:S,[a] 5%)	Mixture (H:S, 15%)	Mixture (H:S, 30%)	Sapwood (100%)	Tébuconazole
Coniophora puteana	Bete						
	MFC	2.5	2.5	2.5	2.5	10	
	IC_{50}	1.02	1.02	1.23	1.31	4.57	
	Badi						
	MFC	5	5	5	5	5	MFC = 0.2
	IC_{50}	1.92	1.97	2.12	2.35	3.54	IC_{50} = 0.145
	Iroko						
	MFC	1.25	1.25	1.25	1.25	5	
	IC_{50}	0.47	0.47	0.57	0.75	2.48	
Pleurotus ostreatus	Bete						
	MFC	1.25	2.5	2.5	2.5	2.5	
	IC_{50}	0.37	1.12	1.31	1.58	1.87	
	Badi						
	MFC	5	5	5	5	5	MFC = 0.015
	IC_{50}	2.33	2.34	2.49	2.85	3.23	IC_{50} = 0.005
	Iroko						
	MFC	1.25	1.25	1.25	1.25	5	
	IC_{50}	0.38	0.4	0.46	0.57	2.91	
Poria placenta	Bete						
	MFC	5	5	5	5	12	
	IC_{50}	1.95	2.02	2.21	2.67	7.45	
	Badi						
	MFC	10	10	10	10	N/A	MFC = 0.015
	IC_{50}	4.33	4.41	4.72	7.04	10.85	IC_{50} = 0.012
	Iroko						
	MFC	1.25	1.25	1.25	1.25	5	
	IC_{50}	0.37	0.41	0.54	0.83	2.43	
Pycnoporus sanguineus	Bete						
	MFC	4	4.5	4.5	4.5	12	
	IC_{50}	1.91	1.98	2.36	2.53	6.67	
	Badi						
	MFC	5	5	5	5	10	MFC = 0.010
	IC_{50}	1.99	2.35	2.4	2.56	4.93	IC_{50} = 0.0035
	Iroko						
	MFC	7.5	9	9	9	N/A	
	IC_{50}	3.06	4.69	5.08	5.2	10.34	
Trametes versicolor	Bete						
	MFC	2.5	2.5	2.5	2.5	10	
	IC_{50}	0.97	1.2	1.43	1.87	7.13	
	Badi						
	MFC	10	10	10	10	N/A	MFC = 0.015
	IC_{50}	4.49	4.98	5.34	6.38	11.08	IC_{50} = 0.0025
	Iroko						
	MFC	5	5	5	5	10	
	IC_{50}	1.93	2.01	2.33	2.98	5.21	

[a] H:S, % = heartwood : sapwood, percentage of sapwood in the mixture; MFC = Minimum fungicidal concentration; IC = inhibitory concentration; N/A = not applicable.

concentrations tested in this study. For this wood-eating fungus, changes in sapwood content in the mixture from 0 to 30 percent had no influence on the MFC for the three woods studied (Table 11). Our plant extracts contain compounds such as tannins, flavonoids, and alkaloids, which have fungicidal properties (Pamo et al. 2003). These major compounds are often responsible for the antifungal activity of plant extracts (Pamo et al. 2003; Giordani et al. 2008).

Efficacy of extracts on P. sanguineus.—In antifungal tests of hydroalcoholic wood extracts on the fungus *P. sanguineus*, extracts of white Iroko were less effective than Badi and Bete extracts. Bete duramen extracts were the most effective on this fungus, with a concentration of MFC = 4 mg mL^{-1}, followed by Badi MFC = 5 mg mL^{-1}. Sapwood–duramen mixtures with 5 to 30 percent sapwood showed no change in the MFC for these three woods, which were 4.5, 5, and 9 mg mL^{-1}, respectively, for Bete, Badi, and Iroko. Iroko extracts had no fungicidal effect but were fungistatic (Table 11).

Efficacy of Extracts on T. versicolor.—Hydroalcoholic extracts of Badi sapwood had no fungicidal effect on the

fungus *T. versicolor* at the concentrations tested. However, the concentration inhibiting 50 percent of fungal growth was determined, $IC_{50} = 11.08$ mg mL^{-1}. Bete heartwood extracts were the most effective, with an MFC of 2.5 mg mL^{-1}, followed by Iroko and Badi, with MFC = 5 mg mL^{-1} and MFC = 10 mg mL^{-1}, respectively. Increasing the amount of sapwood from 0 to 30 percent in the sawdust mixture caused no variation in the MFC of the extracts for each of the trees studied on the *T. versicolor* fungus, which remained, respectively, at MFC = 2.5 mg mL^{-1}, MFC = 5 mg mL^{-1}, and MFC = 10 mg mL^{-1} for Bete, Iroko, and Badi (Table 11). Niamke et al. (2011) has shown that the total sapwood extract of teak wood is less active (IC_{50} = 34.53 mg mL^{-1}) than that of heartwood ($IC_{50} = 0.78$ mg mL^{-1}) against *T. versicolor*. In fact, no lethal action of sapwood extract against *T. versicolor* was observed at the concentrations studied.

These results confirm those obtained in this study, notably for Bete wood heartwood extracts, which showed a $CI_{50} = 0.97$ mg mL^{-1} compared with that of Niamké et al. (2011), which is $CI_{50} = 0.78$ mg mL^{-1} for teak wood heartwood. However, the work of Woo et al. (2010) demonstrated that the fungus *T. versicolor* was capable of degrading more than 45 percent of tebuconazole (the positive control in this study) used in wood treatment. Indeed, the high variability of chemical compounds present in the wood extracts, each potentially possessing specific antifungal activity, could explain the overall effectiveness of these extracts in inhibiting fungal activity. This synergistic action between various secondary metabolites, such as polyphenols, sugar alcohols, or stilbenes, may enhance antifungal effects through complementary mechanisms, including disruption of the fungal cell membrane, inhibition of metabolic enzymes, or induction of oxidative stress. Therefore, rather than a single active compound, it is likely the overall chemical profile of the extract that contributes to the observed activity (Schultz and Nicholas, 2000; Amusant et al. 2007).

Conclusions

This study aimed to determine the antioxidant and antifungal activity of hydroethanolic extracts (1:1, v/v) from three durable woods of Côte d'Ivoire against five wood-decaying fungi, with results highlightiing the significance of this study. In the valorization of sawdust from these woods, which are mixtures of sapwood and heartwood, it was essential to determine whether sawdust comprising 5 percent sapwood and 95 percent heartwood had a more pronounced fungicidal effect than sawdust comprising 30 percent sapwood and 70 percent heartwood. Results showed that a sapwood content in the sawdust ranging between 5 and 30 percent did not have a significant effect on the MFC of the hydroethanolic extracts (1:1, v/v) in combating the studied fungi. This finding raises valuable prospects for the valorization of wood sawdust extracts as natural fungicides and wood preservatives for nondurable woods against white- and brown-rot fungi. Given the nonvariation of the extracts' MFC against these fungi and the large amounts of wood waste present in our environment, industrial-scale extractions could be used in the fight against wood-degrading fungi. Use of chemically derived fungicides could be reduced, along with their harmful effects on the environment and human health.

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