

Evaluation of Solvent Extracts and Fraction of *Khaya senegalensis* on *Tribolium castaneum* and *Tribolium confusum*

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Abstract

This study analyzes the insecticidal activity of extracts derived from *Khaya senegalensis* and their fractions against two major stored-product pests: *Tribolium castaneum* and *Tribolium confusum*. The aim is to evaluate the efficacy of extracts prepared using various solvents and to assess the susceptibility of both species to the treatments applied. Solvents of varying polarities were used to obtain *K. senegalensis* extracts, enabling the extraction of diverse bio-active substances. Tests were subsequently conducted on adults of both species using the extracts and fractions at various concentrations. Based on the results obtained, the percentage for the ether extract was 0% at concentration C1 and 35.73% at C2, while for the hexane fraction it was 25.09% at C1; for the crude methanol extract, the ethyl acetate fraction, and the methanol fraction, the values at C1 against *T. castaneum* were 78.6%, 57.38%, and 93.43%, respectively. All three concentrations produced high adult mortality rates against *T. confusum* at C1: $78.47 \pm 3.77\%$ for the crude methanol extract, $58.47 \pm 2.43\%$ for the ethyl acetate fraction, and $92.37 \pm 4.35\%$ for the methanol fraction; meanwhile, mortality was 46.87% for the ether extract and 33.38% for the hexane fraction at C1. Untreated mortality reaches 12.50% only from the tenth day of treatment. Mortality rates caused by the three doses (C1, C2, and C3) show no statistically significant difference ($p \geq 0.05$). Thus, this study highlights the potential of *K. senegalensis* as a source of natural compounds for protecting stored products and as a substitute for traditional chemical insecticides.

Keywords

Khaya senegalensis, Extracts, Fractions, Solvents, Insecticidal Activity, *Tribolium castaneum*, *Tribolium confusum*

1. Introduction

Preserving stored grain is a crucial challenge for food security in tropical regions [1]-[6]; post-harvest damage caused by insects (particularly *Tribolium castaneum* and *Tribolium confusum*) [7]-[10] is substantial, reducing both the quality and quantity of stocks [11] [12]. The frequent use of synthetic insecticides raises concerns regarding residues, toxicity, and resistance [13]. Consequently, there is growing interest in botanical biocontrol agents which utilize local plant extracts possessing insecticidal, repellent, or anti-oviposition properties [14] [15]. According to local communities, *Khaya senegalensis* (Meliaceae) a species widely used in West Africa is frequently cited for its ability to protect property and for its veterinary and phytosanitary applications. Current ethnobotanical research in the Labé region (Guinea), as well as individual experimental studies, report the use of this plant for pest control and highlight academic interest in analyzing its extracts for insecticidal and larvicidal properties [16] [17].

Thus, the aim of this study is to examine the insecticidal activity (contact toxicity) of solvent extracts and polarity-based fractions of *Khaya senegalensis* against adult *Tribolium castaneum* and *Tribolium confusum*, and to establish a correlation between phytochemical profiles and efficacy. This information will facilitate the development of promising solutions involving botanical mixtures that are safe and suitable for protecting local agricultural stocks.

2. Materials and Methods

General location of collection and preparation of plant powder samples for testing:

Harvesting took place in the Labé region specifically in Madina Toungouroun (within the Dalein sub-prefecture, Koundou N'daggui district, Labé Prefecture, Republic of Guinea) at 7:00 a.m. to ensure a concentration of active molecules effective against the insect. The collected samples were air-dried at laboratory temperature for four (4) weeks and then ground into powder using a manual grinder; the resulting powders were used for the various tests. A 500 µm sieve was used to obtain a particle size range of 250 - 500 µm. The samples were identified by the National Herbarium of Guinea (HNG). “*Kahi*” in Pulaar—*Khaya senegalensis*. Number: 1134. GPS coordinates: 11°37'56.23"N; 12°20'14.69"W. Altitude: 517.34 m. Associated species: *Erythrophleum guineense*; *Senna sieberiana*; *Gmelina arborea*.

2.1. Solvent Extracts

For each plant powder, maceration was performed using either petroleum ether

or methanol. This involved prolonged contact between 200 g of powder and 500 mL of solvent (either petroleum ether or methanol) in a container sealed with aluminum foil and a lid [18]-[20]. The mixture was then kept at a temperature of 25°C. After 48 hours of maceration, the contents of each jar were filtered using a filter and a funnel. A dry residue, known as the crude extract, was obtained by evaporating the filtrate using a rotary evaporator. The collected samples are stored in vials and placed in a desiccator. Their contents will be used to carry out biological tests and biochemical analysis. The diagram below (Figure 1) summarizes the described experimental protocol.

