

Impact of extracts from three durable tropical woods from Côte d'Ivoire (*Nauclea diderrichii*, *Mansonia altissima*, *Milicia excelsa*) on *Spodoptera frugiperda* Smith, 1797 (Lepidoptera: Noctuidae) larvae in the laboratory

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Abstract

Maize, the staple food of many populations, is suffering major losses due to *Spodoptera frugiperda*. Chemical pesticides were being over-used to control this pest. But to preserve the ecosystem, it's important to test products with a low ecological impact. Study aims to evaluate the impact of hydroalcoholic extracts of three tropical woods Badi (*Nauclea diderrichii*), Bete (*Mansonia altissima*) Iroko (*Milicia excelsa*) on the larvae of *S. frugiperda*, the main pest of maize. Different parameters be evaluate: larval mortality rate, LD₅₀, pupation duration, rate of leaves consumed by the larvae, larval mortality rate. Young larvae were collected from untreated maize plants in field. Three doses evaluated (0.04; 0.08 and 0.1g/mL) of sapwood and heartwood extracts proved effective. Heartwood extracts were more effective than extracts from the sapwood at the 0.04g/mL dose. Contrarily, the sapwood extracts of Badi and Bete were significantly ($p < 0.05$) more effective than those of heartwood at the 0.08 and 0.1g/mL (100% death larvae at the first day). LD₅₀ of sapwood extracts were 0.0535; 0.0419 and 0.0219 g/mL, respectively for Badi, Bete, Iroko. LD₅₀ of heartwood extracts were 0.3535 (Badi) and 0.0283 g/mL (Bete). Pupation duration was longer for larvae exposed to sapwood (0.04g/mL) and shorter for those treated with duramen (0.08g/mL). Badi and Iroko sapwood (0.08g/mL) had the best antifeedant activity (0% leaves consumed). Insecticidal activity could be explained by the presence of secondary metabolites: alkaloids, flavonoids, polyphenols, tannins, observed in extracts. Studied wood extracts could be use in the formulation of bioinsecticides for sustainable control crop pests.

Introduction

Maize (*Zea mays* L.) is the most widely produced cereal in the world. In 2022, its production was estimated at more than 1137 million tons, ahead of wheat (*Triticum aestivum* L.) and rice (*Oriza sativa*), each with a production of 757 million tons (Erenstein et al., 2022). Maize is also the world's second most important food crop after wheat in terms of harvested area, with 197 million hectares (ha), around 30 million ha of which are in Sub-Saharan Africa (Erenstein et al., 2022). In West Africa, and particularly in Côte d'Ivoire, maize is one of the staple foods in people's diets. It is used in human and animal feed (Chickens, cattle, sheep, pigs, etc.) and as a raw material in certain agri-food industries: brewing, oil production and biofuels (Barrera-Arellano et al., 2019; Dabija et al., 2021; Nichols et al., 2016; OECD and FAO, 2020). It is also a highly nutritious cereal, thanks to its high starch, protein, lipid, fiber and mineral content. However, this crop suffers significant losses due to insect pests, including the fall armyworm, *Spodoptera frugiperda*. In fact *S. frugiperda* is considered as the main pest of maize in Brazil, the world's third largest maize producer (Aguar et al., 2002), after the USA and China. The economic cost of controlling the larvae that ravage maize is estimated at over 600 million dollar annually (Ferreira et al., 2010). In addition, *S. frugiperda* is responsible for 32% of crop damage in Ethiopia and 47.3% of crop damage in Kenya on average. This damage is estimated to reduce crop yields by between 0.8 and 1 ton/ha. (Goergen et al., 2016; Kumela et al., 2018). This insect is a polyphagous pest that can cause major damage not only to maize in the field (Adja et al., 2023) but also, to other crops such as millet, sorghum and rice (Georgen *et al.*, 2016). It feeds on the leaves and stems of over 80 plant species

belonging to 27 families, including maize, rice, and sorghum sorghum (Polania et al., 2007; Parsanna et al., 2018). Infestations caused yield losses from 15 to 73% when 55 to 100% of plants are infested (Hruska and Gould, 1997; Kpemoua et al., 2021). Controlling this pest has become a major challenge (Adja et al., 2023b). Consequently, researchers and farmers are seeking innovative, ecological, and sustainable methods to manage this pest (Akeme et al., 2021; Guo et al., 2020; Haq et al., 2021). Common practices include the use of plant extracts, oils and chemical pesticides (Tapondjou et al., 2005; Agboyi et al., 2016) or integrated cropping systems to minimize its impact. While pesticides remain the most important method for crop protection due to their rapid and effective action (Grdiša & Gršić, 2013). However, these chemical pesticides generally induce serious environmental, human health and animal health concerns (Saadane, 2018). The emergence of resistance in insect pests and the occurrence of reproductive disorders in birds have dramatically demonstrated the limits of their use. They also caused disturbances in pollinating insects and crop auxiliaries (Charvet et al., 2004). Synthetic insecticides reduce the food resources of beneficial insects. They can also contaminate plants due to the residues (Arnason et al., 1989), contaminate the food of insect pollinators as *Apis* species (Tasei, 1996). Additionally, these chemicals have been associated with some pathologies observed in human Being (Weisskopf et al., 2010 ; Adam et al., 2011). To effectively control insect pests, it's essential to develop safe, practical, environmentally friendly, and inexpensive alternatives solutions. These include bioinsecticides, which can be degraded more rapidly in the environment than synthetic insecticides (Koul & Dhaliwal, 2000). Several studies have investigated plant extracts for their potential insecticidal properties (Lengai et al., 2020). Tropical forest species synthesize biomolecules in their wood that contribute for their natural resistance (Anouhe et al., 2018; Niamke, 2010). The extracts contained in logging residues of forest species could serve as alternatives to chemical pesticides (Jurd & Manners, 1980 ; De Meeûs, 2019).

The forestry industry is one of the world's biggest waste producers. Indeed, many wood-producing countries generate more than 2 million m³ of sawdust per year (Cheah and Ramli, 2013). Logging in Africa also produces large quantities of waste, estimated at over 30,000 m³/year (De Meeûs, 2019). In addition, sawmills alone produce 40–60% of the solid waste resulting from log processing (Frank Eshun et al., 2012; Mwango and Kambole, 2019). Poor management of this waste leads to health and environmental problems such as air pollution, greenhouse gas emissions and, very often, the destruction of plant and aquatic life (Cetiner and Shea, 2018; Mwango and Kambole, 2019). All these under-utilized wastes (De Meeûs, 2019) should be properly valorized as a solution to the problem of waste management and natural resource conservation, since the valorization of these wastes appears to be an opportunity to add value to the by-products of forest exploitation, and even an additional profit for the countries that produce them.

Nevertheless, a lot of applications can be identified, mainly in the treatment of industrial water and the elimination of organic and inorganic pollutants (Adegoke et al., 2022; Morão et al., 2017) and household wastewater (Nakagawa et al., 2006). There are also applications in improving soil structure and fertility (Mayer et al., 2022) and as woody biomass in the manufacture of compost (Golbaz et al., 2021).

Sustainable electricity production from syngas derived from the gasification of wood waste (Veeyee et al., 2021). The manufacture of sustainable panels and insulation (Zou et al., 2020) and many other construction materials (Olaiya et al., 2023), bioplastic composites (Zine et al., 2023), biochar and sawdust-based composite biofuel briquettes for cooking have also been realized (Antwi-Boasiako and Acheampong, 2016; Zanolli et al., 2022). In addition, several studies have revealed that sustainable tropical species synthesize in their wood biomolecules responsible for their natural resistance, namely flavonoids, total phenols and tannins (Niamké et al., 2021). Phenolic compounds are able to neutralize free radicals and slowing down the fungal biodegradation process (Niamké et al., 2012). Isolated chemicals would therefore constitute an additional source of revenue for the forestry industry, and could be used for wood preservation, cosmetics, dermatology and nutraceuticals (Anouhe et al., 2018; Ansel et al., 2016). In addition, numerous studies have confirmed that terpenes have insecticidal properties against a variety of insect pests (Smith et al., 2018). A study carried out on maritime pine wood waste aimed firstly to isolate the extractable molecules present in lignocellulosic materials and then to manufacture wood panels from the waste (bark), another high-value-added material (Feng et al., 2013). The medicinal properties of wood extracts have also been studied. These include the anti-diarrheal and anti-plasmodial properties of *Nauclea diderrichii* and *Milicia excelsa* extracts (Adebayo et al., 2019; Agbebi et al., 2022). The large quantities of bioactive compounds (flavonoids, terpenes, etc.) present in some tree branches, in the nodes, are often discarded or abandoned. Yet knots are much richer in bioactive substances than the heartwood and sapwood of softwoods (Kebbi-Benkeder et al., 2015). Although often chemically characterized, there are few applications of these as biopesticides against crop pests. Given their functional properties, the extractives contained in the waste products of forest tree species could be used as a safe alternative to the chemical pesticides used by farmers (De Meeûs, 2019; Jurd and Manners, 1980). Studies such as those by Hassan et al. (Hassan et al., 2018), Rodrigues (Rodrigues et al., 2011) and Tascioglu, for example, have focused more on evaluating heartwood against wood insects (termites) and lignivorous fungi (Anouhe et al., 2018), (Amusant et al., 2007), yet sapwood and even the nodes and other shoots of trees could also represent an important asset in the fight against insect pests, hence the interest of our study. Indeed, the synthesis of bioactive extractives in sapwood, precursors of extractives stored in heartwood during the duraminization process, demonstrates the role and importance of sapwood in terms of molecules of interest (Hillis, 2012; Taylor et al., 2002). It is also a fact that trees grown in forests today are increasingly disturbed compared to trees previously studied in the literature. New defence and even bioactive molecules are likely to be synthesized in these trees. Studies to date have not focused on biopesticides based on active substances derived from forest waste. However, scientific activities have focused on wood-destroying termites (Kim et al., 2008; Tascioglu et al., 2012) and wood-destroying fungi (Anouhe et al., 2018; Mounguengui et al., 2016). Thus, the valorization of wood extracts for the formulation of biopesticides against food crop pests, against *Spodoptera frugiperda*, a pest of high economic importance and the main polyphagous pest of maize, is proving to be very crucial. This study aims to assess the impact of hydroalcoholic extracts of three tropical woods (Badi (*Nauclea diderrichii*), Bete (*Mansonia altissima*) and Iroko (*Milicia excelsa*)) on the larvae of *Spodoptera frugiperda*, the main pest of maize in the field. Specifically, it