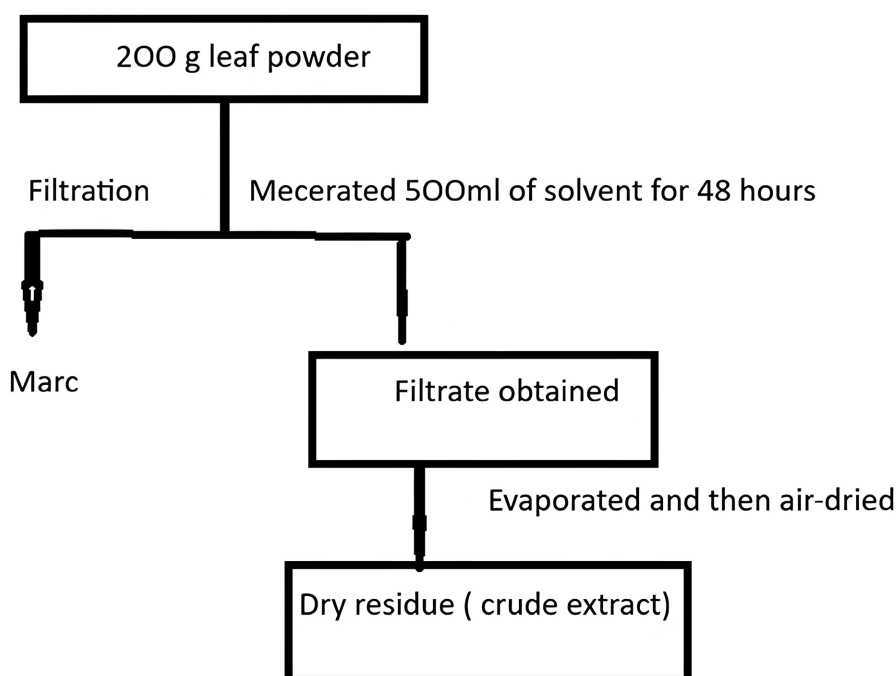


Figure 1. Experimental setup for simple maceration.

2.2. Fractions of the Crude Methanol Extract

This process involves a series of extractions starting from the crude methanolic extract obtained directly from the leaf powder using three solvents of increasing polarity: hexane, ethyl acetate, and methanol. To achieve this, an initial maceration is performed using hexane. This entails combining the dry methanolic residue with 500 mL of hexane for one day, followed by mixing and filtration. The hexane phase is evaporated to dryness at 45°C using a rotary evaporator. The dry residue is placed in a desiccator to remove any remaining solvent.

The residue, now in the form of a dry paste, is then mixed again with 500 mL of ethyl acetate for 24 hours under the same conditions as before. The final solution is then evaporated to yield a dry residue known as the methanol fraction, which differs from the crude methanol extract (Figure 2). The hexane, ethyl acetate, and methanol fractions are all collected in three vials, which are then placed in a desiccator.

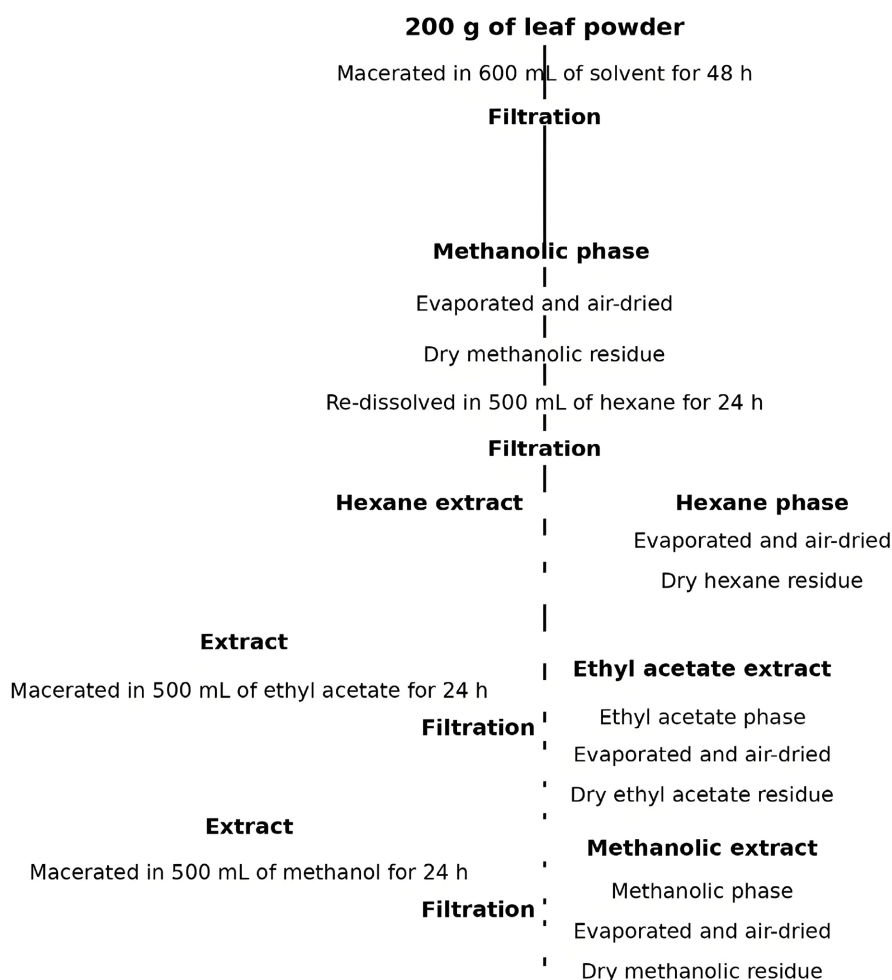


Figure 2. Experimental scheme for the protocol of re-dissolving the crude methanol extract in other solvents of varying polarity.

2.3. Contact Toxicity of Solvent Extracts and Extract Fractions

Direct tests are conducted on young adult insects (less than 24 hours old) from laboratory cultures, using various biocidal products derived from *Khaya senegalensis*. The analysis is performed in glass Petri dishes (90 mm in diameter and 15 mm in height) [21]. These dishes contain a Whatman filter paper previously impregnated with 3 ml of the test solution. For each pure extract or extract fraction, three predefined concentrations are applied, alongside a blank control and a solvent control (extracts using methanol, petroleum ether, hexane; ethyl acetate and methanol ether). For each concentration (specifically 0.1, 0.01, and 0.001 g/ml) and each control group, the ten adult insects are placed in a Petri dish.

Each concentration is tested in three separate trials. The number of dead and living individuals is recorded at two, six, twelve, and twenty-four hours after the start of the procedure. Subsequently, mortality is assessed every 24 hours. For each concentration of the tested solution, the percentage of dead adults is calculated (number of dead individuals/numbers used $\times$ 100). The results are corrected using Abbott's formula (1925) and then presented in graphs and tables. In total, adulti-

cide tests were conducted on 1800 individuals and ten biocidal products. The statistical model used is one-way ANOVA (Figures 3-6).

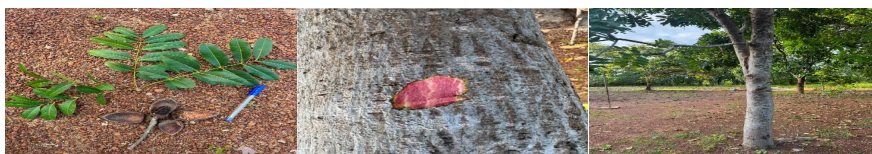


Figure 3. *Khaya senegalensis* (Author; 2025).



Figure 4. Electric scale.



Figure 5. Magnetic stirrer.



Figure 6. Fraction.

3. Results and Discussion

3.1. Results of Tests Using Solvent Extracts and Fractions of *Khaya senegalensis* *Tribolium castaneum* and *Tribolium confusum*

The results obtained regarding the adulticidal activity of solvent extracts and fractions derived from *Khaya senegalensis* leaf powder are presented as histograms. Adult mortality rates for *Tribolium castaneum* exposed to *Khaya senegalensis* biocidal products at various concentrations are shown in **Figure 7**. For a given crude sample or sample fraction, bars marked with the same letter do not differ significantly at $p \geq 0.05$.

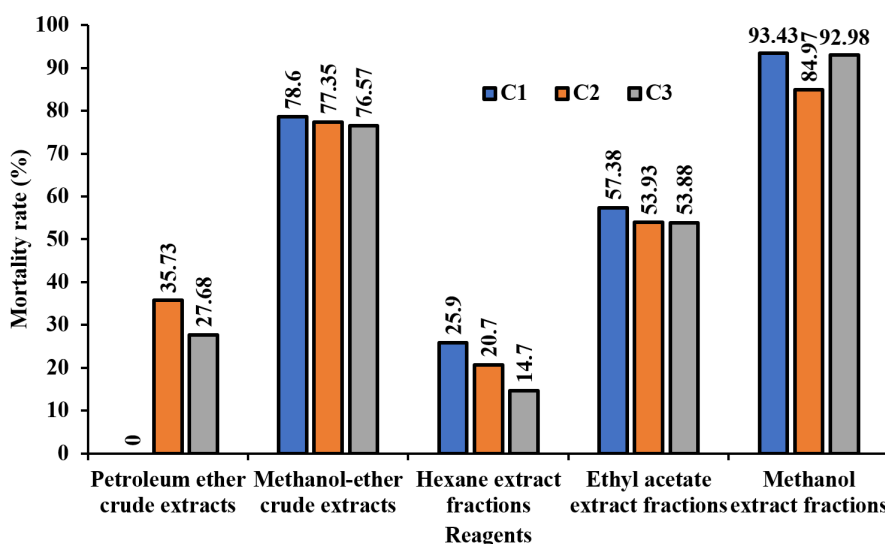


Figure 7. Mortality of adult *Tribolium castaneum* exposed to *Khaya senegalensis* biocidal products at various concentrations.

The graph above generally shows that all concentrations result in high mortality among adult *Tribolium castaneum* compared to the controls, regardless of the extract or extract fraction used. Regarding the crude petroleum ether extract and the hexane fraction, adult mortality caused by concentration C1 is significantly higher than that caused by the other concentrations.

For the ether extract, the mortality rate is 35.73%, whereas for the hexane fraction, it is 25.09%. The other concentrations, C2 and C3, produce statistically similar effects. Mortality rates of 20.70% and 14.7% were observed for concentrations C2 and C3 of the hexane fraction, respectively.