focuses on the assessment of several parameters mainly the larval mortality rate, the pupation duration, the rate of leaves consumed by the larvae and the larval mortality rate.

Materials and methods

1-1-Materials

1-1-1-Plants materials

Samples were collected in the Besso classified forest in Akoupe, in the south-eastern Mé region of Côte d'Ivoire (06°14'- 06°30' N and 003°37' -003°48' W). The sampling criteria were the potential for bioactive substances and the availability of the resource. A bibliographical approach was followed by a survey of Ivorian forestry research and management structures. A total of 3 trees of each species were harvested at 1.30 m breast diameter (DBH). These were Badi (*Nauclea diderrichii*), Bete (*Mansonia altissima*) and white Iroko (*Milicia excelsa*). Trees with straight trunks, high forks and no signs of disease were selected and collected to rule out as many hypotheses of heterogeneity as possible. In terms of dendrometry characteristics, the trees collected had diameters of between 50 and 80 cm and heights of between 13 and 19 m. After the trees had been cut in the field, each tree was sampled by taking a 1.3 m long log. The samples were then transferred to the sawmill. Once at the sawmill, each log was cut into 2 central planks, each 4 cm high (Fig. 1). The boards from the sawn logs were stored at room temperature in Yamoussoukro ($27 \pm 2^{\circ}\text{C}$).

1-1-2-Insects

The animal materials consisted of *Spodoptera frugiperda* larvae. *S. frugiperda* larvae were collected from an untreated experimental plot and subsequently sent to the Agricultural Zoology Laboratory of the same institute. The larvae at the second stage, which exhibited voracious. Behaviour, were considered suitable for the trial.

Figure 1: Collection and processing of wood samples and wood shavings

1-2-Methods

1-2-1- Preparation and extraction

Once the logs had been dried, they were separated according to their wood type, namely sapwood and heartwood. The components, namely sapwood and heartwood, were then reduced to test pieces. The specimens were then crushed into small pieces and ground to a fine powder measuring 2.5 mm in diameter using an electric grinder. The powders were stored in jars and sealed for scheduled experiments (Fig. 1).

Hydroalcoholic extracts were prepared by mixing and macerating 30 g of crushed material in 300 mL of hydroalcoholic solvent (V/V) for 2 h, at the Laboratory of Industrial Processes and Synthesis of the

1-2-2-Experimental design

The experimental design comprised nine treatments, including three heartwood extracts, three sapwood extracts from the three wood species, and a reference control (Crf) represented by the chemical insecticide Viper 46 EC (30 g.l⁻¹ Indoxacarb and 16 g.l⁻¹ Acetamiprid) supplied by Callivoire. The Ivory Coast-based subsidiary of the UPL group, a global leader in the plant protection industry, has obtained ISO 9001 certification. It has developed a hydroalcoholic solution (water + alcohol: v/v (50:50)) of 100 mL as a positive control (Cwa) and a control cut representing the negative control. Each treatment was conducted in triplicate. Each treatment was conducted in triplicate. Four larvae were treated simultaneously but separately for each product, with the test being repeated on three occasions. Thus, a total of 12 larvae were utilized for each product under examination. A total of 108 Petri dishes, each with a diameter of 90 mm and a height of 14 mm, in compliance with ISO 24998 standards, were employed in the experiment. Maize leaf discs (4 cm in diameter) were positioned in each dish, followed by the introduction of larvae at a rate of one larva per dish to mitigate the effect of cannibalism. The dishes were sealed with cloth lids to guarantee adequate aeration and prevent the larvae from asphyxiating. The temperature was maintained at 27 ± 2°C and the relative humidity at 60 ± 10 in the experimental room. The methodology of the study, or even the detailed process, is illustrated in the following diagram (Fig. 2).

1-2-3-Data collection

Larval mortality

The larvae were deemed to be deceased when no coordinated response was elicited upon tactile stimulation with a blunt needle. The mortality rate of *Spodoptera frugiperda* larvae was calculated using the method proposed by Abbott (1925). This formula provides corrected percentage mortality values by accounting for mortalities observed in both treated samples and the control. This correction allows for the avoidance of the natural mortality observed under experimental conditions. The following symbols are used in this text:

$$\%M = \frac{NDLTc - NDLCut}{TNL - NDLCut} \times 100 \text{ (Abbott, 1925).}$$

Legend:

%M

Percentage of corrected mortality;

NDLTc

Number of deceased larvae in the treated box;

NDLCut

Number of deceased larvae in the control box;

TNL

Total number of larvae.

The dose (g/mL) of extract (sapwood and heartwood) required to kill 50% of the larvae (LD₅₀) was determined for each treatment using the Probit Logit models of the XLSAT.2023 program. The Probit models facilitated an understanding of, and prediction regarding, the effects of extract doses in relation to larval mortality.

Pupal stage period

The pupal stage period is defined as the duration between the commencement of the pupal stage and the stage of adult emergence (Karabey and Sert, 2018). Pupation represents a stage in the metamorphic journey of an insect, marking the transition from the larval stage to adulthood. The pupation duration is defined as the number of days required for a larva to progress from the final larval stage to the adult stage (Munene, 2018). The number of days required for larvae to transform into pupae and then into adults was determined following the application of the treatment.

Leaves consumption rate

The rate of leaf consumption (%L) by individual larva was determined through measurements using graph paper and a dial marked on each leaf disc, recorded at 24 hours intervals. The average rate of leaf consumption is calculated using the following formula:

$$\%L = \frac{QLC}{QLG} \times 100$$

Legend:

%L

Rate of leaves consumed

QLC: Quantity of leaves consumed; QLG: Quantity of leaves given.

1-2-4- Statistical analysis

Data were analyzed using XLSTAT 2023.1.2 (version 1406) incorporated into Excel office 365. The larval mortality rates obtained were subjected to an analysis of variance (ANOVA) and the Kruskal Wallis test at a significance level of 5% to separate significantly different means. The number of days required for larvae to transform into pupae and then into adults (pupation stage) was determined after spraying extracts, and the average rate of leaf consumption by larvae was calculated. The LD₅₀ for wood extract

was calculated using Probit regression analysis against log (wood extract concentration) using the XLSTAT program Lifesciences.

Results and discussion

2-1-Results

2-1-1- Effect of treatments on the mortality rate of *Spodoptera frugiperda* larvae

Regarding the outcomes of the tests (Fig. 3), at a concentration of 0.04g/mL, heartwood extracts were significantly ($p < 0.05$) more active than sapwood extracts, resulting in higher mortality rates. Indeed, Badi heartwood extract had 100% mortality rate from day 7, while the mortality rates achieved by Bete and Iroko heartwood extracts on days 6 and 11 were $66.67 \pm 0.58\%$ (Fig. 3b). Iroko sapwood extract showed the best insecticidal activity, with a mortality rate of $66.67 \pm 0.58\%$ from day 6 to day 11, compared to 33.33% for Bete sapwood from day 3 to day 11 (Fig. 3a). At a concentration of 0.08 g/mL, sapwood extracts were more active than heartwood extracts, with a significantly higher mortality rate ($p < 0.05$). Indeed, the sapwood extracts from Bete and Badi presented 100% of mortality on day 1, whereas Iroko had $66.67 \pm 0.58\%$ mortality (Fig. 3c). Among heartwood extracts, Bete and Badi extracts yielded identical mortality rates of $66.67 \pm 0.58\%$ on day 4, compared to 33.33% mortality for Iroko on the same day (Fig. 3d). At a concentration of 0.1g/mL, sapwood extracts were significantly more active ($p < 0.05$) than heartwood extracts. Sapwood extracts from Badi and Iroko induced 100% mortality rate at day 1, compared to $66.67 \pm 0.58\%$ at day 3 and 100% at day 5 (Fig. 3e). Bete and Badi heartwood extracts presented 100% mortality at days 3 and 4 respectively, while Iroko extract had a mortality rate of $66.67 \pm 0.58\%$ from day 7 to day 11 (Fig. 3f). The lethal dose 50 (LD_{50}) for Badi, Bete, and Iroko sapwood extracts were, respectively 0.0535; 0.0419 and 0.0219 g/mL. The LD_{50} for Badi and Bete heartwood extracts were, respectively 0.3535 and 0.0283 g/mL. Iroko sapwood extract was the lowest LD_{50} (0.0219), while the bete heartwood extract (0.0283) was the lowest. Nevertheless, the LD_{50} of Iroko was not determined due to the natural mortality rate of 0.5 (Table 1).

Table 1
Mortality obtained of estimate of LD₅₀ value

	Scientific name	Concentration (g/mL)	Mortality (%)	DL ₅₀ (g/mL)
Sapwood Badi	<i>Nauclea diderrichii</i> (Rubiaceae)	0.04	0	0.0535
		0.08	100	
		0.1	100	
Sapwood Bete	<i>Mansonia altissima</i> (Malvaceae)	0.04	33.33	0.0419
		0.08	100	
		0.1g	100	
Sapwood Iroko	<i>Milicia excelsa</i> (Moraceae)	0.04	66.67	0.0219
		0.08	66.67	
		0.1	100	
Heartwood Badi	<i>Nauclea diderrichii</i> (Rubiaceae)	0.04	100	0.3535
		0.08	66.67	
		0.1	100	
Heartwood Bete	<i>Mansonia altissima</i> (Malvaceae)	0.04	66.67	0.0283
		0.08	66.67	
		0.1	100	
Heartwood Iroko	<i>Milicia excelsa</i> (Moraceae)	0.04	66.67	-
		0.08	33.33	
		0.1	66.67	

LD₅₀ corresponding to the Iroko heartwood extract could not be calculated due to the application of a natural mortality rate of 0.5.

Legend: LD₅₀: Lethal dose that is estimated to be fatal to 50% of the larval population.

2-1-2- Effect of treatments on the pupation of *Spodoptera frugiperda*

The insecticide (Crf) caused the death of all larvae (100%) at day one. So, there was no pupation with the insecticide (Table 2). Conversely, on control boxes (Cut), pupation began at day 7, lasted 4 days and the adult emerged on day 11. For the hydroalcoholic boxes (Cwa), pupation began at day 3, lasted 6 days

and the adult emerged at day 9 (Table 2). For larvae exposed to sapwood extracts from the three wood species, 44.44% of larvae started pupation between days 4 to 8, with an average of 5.75 ± 2 days after spraying of the extracts. Pupation duration ranged from 5 to 6 days, with an average of 5.75 ± 0.5 days. Adult emerged between days 10 to 14, with an average of 11.5 ± 1.73 days. Thus, the emergence rate was 100% (Table 2). For the larvae exposed to heartwood extracts from the three wood species, 66.67% of the larvae initiated pupation between days 2 to 5 days, with an average of 3.17 ± 0.98 days after spraying of the extracts. Pupation duration ranged from 5 to 8 days, with an average of 6.67 ± 1.53 days. Adult emergence occurred between days 10 to 14, with an average of 11.5 ± 1.73 days. Thus, the emergence rate was 50%. Additionally, 50% of the nymphs died 4 to 5 days post-spray (Table 2).

Table 2

Number of days of larval and pupal mortality and duration of pupation after application of treatments

Treatments		Beginning of Nymphosis	End of Pupation	Duration of Pupation (Days)	Days to mortality (Days)
	Cut (Control)	7	10	4	
	Cwa (Positive control)	3	8	6	
	Crf (Viper 46EC)	DL			1
Sapwood	Badi (0,04g/mL)	8	13	6	
Sapwood	Badi (0,08g/mL)	DL			1
Sapwood	Badi (0,1g/mL)	DL			1
Sapwood	Bete (0,04g/mL)	4	9	6	
Sapwood	Bete (0,08g/mL)	DL			1
Sapwood	Bete (0,1g/mL)	DL			4
Sapwood	Iroko (0,04g/mL)	5	10	6	
Sapwood	Iroko (0,08g/mL)	6	10	5	
Sapwood	Iroko (0,1g/mL)	DL			1
Heartwood	Badi (0,04g/mL)	3	DP		5
Heartwood	Badi (0,08g/mL)	5	9	5	
Heartwood	Badi (0,1g/mL)	3	DP		4
Heartwood	Bete (0,04g/mL)	DL			2
Heartwood	Bete (0,08g/mL)	3	9	7	
Heartwood	Bete (0,1g/mL)	3	DP		
Heartwood	Iroko (0,04g/mL)	DL			2
Heartwood	Iroko (0,08g/mL)	2	9	8	
Heartwood	Iroko (0,1g/mL)	DL			2
Legend: DL: Dead Larva; DP: Dead pupa, Cut: control, Crf: reference control, Cwa: positive control (water + alcohol)					

2-1-3- Effect of treatments on the quantities of leaves consumed by larvae

The leaves distributed as food to the larvae treated with the insecticide (Crf) were not consumed. However, those distributed to the larvae of untreated boxes (Cut) had been totally consumed (100%) at day one. Approximately, $68.33 \pm 54.85\%$ of leaves were consumed at day 3 by larvae treated with hydroalcoholic (Cwa).

At 0.04g/mL, leaves distributed to larvae treated with sapwood were significantly ($p \leq 0.05$) more consumed than those treated with heartwood. All (100%) the leaves were consumed by larvae treated with sapwood of Badi, Iroko and Bete, respectively at days 1, 2 and 4 (Fig. 4a). Larvae treated with Iroko heartwood (0.04g/mL) had consumed all the leaves (100%) at day 4, those treated with Bete had consumed $68.33 \pm 54.85\%$ of leaves at day 8, and those treated Badi consumed $35 \pm 18.03\%$ at day 7 (Fig. 4b).

At 0.08g/mL, $66.67 \pm 28.87\%$ of leaves treated with Iroko sapwood were consumed at day 5. In contrast, leaves treated with Badi and Bete had not been consumed (0%) (Fig. 4c). On average, $86.33 \pm 18.58\%$ and $61.66 \pm 57.74\%$ of the leaves treated with heartwood Iroko and Bete leaves, respectively, had been consumed at day 8, compared to $61.66 \pm 53.93\%$ of the leaves treated with Badi at day 2 (Fig. 4d). Leaves treated with heartwood extracts were significantly more consumed than the leaves treated with sapwood extracts at 0.08g/mL ($p \leq 0.05$). At 0.1g/mL, Bete sapwood extract (0.1g/mL) reduced leaves consumption, with only $16.67 \pm 28.87\%$ of leaves consumed at day one to day 11. Extracts of Badi and Iroko sapwood prevented leaves consumption (0% of leaves consumed) (Fig. 4e). Bete heartwood extract forced the larvae to consume only $6.67 \pm 7.64\%$ of leaves. In contrast, Badi and Iroko extracts were unable to prevent the larvae from feeding. Thus, 100% of the leaves were consumed at day 11 for Iroko and $66.67 \pm 57.74\%$ at day 2 for Badi. Leaves exposed to larvae treated with sapwood were better protected than those treated with heartwood at 0.1g/mL (Fig. 4f).