Regarding the other products tested such as the crude methanol extract, the ethyl acetate fraction, and the methanol fraction the adjusted mortality rates resulting from the three doses (C1, C2, and C3) show no statistically significant differences ($p \geq 0.05$). The mean adult mortality rates determined at these three concentrations are approximately 90% for the crude methanol extract, $57.38\% \pm 2.35\%$ for the ethyl acetate fraction, and $93.43\% \pm 3.21\%$ for the methanol fraction. Mortality among untreated adults reaches 12.50% only from the tenth day of treatment onwards (**Figure 7**).

When examining the adult mortality rate of *Tribolium castaneum* in relation to exposure duration (24 h, 48 h, 72 h, 96 h, 120 h, 6 days, etc.), it is observed that *Khaya senegalensis* begins to cause mortality after the first 24 hours of treatment. The experiment was conducted over a 10-day period, after which no further samples of dead organisms were collected. The study indicates that for an exposure period of 0 to 6 days from the start of treatment, the *Khaya senegalensis* C1 dose demonstrates more pronounced adulticidal activity compared to doses C2 and C3. Conversely, between 6 and 10 days of exposure, the opposite effect is observed.

This observation is more pronounced with the methanol extract, the ethyl acetate fraction, and the methanol fraction. To illustrate, doses C2 and C3 of the hexane fraction caused no mortality prior to the sixth day of treatment, whereas the 33.38% adult mortality induced by C1 was observed between 24 hours and the seventh day of treatment (Figure 8). Thus, it can be concluded that higher doses would be more effective than lower doses for a shorter exposure duration.

Overall, the graph above shows that all concentrations cause significant mortality among adult *Tribolium confusum* compared to the controls, regardless of the extract or extract fraction used. Regarding the crude petroleum ether extract and the hexane fraction, concentration C1 causes a markedly higher adult mortality rate compared to the other concentrations. For the ether extract, this rate is 46.87%, while for the hexane fraction, it reaches 31.86%. Consistent statistical effects are observed for the other concentrations, C2 and C3. Mortality caused by the ether extract stands at 33.56% for C2 and 28.78% for C3, respectively. For the hexane fractions at concentrations C2 and C3, mortality rates of 23.71% and 15.6% are observed, respectively. Figure 8 illustrates the mortality rates of adult *Tribolium confusum* exposed to various biocidal products derived from *Khaya senegalensis* at different concentrations.

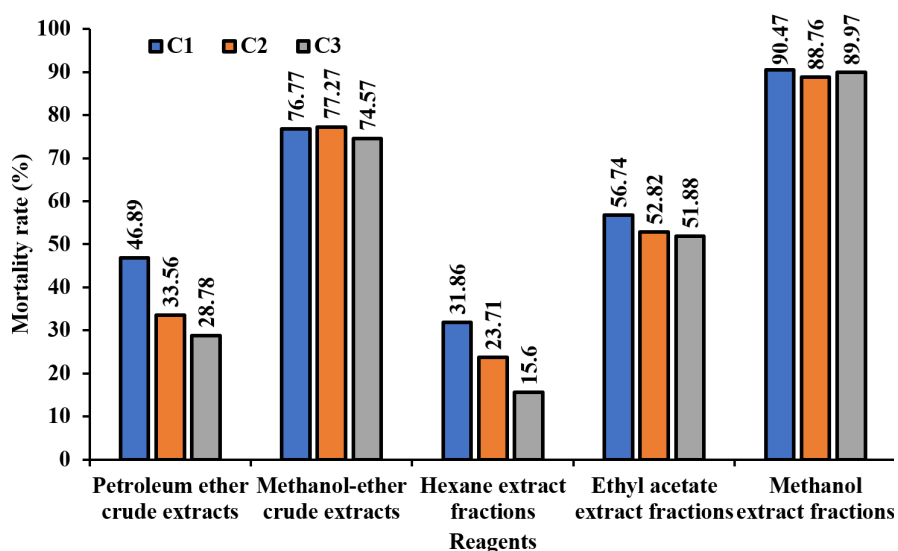


Figure 8. Mortality rates of *Tribolium confusum* adults exposed to various biocidal products derived from *Khaya senegalensis* at different concentrations.

Regarding the ethyl acetate and methanol fractions, there is no statistically significant difference ($p \geq 0.05$) between the adjusted mortality rates induced by the three doses (C1, C2, and C3). These three concentrations produced mean adult mortality rates of $78.47 \pm 3.77\%$ for the crude methanol extract, $58.47 \pm 2.43\%$ for the ethyl acetate fraction, and $92.37 \pm 4.35\%$ for the methanol fraction. Only 11.87% of untreated adults died from the tenth day of treatment onwards (Figure 8).

Based on the assessment of mortality in adult *Tribolium confusum* relative to exposure time (24 h, 48 h, 72 h, 96 h, 120 h, 6 days, etc.), *Khaya senegalensis* begins to induce mortality after the first 24 hours of treatment. The study covered a 10-day period, after which no further sampling of dead individuals was conducted. The results indicate that for exposure durations ranging from 0 to 6 days, the C1 dose of *Khaya senegalensis* exhibits greater adulticidal activity than the C2 and C3 doses. However, this trend appears to reverse when the exposure period extends from 6 to 10 days.

This observation is particularly evident with the methanol extract, the ethyl acetate fraction, and the methanol fraction. For instance, the C2 and C3 doses of the hexane fraction caused no mortality prior to the sixth day of treatment, whereas 29.8% of adult deaths attributed to C1 were recorded between 24 hours and the seventh day of treatment (Figure 9). It can therefore be inferred that higher doses are more effective than lower doses over shorter exposure periods. Figure 9 illustrates the mortality rate of adult *Tribolium confusum* over time following treatment with three concentrations of the *Khaya senegalensis* hexane fraction.

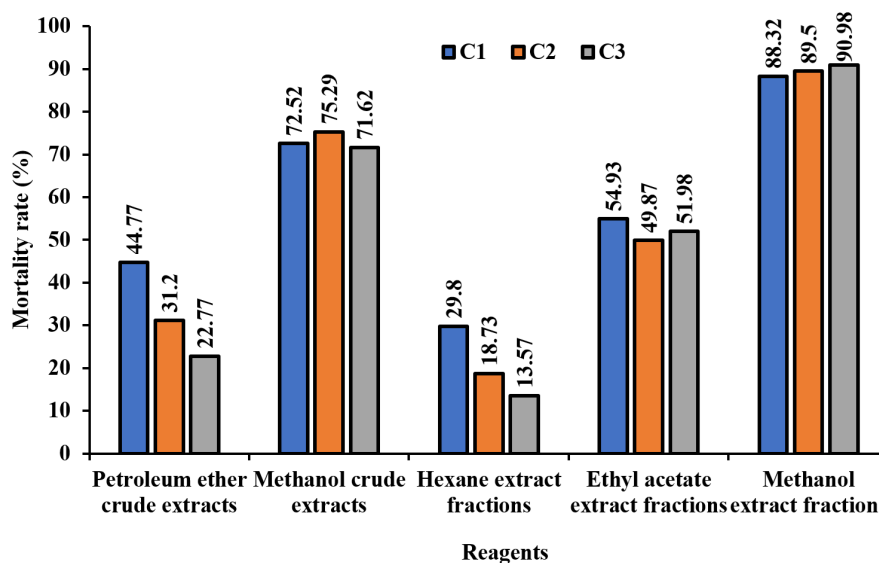


Figure 9. Mortality rate of adult *Tribolium confusum* over time following treatment with three concentrations of the *Khaya senegalensis* hexane fraction.

Figure 9 summarizes the results of the comparative study on adulticidal efficacy among various *Khaya senegalensis* test products at a specific concentration. A chart illustrates the adult mortality rates caused by various biocidal products

for each concentration. At a p -value ≥ 0.05 , the plots follow the same distribution. There is no significant difference between the letter designations.

In this chart, it is generally observed that polar products (methanol extract and methanolic fraction) induce significantly higher adult mortality rates compared to the others, regardless of the concentration used. This first homogeneous statistical set is followed at concentration C1 by a second homogeneous group comprising the petroleum ether and ethyl acetate fractions which cause mortality rates of 44.77% and 54.93%, respectively. The hexane fraction results in the lowest mortality among adult *Tribolium confusum*, regardless of the dosage applied (C1, C2, or C3). **Figure 10** shows the mortality rate of adult *Tribolium castaneum* treated with three concentrations of the *Khaya senegalensis* hexane fraction over time.

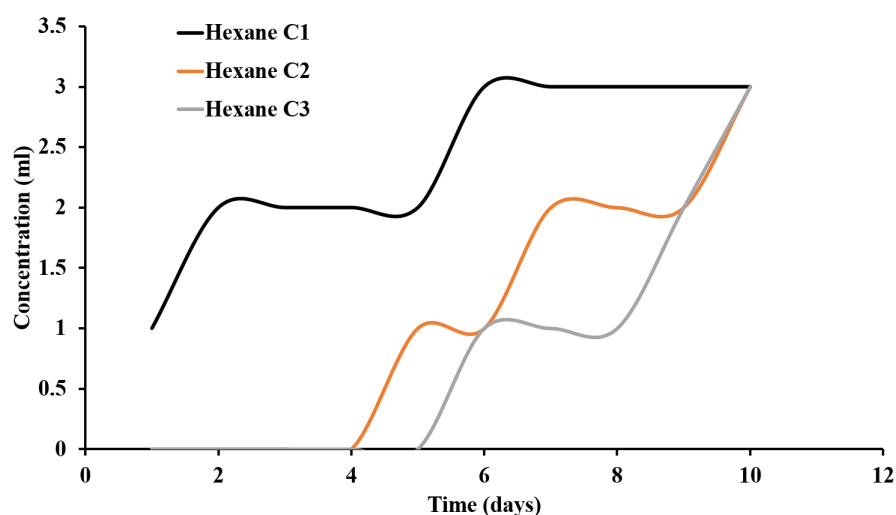


Figure 10. Mortality rates of *Tribolium castaneum* adults treated with three concentrations of the *Khaya senegalensis* hexane fraction, plotted against time.