2-2 Discussion

2-2-1- Effect of treatments on *Spodoptera frugiperda* larvae

Larvae exposed to the insecticide (Viper 46 EC) died rapidly (100% of mortality in 24 hours). This mortality rate is due to the two active substances (Acetamiprid 16 g/L and Indoxacarb 30 g/L) belonging to two chemical families (Neonicotinoids and Oxadiazines). These substances first bind to nicotinic acetylcholine receptors of the insects' central nervous system, thereby overstimulating nerve cells. This effect causes generalized paralysis and leads to the rapid death of the insect. They also affect growth, disrupting the pupation process and preventing larvae from transforming into adults (Nicolas, 2018; Takwa et al., 2022). The safety of the hydroalcoholic solvent and its neutrality towards the extracts were demonstrated during the evaluation of the different extracts studied on *S. frugiperda* larvae. Then, there is absence of mortality in larvae exposed to this solvent. Regarding the effectiveness of the extracts,

heartwood was more active than sapwood at the dose of 0.04g/mL. However, Iroko sapwood was more toxic than Badi and Bete sapwood. Furthermore, according to De Meeûs (2019), the toxicity of Iroko sapwood is due to the presence of an antioxidant (resveratrol) and a bioactive substance (rosmarinic acid). The toxicity of heartwood on *S. frugiperda* larvae is due to substances such as alkaloids, polyphenols, flavonoids, tannins and saponins. These results are similar to those of De Meeûs (2019) and Thomas et al. (2023) on the same wood species. Indeed, these extracts are effective against fungi (Thomas et al., 2023; Valette et al., 2017), wood termites (Rodrigues et al., 2011; Tascioglu et al., 2012) and other pests (Jurd & Manners, 1980). Secondary metabolites, especially alkaloids, affect insects by biologically disrupting cellular and physiological processes by a redox imbalance and hormonal regulation (Fowsiya & Madhumitha, 2020). According to Attou (2011) (Attou, 2011), plants that are likely to produce phenols have the ability to protect themselves against infection and attack by phytophagous insects because they are antioxidant, anti-inflammatory, antiviral and antiseptic. Sapwood extracts were more toxic than those derived from heartwoods, causing rapid insect death at doses of 0.08 and 0.1g/mL. This could be explained by the presence of sugars (carbon compounds), as after spray of the sapwood extracts, the larvae weakened and remained immobile after caramelization of the extracts. Once the extract is dry, it holds the larvae in place, preventing them from moving around and feeding, resulting in contact toxicity. The death of the larvae is due to the substances (phenols, terpenes, alkaloids) present in the sapwood extracts, which penetrate the larvae. Methanolic extracts of fir (*Abies* sp.) have good insecticidal and fungicidal activity (Lim et al., 2008). Mimosa (*Acacia* sp.) extract, at 12%, was very active on *Spondylis buprestoides* larvae (Sen et al., 2017). All the wood extracts tested showed high to moderate larvicidal activity. Iroko sapwood (LD₅₀ = 0.0219) showed the highest activity, followed by Bete heartwood (LD₅₀ = 0.0283). The results showed that mortality increased with the concentration of the 3 sapwood extracts, indicating that the effect of the sapwood extracts was dose-dependent. In contrast, the activity of heartwood of Badi and Iroko extracts decreased with increasing concentration, contrary to Bete. Our results are similar to Jumenez-Duran et al. (2021), who revealed the antifeedant of *Piper auritum* (LC₅₀ = 22.1mg/cm²) on *S. frugiperda* larvae. They observed malformation of cuticle tissues of larvae and pupae and deformation of adults after emergence (Jiménez-Durán et al., 2021). Hexane extract of *Libidibia coriaria* fruit on *S. frugiperda* caused 93.33% mortality at 100 mg/mL in 24 hours and a low adult emergence rate (25%) at 50 mg/mL (Sánchez-Alonso et al., 2024). The ethanolic extract of *Combretum trifoliatum* was found to be toxic to *S. frugiperda* larvae, affecting egg hatching. Concentrations of the extract (5,10 and 20 µg/egg) significantly reduced egg hatching.

The toxicity of ethanolic extracts of mature leaves, stems and seeds of *Piper tuberculatum* assessed on *Anticarsia gemmatilis* larvae showed that the LD₅₀ of leaves, stems and seeds extracts was respectively 493.8, 244 and 1.60µL/insect (Navickiene et al., 2007). The results suggested that wood extracts have excellent potential for the control of *S. frugiperda*.

2-2-2-Effect of extracts on pupation of *Spodoptera frugiperda*

The long pupation period observed in larvae exposed to sapwood extracts could be due to the low concentration of secondary metabolites. However, the relatively short pupation period observed in larvae

exposed to heartwood could be due to the presence of secondary metabolites. Similar work, carried out on methanolic extracts of seven plant species, prevented the development of *Tribolium castaneum* larvae. The duration of the larval, pupal and emergence periods varied according to the wood species (Jbilou et al., 2008). The insecticidal power of these plants is due to their bioactive compounds, such as alkaloids (Fowsiya and Madhumitha, 2020; Hassani et al., 2002). According to Nascimento et al, (2004) (Nascimento et al., 2004), revealed that the acetone extract reduced the viability of the larval period, and leads malformed adults compared with the ethanolic extract on the larvae of *Anticarsia gemmatilis*. Similarly, Kubo and Klocke (1982) revealed that azadirachtin has an effect on the hormonal system which produces a reduction in the rate of embryonic development, an impairment of metamorphosis, the appearance of multiple larval stages, an inability to molt and even the death of the insect. According to (Simmonds et al., 1990), larval mortality is due to molt failure, while (Juan et al., 2000) showed that most insects that had reached the pupal stage responded as apparently normal adults.

2-2-3- Effect of extracts on quantities of leaves consumed by larvae

Leaves exposed to the insecticide (Viper 46EC), haven't been consumed by the larvae, unlike those exposed to control larvae, and were completely consumed (100%) from day one. In fact, Viper 46 EC, (Acetamiprid (Neonicotinoids) and Indoxacarb (Oxadiazines)), had a toxicity activity on the pest larvae. Insects exposed to the insecticide, stopped feeding, paralysed and died. Indoxacarb with translocation properties, and acetamiprid with systemic properties, presented highly toxic (EFSA, 2013). Leaves treated with hydroalcoholic solvent were eaten at 66.67%. Sapwood extracts protected the leaves better than heartwood extracts at doses of 0.08 and 0.1 g/mL. The rapid death of the larvae is due to the contact toxicity of the sapwood, and the presence of secondary metabolites and sugar. *Melia azedarach* L. (Meliaceae) seed extract had an impact on the nutritional indices of the larvae of *Cnaphalocrocis medinalis* (Lepidoptera, Pyralidae). The seed extract reduced the larval activity of *C. medinalis*. According to Nathan (2006), the conversion efficiency of ingested and digested food decreased after ingestion of treated rice leaves. These studies show that natural plant products inhibit growth, have an anti-appetizing effect and probably have toxic effects on insect pests. Neem extracts are effective against larvae, with significant toxic effects and a significant reduction in food consumption (Saxena et al., 1984; Nathan et al., 2005). The extracts must be applied early when the insects are still in the egg, neonate or second larval stage in order to effectively prevent foliar damage (Nathan, 2006). Additionally, a similar study carried out on methanolic extracts of *Melia azedarach* fruit (2000 ppm) and seed (1000 ppm) showed strong anti-feeding activity on *Sesamia nonagrioides* larvae. Larvae treated with 2000 ppm fruit extract and 1000 ppm seed extract showed identical behavior to those treated with azadirachtin (0.25 ppm) and Mubel (12.5 ppm).

Conclusion

The aim of this study was to evaluate in the laboratory the impact of hydroalcoholic extracts of sapwood and heartwood from three tropical woods: Badi, Bete and Iroko, on the larvae of *Spodoptera frugiperda*, the main maize pest in the field. The results showed that the molecules contained in the wood rejects are highly bioactive against pests and could contribute to the formulation of biopesticides. Contrary to some research, our study showed a high bioefficacy of sapwood on larval pests. The most active extracts, were the sapwood extracts of Badi and Bete at 0.08 g/mL (100% mortality, first day). Sapwood extracts at higher concentrations (0.1g/mL) were more effective than heartwood extracts. Badi and Iroko sapwood eliminated (100% mortality, first day). Badi heartwood extract, at a concentration of 0.04 g/mL, also showed good insecticidal activity but after seven days. The LD₅₀ of sapwood extracts ranged from 0.0219 to 0.0535g/mL, and that of heartwood from 0.0283 to 0.3535g/mL. The duration of pupation was generally longer in larvae that survived after the sapwood treatment (0.04g/mL) and shorter after the heartwood treatment at 0.08g/mL. Doses of 0.04 and 0.1g/mL from Badi and Bete heartwood prevented metamorphosis. In terms of anti-feeding activity, at 0.08g/mL, Badi sapwood and Iroko had the best anti-feeding activity. At 0.1g/mL, Bete heartwood and sapwood also had interesting anti-feeding activity, with heartwood and sapwood. The hydroalcoholic extracts of Badi, Bete and Iroko revealed high and moderate insecticidal activity on *S. frugiperda* larvae. The insecticidal activity could be explained by the presence of secondary metabolites (alkaloids, flavonoids, total polyphenols, tannins, etc.). A high chemical analysis is currently underway, involving the chemical signature of major molecular groups of extract. The wood extracts could contribute of the formulation of bioinsecticides for more ecological and sustainable management of the larvae of *S. frugiperda*, an emerging insect pest of maize crops in Côte d'Ivoire.

Declarations

5-Authors contribution

Appolinaire Bley Bley-Atse: Investigation, data analysis, methodology, drafting of final version, revision, and editing. Armand Nahoulé Adja: Supervision, Visualization and Revision. Bobelé Florence Niamké: Supervision, Revision, Fund acquisition and project coordinator. Tahiana Ramananantoandro: Supervision, Recommendation and Revision. Danho Mathias: Supervision and Visualization, Abo Kouabenan: Supervision and visualization, Nadine Amusant: Supervision and visualization, Augustin Amissa Adima: Supervision and visualization.

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7-Conflicts of interests

No potential conflict of interest was reported by the authors.

8-Data availability statement

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

References

1. Abbott, W.S., 1925. A method of computing the effectiveness of an insecticide. *J. econ. Entomol* 18, 265–267.
2. Adam, S., Edorh, P., Totin, H., Koumolou, L., Amoussou, E., Aklikokou, K., Boko, M., 2011. Pesticides et métaux lourds dans l'eau de boisson, les sols et les sédiments de la ceinture cotonnière de Gogounou, Kandi et Banikoara (Bénin). *International Journal of Biological and Chemical Sciences* 4. <https://doi.org/10.4314/ijbcs.v4i4.63054>
3. Adebayo, M.A., Adedokun, O.A., Akinpelu, L.A., Okafor, P.O., 2019. Evaluation of Anti-Diarrheal Activity of Methanol Root Bark Extract of *Milicia Excelsa* (Welw) C. C Berg (Moraceae) in Rats. *Drug Res (Stuttg)* 69, 439–444. <https://doi.org/10.1055/a-0825-6337>
4. Adegoke, K.A., Adesina, O.O., Okon-Akan, O.A., Adegoke, O.R., Olabintan, A.B., Ajala, O.A., Olagoke, H., Maxakato, N.W., Bello, O.S., 2022. Sawdust-biomass based materials for sequestration of organic and inorganic pollutants and potential for engineering applications. *Current Research in Green and Sustainable Chemistry* 5, 100274.
5. Adja, A.N., Bley-Atse, A.B., Gnago, J.A., Tienebo, E.-O., Danho, M., 2023. Damage Caused by Lepidopteran Pests on Maize Fields in Yamoussoukro, Central Côte d'Ivoire. *International Journal of Plant & Soil Science* 35, 815–823. <https://doi.org/10.9734/ijpss/2023/v35i183348>
6. Adja, A.N., Bley-Atse, A.B., Tienebo, E.-O., Gnago, J.A., Danho, M., 2023b. Use of Selected Chemical and Biological Insecticides to Control Lepidopteran Pests of Maize Fields in Central Côte d'Ivoire. *International Journal of Environment and Climate Change* 13, 812–825. <https://doi.org/10.9734/ijecc/2023/v13i113229>
7. Agbebi, E.A., Alabi, O.S., Nkrumah, A.O., Ogbole, O.O., 2022. Evaluation of the antibacterial and antifungal potentials of peptide-rich extracts from selected Nigerian plants. *European Journal of Integrative Medicine* 54, 102163. <https://doi.org/10.1016/j.eujim.2022.102163>
8. Agboyi, L.K., Ketoh, G.K., Martin, T., Glitho, I.A., Tamò, M., 2016. Pesticide resistance in *Plutella xylostella* (Lepidoptera: Plutellidae) populations from Togo and Benin. *Int. J. Trop. Insect Sci.* 36, 204–210. <https://doi.org/10.1017/S1742758416000138>
9. Aguiar, S., Vieira, S.M.J., de Oliveira, H.G., Holtz, A.M., 2002. Revisão da biologia, ocorrência e controle de *Spodoptera frugiperda* (Lepidoptera, noctuidae) em milho no Brasil biology review, occurrence and control of *Spodoptera frugiperda* (Lepidoptera, noctuidae) in corn in Brazil.

10. Akeme, C.N., Ngosong, C., Sumbele, S.A., Aslan, A., Tening, A.S., Krah, C.Y., Kamanga, B.M., Denih, A., Nambangia, O.J., 2021. Different controlling methods of fall armyworm (*Spodoptera frugiperda*) in maize farms of small-scale producers in Cameroon, in: IOP Conference Series: Earth and Environmental Science. IOP Publishing, p. 012053.
11. Amusant, N., Moretti, C., Richard, B., Prost, E., Nuzillard, J.M., Thévenon, M.F., 2007. Chemical compounds from *Eperua falcata* and *Eperua grandiflora* heartwood and their biological activities against wood destroying fungus (*Coriolus versicolor*). *European Journal of Wood and Wood Products* 65, 23–28.
12. Anouhe, J.-B.S., Niamké, F.B., Faustin, M., Virieux, D., Pirat, J.-L., Adima, A.A., Kati-Coulibaly, S., Amusant, N., 2018. The role of extractives in the natural durability of the heartwood of *Dicorynia guianensis* Amsh: new insights in antioxydant and antifungal properties. *Annals of Forest Science* 75, 1–10. <https://doi.org/10.1007/s13595-018-0691-0>
13. Ansel, J.-L., Butaud, J.-F., Raharivelomanana, P., 2016. Bibliographical analysis of main lignified taxons used in tropical cosmetopoiea. *Comptes Rendus. Chimie* 19, P. 1035-1048. <https://doi.org/10.1016/j.crci.2016.03.017>
14. Antwi-Boasiako, C., Acheampong, B.B., 2016. Strength properties and calorific values of sawdust-briquettes as wood-residue energy generation source from tropical hardwoods of different densities. *Biomass and Bioenergy* 85, 144–152.
15. Arnason, J.T., Philogène, B.J.R., Morand, P. (Eds.), 1989. *Insecticides of Plant Origin*, ACS Symposium Series. American Chemical Society, Washington, DC. <https://doi.org/10.1021/bk-1989-0387>
16. Attou, A., 2011. Contribution à l'étude phytochimique et activités biologiques des extraits de la plante *Ruta chalepensis* (Fidjel) de la région d'Ain Témouchent 119.
17. Barrera-Arellano, D., Badan-Ribeiro, A.P., Serna-Saldivar, S.O., 2019. Corn oil: composition, processing, and utilization, in: *Corn*. Elsevier, pp. 593–613.
18. Cetiner, I., Shea, A.D., 2018. Wood waste as an alternative thermal insulation for buildings. *Energy and Buildings* 168, 374–384. <https://doi.org/10.1016/j.enbuild.2018.03.019>
19. Changkeb, V., Nobsathian, S., Le Goff, G., Coustau, C., Bullangpoti, V., 2023. Insecticidal efficacy and possibility of *Combretum trifoliatum* Vent. (Myrtales: Combretaceae) extracts in controlling *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae). *Pest Management Science* 79, 4868–4878. <https://doi.org/10.1002/ps.7688>
20. Charvet, R., Katouzian-Safadi, M., Colin, M.-E., Marchand, P.-A., Bonmatin, J.-M., 2004. Insecticides systémiques: de nouveaux risques pour les insectes pollinisateurs. *Annales Pharmaceutiques Françaises* 62, 29–35. [https://doi.org/10.1016/S0003-4509\(04\)94278-2](https://doi.org/10.1016/S0003-4509(04)94278-2)
21. Cheah, C.B., Ramli, M., 2013. The engineering properties of high performance concrete with HCWA–DSF supplementary binder. *Construction and Building Materials, Special Section on Recycling Wastes for Use as Construction Materials* 40, 93–103. <https://doi.org/10.1016/j.conbuildmat.2012.10.010>