A comparative study of the adulticidal effect of various *Khaya senegalensis* test products at identical concentrations yielded the results summarized in **Figure 11**, which shows the adult mortality levels caused by the different biocidal products at each concentration. Bars sharing the same letter do not differ significantly at $p \geq 0.05$.

The graph generally shows that adult mortality rates caused by polar products (methanol extract and methanol fraction) are significantly higher than those caused by the other products, regardless of the dose used. This first statistically homogeneous dataset is followed at concentration C1 by a second homogeneous group comprising the petroleum ether extract and the ethyl acetate fraction which induce adult mortality rates of 48.82% and 58.36%, respectively. Regardless of the dose used (C1, C2, or C3), the hexane fraction results in the lowest mortality rate for adult *Tribolium castaneum*. When considering the other concentrations (C2 and C3), which produce virtually identical effects for each tested product, we also identify three statistically distinct categories. Adult mortality rates caused by the methanol extract (at C2 and C3) and its methanol fraction (at C2 and C3) are the

highest, standing statistically above the others. The ethyl acetate fraction, which has intermediate polarity, follows next; this second group results in intermediate mortality levels.

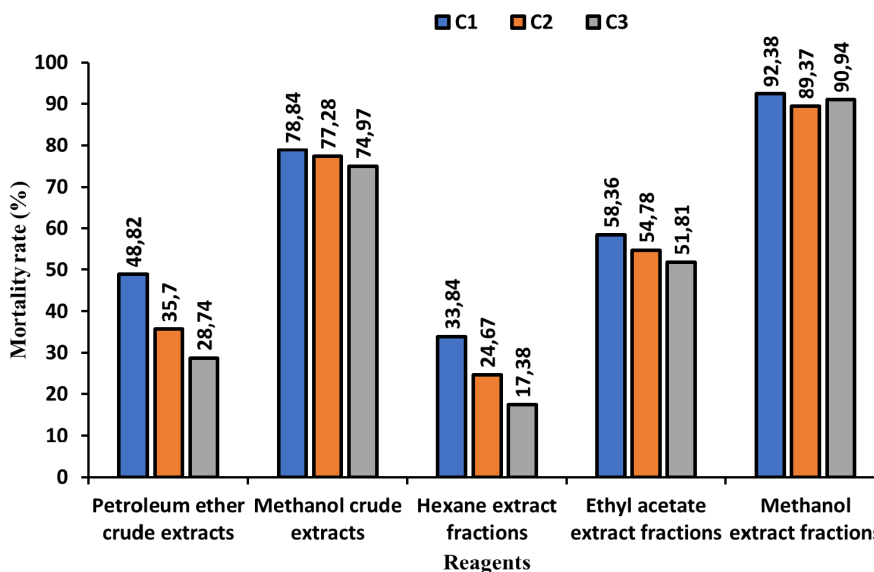


Figure 11. Comparison of adult mortality rates for various *Khaya senegalensis* derived biocidal products, according to concentration.

This second group causes intermediate mortality rates. The third and final homogeneous group therefore comprises the least polar biocidal products namely, the ethereal extract and the hexane fraction.

3.2. Insecticidal Activity of Crude Extracts and Extract Fractions of *Khaya senegalensis*

The extract fractions and crude extracts of *Khaya senegalensis* exhibit adulticidal activity against the biocidal products shown in **Figure 12**. The graph below summarizes the mortality rates caused by the extracts and extract fractions of *Khaya senegalensis* on adult *Tribolium confusum* insects. Graphs labeled with the same letter show no significant differences for the same extract at $p \geq 0.05$.

Compared to the results from the control group, all concentrations caused significant mortality in adult *Tribolium confusum* after a 10-day treatment period, regardless of the product tested. However, no significant difference ($p > 0.05$) was observed in adult mortality rates among the three concentrations. It is therefore noted that there is no correlation between the effect and concentration. Hexane fractionation and petroleum ether extraction resulted in mortality rates of 20.80 ± 1.35 and 31.30 ± 1.54 , respectively, among adults. The most environmentally friendly biocides result in the lowest mortality rates among adults. Polar biocides caused the highest mortality rates among adults, particularly the crude methanol extract and the methanol fraction, which resulted in 72.47 ± 2.95 and 85.94 ± 5.17 deaths, respectively, in this population. For all three doses, the average mortality rate for the ethyl acetate fraction, which has intermediate polarity, was 50.70 ± 2.78 .