22. Dabija, A., Ciocan, M.E., Chetrariu, A., Codină, G.G., 2021. Maize and sorghum as raw materials for brewing, a review. *Applied Sciences* 11, 3139.
23. De Meeûs, T., 2019. Caractérisation des extraits phénoliques et du latex de l'Iroko (*Milicia excelsa*).
24. EFSA, A. européenne de sécurité des aliments, 2013. Scientific Opinion on the developmental neurotoxicity potential of acetamiprid and imidacloprid. EFSA Panel on Plant Protection Products and their Residues (PPR)2, 3European Food Safety Authority (EFSA), Parma, Italy. URL <https://www.europeansources.info/record/scientific-opinion-on-the-developmental-neurotoxicity-potential-of-acetamiprid-and-imidacloprid/> (accessed 11.14.23).
25. Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K., Prasanna, B.M., 2022. Global maize production, consumption and trade: trends and R&D implications. *Food Sec.* 14, 1295–1319. <https://doi.org/10.1007/s12571-022-01288-7>
26. Feng, S., Cheng, S., Yuan, Z., Leitch, M., Xu, C.C., 2013. Valorization of bark for chemicals and materials: A review. *Renewable and Sustainable Energy Reviews* 26, 560–578.
27. Ferreira, F.J.B. de S., Alves, L.R.A., Gottardo, L.C.B., Georgino, M., 2010. Dimensionamento do custo econômico representado por *Spodoptera Frugiperda* cultura do milho no Brasil. *Tecnologias, desenvolvimento e integração social; anais*.
28. Fowsiya, J., Madhumitha, G., 2020. A review of bioinsecticidal activity and mode of action of plant derived alkaloids. *Research journal of pharmacy and technology* 13, 963–973.
29. Frank Eshun, J., Potting, J., Leemans, R., 2012. Wood waste minimization in the timber sector of Ghana: a systems approach to reduce environmental impact. *Journal of Cleaner Production* 26, 67–78. <https://doi.org/10.1016/j.jclepro.2011.12.025>
30. Golbaz, S., Zamanzadeh, M.Z., Pasalari, H., Farzadkia, M., 2021. Assessment of co-composting of sewage sludge, woodchips, and sawdust: feedstock quality and design and compilation of computational model. *Environ Sci Pollut Res* 28, 12414–12427. <https://doi.org/10.1007/s11356-020-11237-6>
31. Grdiša, M., Gršić, K., 2013. Botanical insecticides in plant protection. *Agriculturae conspectus scientificus* 78, 85–93.
32. Guo, J., Wu, S., Zhang, F., Huang, C., He, K., Babendreier, D., Wang, Z., 2020. Prospects for microbial control of the fall armyworm *Spodoptera frugiperda*: a review. *BioControl* 65, 647–662. <https://doi.org/10.1007/s10526-020-10031-0>
33. Haq, I.U., Khurshid, A., Inayat, R., Zhang, K., Liu, C., Ali, S., Zuan, A.T.K., Al-Hashimi, A., Abbasi, A.M., 2021. Silicon-based induced resistance in maize against fall armyworm [*Spodoptera frugiperda* (Lepidoptera: Noctuidae)]. *Plos one* 16, e0259749.
34. Hassan, B., Mankowski, M.E., Kirker, G.T., Clausen, C.A., Ahmed, S., 2018. Effects of white mulberry (*Morus alba*) heartwood extract against *Reticulitermes flavipes* (Blattodea: Rhinotermitidae). *Journal of Economic Entomology* 111, 1337–1345.
35. Hassani, I.L.M., Ahmedou, M., Mayad, E.H., Bouaichi, A., 2002. Pouvoir insecticide de *Peganum harmala* sur *Schistocerca gregaria*: Effets de l'huile et des extraits de feuilles. *Biologie et Santé*.

36. Hillis, W.E., 2012. Heartwood and Tree Exudates. Springer Science & Business Media.
37. Jbilou, R., Amri, H., Bouayad, N., Ghailani, N., Ennabili, A., Sayah, F., 2008. Insecticidal effects of extracts of seven plant species on larval development, α -amylase activity and offspring production of *Tribolium castaneum* (Herbst)(Insecta: Coleoptera: Tenebrionidae). *Bioresource technology* 99, 959–964.
38. Jiménez-Durán, A., Barrera-Cortés, J., Lina-García, L.P., Santillan, R., Soto-Hernández, R.M., Ramos-Valdivia, A.C., Ponce-Noyola, T., Ríos-Leal, E., 2021. Biological Activity of Phytochemicals from Agricultural Wastes and Weeds on *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae). *Sustainability* 13, 13896. <https://doi.org/10.3390/su132413896>
39. Juan, A., Sans, A., Riba, M., 2000. Antifeedant activity of fruit and seed extracts of *Melia azedarach* and *azadirachta indica* on larvae of *Sesamia nonagrioides*. *Phytoparasitica* 28, 311–319. <https://doi.org/10.1007/BF02981826>
40. Jurd, L., Manners, G.D., 1980. Wood extractives as models for the development of new types of pest control agents. *J. Agric. Food Chem.* 28, 183–188. <https://doi.org/10.1021/jf60228a009>
41. Karabey, T., Sert, O., 2018. The analysis of pupal development period in *Lucilia sericata* (Diptera: Calliphoridae) forensically important insect. *Int J Legal Med* 132, 1185–1196. <https://doi.org/10.1007/s00414-014-0968-2>
42. Kebbi-Benkeder, Z., Colin, F., Dumarçay, S., Gérardin, P., 2015. Quantification and characterization of knotwood extractives of 12 European softwood and hardwood species. *Annals of Forest Science* 72, 277–284. <https://doi.org/10.1007/s13595-014-0428-7>
43. Koul, O., Dhaliwal, G.S., 2000. Phytochemical biopesticides. CRC Press.
44. Kubo, I., Klocke, J.A., 1982. Azadirachtin, insect ecdysis inhibitor. *Agricultural and Biological Chemistry* 46, 1951–1953.
45. Lengai, G.M.W., Muthomi, J.W., Mbega, E.R., 2020. Phytochemical activity and role of botanical pesticides in pest management for sustainable agricultural crop production. *Scientific African* 7, e00239. <https://doi.org/10.1016/j.sciaf.2019.e00239>
46. Lim, J.-A., Choi, Y.-A., Jung, M.-H., Kang, S.-Y., Chung, Y.-J., 2008. Antifungal and insecticidal activity of methanol extract from 11 Korean wood species. *Journal of conservation Science* 23, 95–102.
47. Mayer, E., Eichermüller, J., Endriss, F., Baumgarten, B., Kirchhof, R., Tejada, J., Kappler, A., Thorwarth, H., 2022. Utilization and recycling of wood ashes from industrial heat and power plants regarding fertilizer use. *Waste Management* 141, 92–103.
48. Morão, G.L., Dilarri, G., Renato Corso, C., 2017. An approach to textile dye removal using sawdust from *Aspidosperma polyneuron*. *International Journal of Environmental Studies* 74, 75–85. <https://doi.org/10.1080/00207233.2016.1236651>
49. Munene, V., 2018. Surveillance et gestion de la chenille légionnaire (*Spodoptera frugiperda*). <https://doi.org/10.13140/RG.2.2.14831.69284>
50. Mwango, A., Kambole, C., 2019. Engineering Characteristics and Potential Increased Utilisation of Sawdust Composites in Construction—A Review. *Journal of Building Construction and Planning*

- Research 7, 59–88. <https://doi.org/10.4236/jbcpr.2019.73005>
51. Nakagawa, N., Otaki, M., Miura, S., Hamasuna, H., Ishizaki, K., 2006. Field survey of a sustainable sanitation system in a residential house. *Journal of Environmental Sciences* 18, 1088–1093.
 52. Nascimento, I.R., Murata, A.T., Bortoli, S.A., Lopes, L.M., 2004. Insecticidal activity of chemical constituents from *Aristolochia pubescens* against *Anticarsia gemmatilis* larvae. *Pest Management Science* 60, 413–416. <https://doi.org/10.1002/ps.805>
 53. Nathan, S.S., 2006. Effects of *Melia azedarach* on nutritional physiology and enzyme activities of the rice leaffolder *Cnaphalocrocis medinalis* (Guenée)(Lepidoptera: Pyralidae). *Pesticide Biochemistry and Physiology* 84, 98–108.
 54. Nathan, S.S., Chung, P.G., Murugan, K., 2005. Effect of biopesticides applied separately or together on nutritional indices of the rice leaffolder *Cnaphalocrocis medinalis*. *Phytoparasitica* 33, 187–195. <https://doi.org/10.1007/BF03029978>
 55. Navickiene, H.M.D., Miranda, J.E., Bortoli, S.A., Kato, M.J., Bolzani, V.S., Furlan, M., 2007. Toxicity of extracts and isobutyl amides from *Piper tuberculatum*: potent compounds with potential for the control of the velvetbean caterpillar, *Anticarsia gemmatilis*. *Pest Management Science* 63, 399–403. <https://doi.org/10.1002/ps.1340>
 56. Niamke, F.B., 2010. Recherche de determinants biochimiques de la durabilite naturelle du bois de teck (*Tectona Grandis* L. F.) (Thèse en Cotutelle). Université d'Abidjan et Université de Montpellier II, Côte d'Ivoire et France.
 57. Niamké, F.B., Amusant, N., Augustin, A.A., Chaix, G., 2021. Teakwood Chemistry and Natural Durability, in: Ramasamy, Y., Galeano, E., Win, T.T. (Eds.), *The Teak Genome, Compendium of Plant Genomes*. Springer International Publishing, Cham, pp. 83–102. https://doi.org/10.1007/978-3-030-79311-1_7
 58. Niamké, F.B., Amusant, N., Stien, D., Chaix, G., Lozano, Y., Kadio, A.A., Lemenager, N., Goh, D., Adima, A.A., Kati-Coulibaly, S., 2012. 4', 5'-Dihydroxy-epiisocatalponol, a new naphthoquinone from *Tectona grandis* L. f. heartwood, and fungicidal activity. *International Biodeterioration & Biodegradation* 74, 93–98.
 59. Nichols, N.N., Dien, B.S., Bothast, R.J., Cotta, M.A., 2016. The corn ethanol industry, in: *Alcoholic Fuels*. CRC Press, pp. 59–78.
 60. Nicolas, S., 2018. Les néonicotinoïdes: une menace pour la biodiversité, les écosystèmes et la sécurité alimentaire.
 61. Olaiya, B.C., Lawan, M.M., Olonade, K.A., 2023. Utilization of sawdust composites in construction—a review. *SN Appl. Sci.* 5, 140. <https://doi.org/10.1007/s42452-023-05361-4>
 62. Rodrigues, A.M., Amusant, N., Beauchêne, J., Eparvier, V., Leménager, N., Baudassé, C., Espindola, L.S., Stien, D., 2011. The termiticidal activity of *Sextonia rubra* (Mez) van der Werff (Lauraceae) extract and its active constituent rubrynolide. *Pest. Manag. Sci.* 67, 1420–1423. <https://doi.org/10.1002/ps.2167>

63. Saadane, O., 2018. L'impact des pesticides sur l'environnement et la sante humaine et methodes alternatives (PhD Thesis).
64. Sánchez-Alonso, I., Fonseca-González, A., Olmedo-Juárez, A., Olivares-Pérez, J., González-Cortazar, M., Monteon-Ojeda, A., Rojas Hernández, S., 2024. Insecticidal activity of two organic extracts from *Libidibia coriaria* (Jacq.) Schltdl. fruits against *Spodoptera frugiperda* J. E. Smith. *Natural Product Research* 0, 1–7. <https://doi.org/10.1080/14786419.2024.2368274>
65. Saxena, R.C., Epino, P.B., Tu, C.-W., Puma, B.C., 1984. Neem, chinaberry and custard apple: antifeedant and insecticidal effects of seed oils on leafhopper and planthopper pests of rice. *Schriftenreihe der Gesellschaft fur Technische Zusammenarbeit*.
66. Sen, S., Yalçın, M., Tasçioğlu, C., Özbayram, A.K., 2017. Larvicidal activities of some bark and wood extracts against wood-damaging insects. *Maderas. Ciencia y tecnología* 19, 273–284.
67. Simmonds, M.S.J., Blaney, W.M., Ley, S.V., Anderson, J.C., Toogood, P.L., 1990. Azadirachtin: structural requirements for reducing growth and increasing mortality in lepidopterous larvae. *Entomologia Exp Applicata* 55, 169–181. <https://doi.org/10.1111/j.1570-7458.1990.tb01360.x>
68. Smith, G.H., Roberts, J.M., Pope, T.W., 2018. Terpene based biopesticides as potential alternatives to synthetic insecticides for control of aphid pests on protected ornamentals. *Crop Protection* 110, 125–130.
69. Takwa, A., Assala, M., Melazem, L., 2022. Etude des effets néfastes du pesticides néonicotinoïdes sur la santé humaine et l'environnement (PhD Thesis). Université Larbi Tébessi-Tébessa.
70. Tapondjou, A.L., Adler, C., Fontem, D.A., Bouda, H., Reichmuth, C., 2005. Bioactivities of cymol and essential oils of *Cupressus sempervirens* and *Eucalyptus saligna* against *Sitophilus zeamais* Motschulsky and *Tribolium confusum* du Val. *Journal of Stored Products Research* 41, 91–102. <https://doi.org/10.1016/j.jspr.2004.01.004>
71. Tascioglu, C., Yalcin, M., de Troya, T., Sivrikaya, H., 2012. Termiticidal properties of some wood and bark extracts used as wood preservatives 10.
72. Tasei, J.-N., 1996. Impact des pesticides sur les Abeilles et les autres pollinisateurs. *Le Courrier de l'environnement de l'INRA* 29, 9–18.
73. Taylor, A.M., Gartner, B.L., Morrell, J.J., 2002. Heartwood formation and natural durability-a review.
74. Thomas, D., Florence, N.B., Félix, A., Appolinaire, B.B., Yao, N.J.C., René, D.K., Armand, A.N., Kouabenan, A., Fabrice, T., Augustin, A.A., Nadine, A., 2023. Valorisation et étude de l'activité antifongique et antioxydante d'extraits de trois bois durables de la Côte d'Ivoire. *A. A.* 38.
75. Valette, N., Perrot, T., Sormani, R., Gelhay, E., Morel-Rouhier, M., 2017. Antifungal activities of wood extractives. *Fungal Biology Reviews* 31, 113–123. <https://doi.org/10.1016/j.fbr.2017.01.002>
76. Veeyee, K.F., Bup, N.D., Boldor, D., Elambo, N.G., 2021. Potentials of sustainable electricity production from sawdust by small-scale wood transformation units: a case study in Cameroon. *Int J Energy Environ Eng* 12, 101–114. <https://doi.org/10.1007/s40095-020-00362-0>
77. Weisskopf, M.G., Knekt, P., O'reilly, E.J., Lyytinen, J., Reunanen, A., Laden, F., Altshul, L., Ascherio, A., 2010. Persistent organochlorine pesticides in serum and risk of Parkinson disease. *Neurology* 74,

1055–1061.

78. Zanli, B.L.G.L., Gbossou, K.C., Tang, W., Kamoto, M., Chen, J., 2022. A review of biochar potential in Cote d'Ivoire in light of the challenges facing Sub-Saharan Africa. *Biomass and Bioenergy* 165, 106581. <https://doi.org/10.1016/j.biombioe.2022.106581>
79. Zine, O., Taoukil, D., El Abbassi, I., Laaroussi, N., Kadri, E.-H., Lahlaouti, M. Ihassane, El bouardi, A., 2023. Experimental and theoretical thermal investigation of bio-composite panels based on sawdust particles. *Journal of Building Engineering* 76, 107251. <https://doi.org/10.1016/j.job.2023.107251>
80. Zou, S., Li, H., Wang, S., Jiang, R., Zou, J., Zhang, X., Liu, L., Zhang, G., 2020. Experimental research on an innovative sawdust biomass-based insulation material for buildings. *Journal of Cleaner Production* 260, 121029. <https://doi.org/10.1016/j.jclepro.2020.121029>