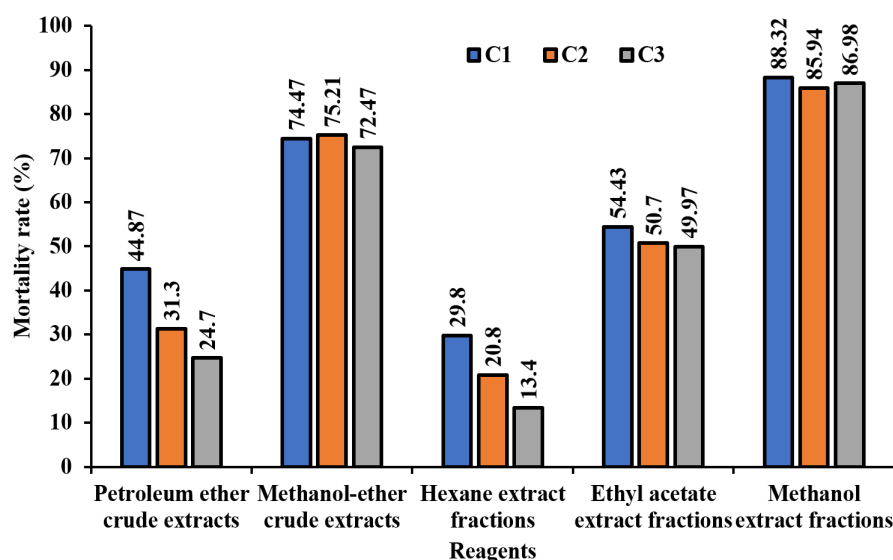


Figure 12. Mortality rates of adult *Tribolium confusum* exposed to various concentrations of *Khaya senegalensis* biocides.

Figure 13 below presents a comparative analysis of the adult mortality rate of *Tribolium castaneum* induced by various biocidal products. Concentrations marked with the same letter show no significant difference at $p \geq 0.05$.

Analysis of the adulticidal effect of crude extracts and fractions derived from the *Khaya senegalensis* crude methanol extract reveals the presence of two statistically distinct groups at each concentration. Regardless of the quantity used, mortality rates caused by the crude methanol extract, the ethyl acetate fraction, and the methanolic fraction are clearly higher than those induced by the other treatments. Statistically similar effects are observed for the petroleum ether crude extract and the hexane fraction.

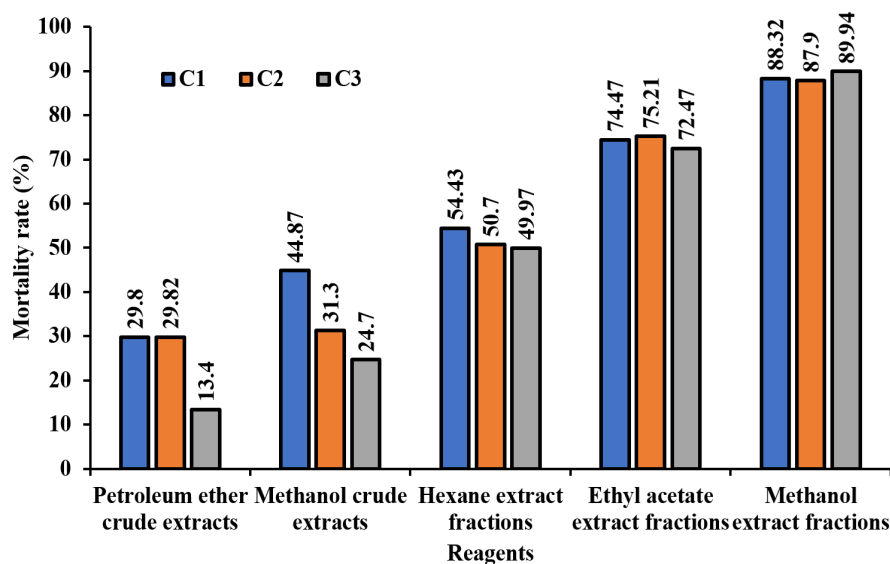


Figure 13. Comparative analysis of adult mortality (*Tribolium castaneum*) treated with various *Khaya senegalensis* based biocidal products, according to the concentration used.

This reinforces the previously proposed hypothesis regarding *Khaya senegalensis* and confirms that the adulticidal effect is determined by the polarity of the tested products.

3.3. Discussion

3.3.1. Experiments with Crude Extracts and Extract Fractions of *Khaya senegalensis* on *Tribolium castaneum*

Laboratory research focused on the adulticidal activity of two crude extracts (etheral and methanolic) and three extract fractions (hexane, ethyl acetate, and methanol) derived from *Khaya senegalensis* leaf powder. The petroleum ether extract and the hexane fraction from *Khaya senegalensis* induced the lowest adult mortality rates in *Tribolium castaneum*, varying according to concentration. For these two biocides, adulticidal efficacy increased in proportion to the applied dose [22] [23]. In contrast, the efficacy observed with the other tested products did not fluctuate based on the concentration used. Mean adult mortality rates for *Tribolium castaneum* observed at concentrations C1, C2, and C3 with the crude methanol extract, the ethyl acetate fraction, and the methanol fraction.

However, a closer examination of the results reveals specific patterns in mortality rates depending on the concentrations and plant materials used. These observations align with those of several researchers who have studied the effects of plant extracts, sulfur compounds, or terpenes on various bruchid species. According to Théophile *et al.* [24], ether, ethanol, and aqueous extracts derived from *Capsicum frutescens* demonstrated a negative impact on the viability of adult *Bemisia tabaci*. Mathole and colleagues [25] also reported similar findings.