Figures

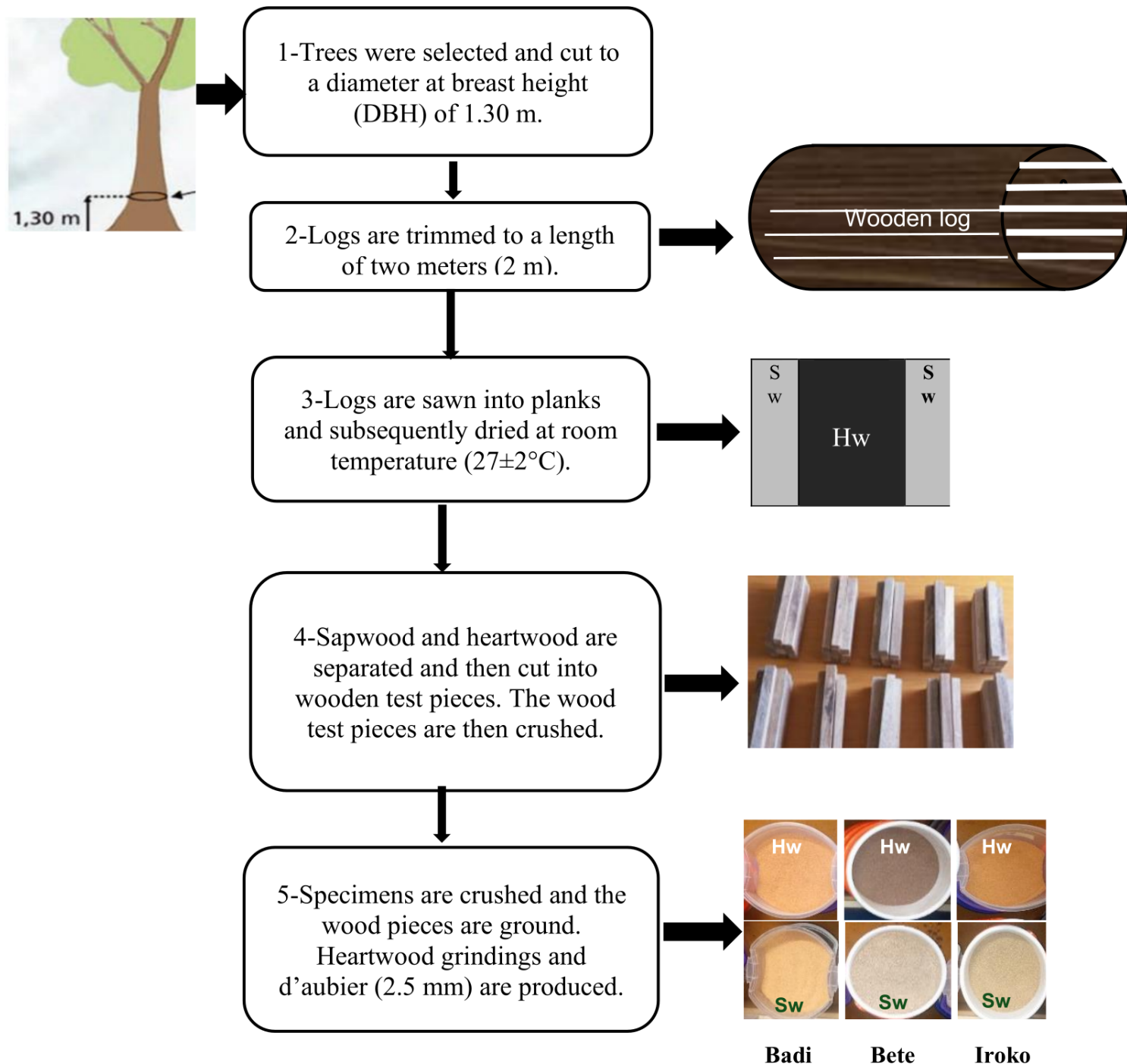


Figure 1

Collection and processing of wood samples and wood shavings

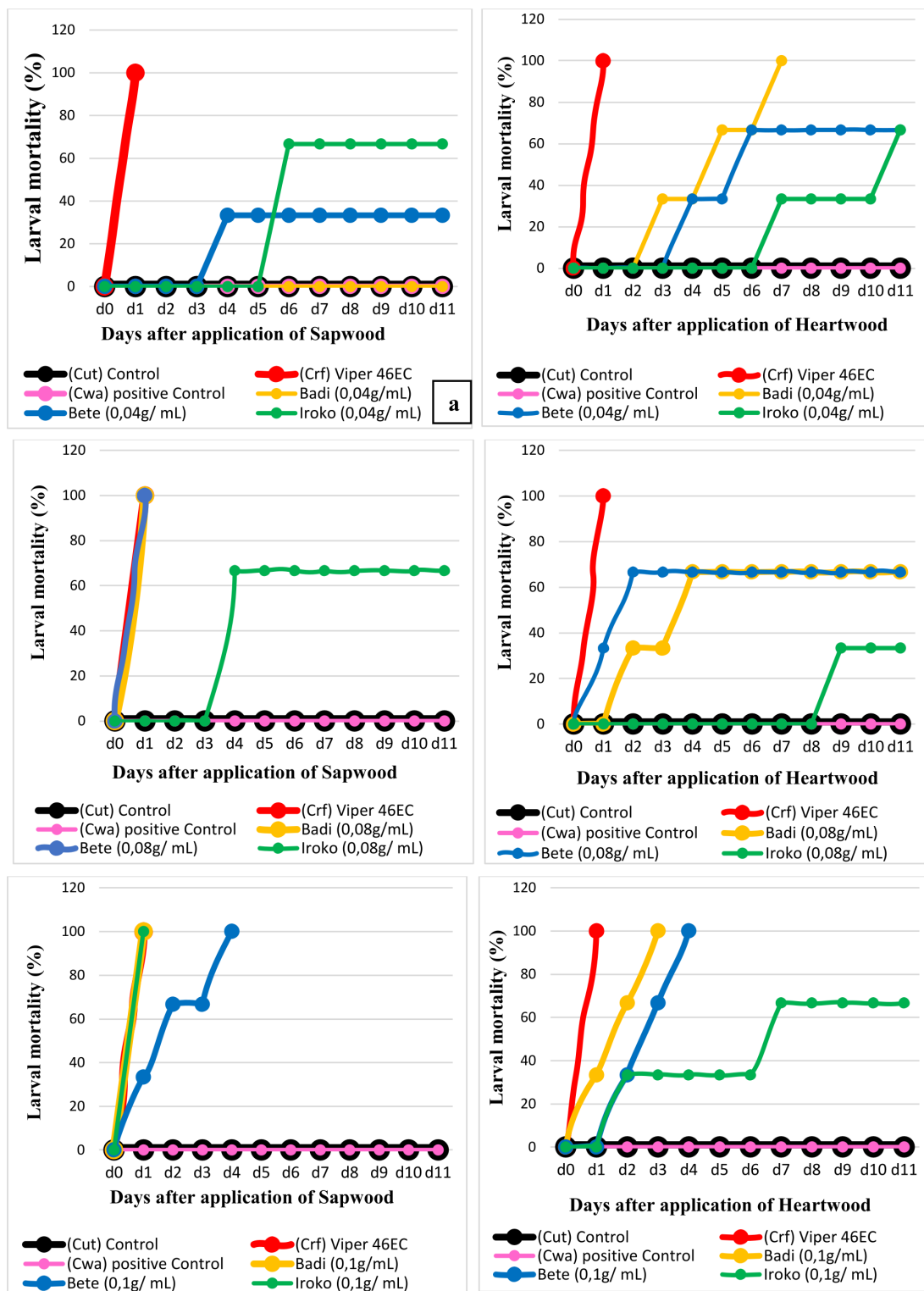


Figure 3

Larval mortality after application of sapwood and heartwood extracts

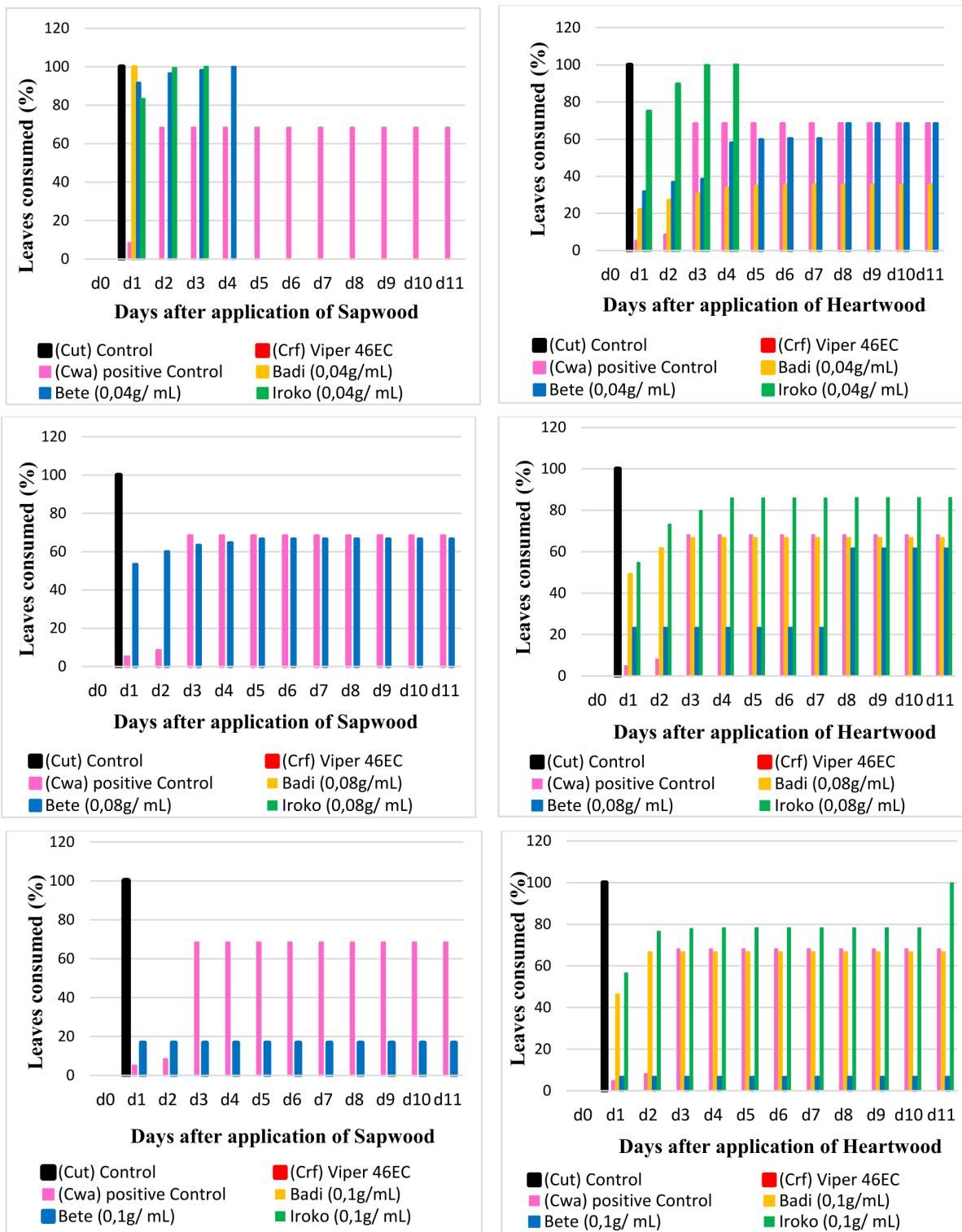


Figure 4

Anti-appetizing activity of sapwood and heartwood extracts from the woods studied.