Following the extraction and selection of three categories of putatively active compounds found in hot pepper fruits, it was demonstrated that alkaloids, saponins, and flavonoids derived from *C. frutescens* fruits affect the survival of adult *B. tabaci* an effect also observed in adult *Trialeurodes vaporariorum* by Hannour *et al.* [26]. Furthermore, it is possible that insects treated with these biocides succumbed to starvation caused by repellent or antifeedant effects, a phenomenon observed in other invertebrates by Bouchelta *et al.* [27].

The petroleum ether-based extract and the hexane fraction produced the lowest mortality rates in adult *Tribolium confusum*, with results varying according to concentration. The quantity of these two biocidal products used had an increasingly significant impact on their efficacy against adults. However, the results observed with the other tested products specifically the crude methanol extract, the ethyl acetate fraction, and the methanol fraction did not vary significantly based on the concentration used across groups C1, C2, and C3.

3.3.2. Lethal Impact of Crude Extracts and Extract Fractions from *Khaya senegalensis* on *Tribolium confusum* and *Tribolium castaneum*

The adulticidal efficacy of two types of crude extracts (ether- and methanol-based) and three extract fractions (hexane, ethyl acetate, and methanol) derived from the leaf powder of *Khaya senegalensis* was studied in the laboratory.

The petroleum ether extract and the hexane fraction resulted in the lowest mortality rates for adult *Tribolium confusum*, ranging from 44.87% to 24.70% (**Figure 13**) and from 29.80% to 13.4% (**Figure 12**), respectively, depending on the concentration. The quantity used for these two biocidal products had a progressively greater impact on their efficacy against adults. However, the results observed with the other tested products were not affected by the concentration employed. For group C1, the mean adult mortality rates for *Tribolium confusum* were $74.47 \pm 3.77\%$ (**Figure 13**) with the crude methanol extract, $54.43 \pm 2.43\%$ with the ethyl acetate fraction, and $88.32 \pm 4.35\%$ (**Figure 13**) with the methanol fraction.

Similar adulticidal behavior was observed with the biocidal products derived from *Khaya senegalensis*; nevertheless, a more detailed analysis of the results reveals specific differences in mortality rates depending on the concentrations and plant materials used. These results align with those of several researchers who have examined the impact of botanical extracts, sulfur compounds, or terpenes on various species; for instance, studies [28] [29] reported that a 350ppm concentration of *Pemphis acidula* methanol extract caused total egg mortality in *Cx. quinquefasciatus* and *Cx. tritaeniorhynchus*, by Mahanta *et al.* [30]. They stated that the efficacy of phytochemicals against mosquito larvae can vary widely depending on the plant species, the plant parts used, the age of those parts (young, mature, or senescent), the solvent used for extraction, and the vector species present. A positive correlation was also observed between the observed adulticidal effect and the polarity of the biocidal products evaluated, regardless of the plant species used. A decrease in the polarity of the tested product resulted in a reduction of the adulticidal effect. It was observed that the least polar biocidal products (ether and hexane extracts) caused the lowest adult mortality rates, with means of $29.80 \pm 1.35\%$ and $54.43 \pm 1.54\%$, respectively (**Figure 13**). The most polar products such as the crude methanol extract and the methanol and ethyl acetate fractions exhibited very high adult mortality rates against *Tribolium castaneum*, reaching $74.47 \pm 2.95\%$, $88.32 \pm 5.17\%$, and $44.87 \pm 2.78\%$ (**Figure 13**), respectively. Similar results have also been reported by Kuppusamy *et al.*, B. Sane *et al.*, and Kobenan *et al.* [31]-[33].

The disparity in insecticidal efficacy linked to the polarity of our various biocidal products can be attributed solely to quantitative and/or qualitative variations in the constituent compounds. As Agbo *et al.* [34] maintain, a polar solute dissolves more effectively in a polar solvent than in a non-polar solvent. We can thus infer that the lethal effect of the non-polar biocidal products derived from *Khaya senegalensis* is comparable to that of non-volatile vegetable oils, which have long been used in insect control in the form of emulsions.

4. Conclusion

Tests conducted using solvent extracts and fractions from *Khaya senegalensis* on the insects *Tribolium castaneum* and *Tribolium confusum* confirmed the potential insecticidal activity of this plant, which is commonly used in traditional med-

icine and food preservation. Analyses of extracts obtained using solvents of varying polarities revealed marked differences in efficacy, reflecting the chemical diversity and selectivity of the compounds present in each fraction. Observations indicated that certain fractions particularly those derived from medium-polarity solvents (such as ethyl acetate) exhibited significant toxicity and pronounced repellent effects on adult *Tribolium castaneum* and *Tribolium confusum*. This suggests the presence of bioactive secondary metabolites such as flavonoids, terpenoids, and saponins.

Author Contributions

Ramatoulaye Binta DIALLO: sampling, analysis, and processing of results; **Mamadou Laho BAH** participated in the laboratory work and data analysis. **Mamadou Yaya BALDE**: contributed to data analysis and manuscript drafting; **Salimatou DIALLO**: contributed to sample preparation. **Adma Moussa SAKHO** and **Ousmane BARRY** supervised the work and reviewed the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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