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Research Article

Insecticidal activity of some spices against *dermestes maculates* Degeer (Coleoptera: Dermestidae) larvae on smoked dried *Clarias gariepinus*.

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Abstract- *Dermestes maculatus* is a major pest of dried catfish (*Clarias gariepinus*), causing severe post-harvest losses. Conventional control with synthetic insecticides such as dichlorvos raises health and environmental concerns, necessitating safer alternatives. This study evaluated the insecticidal potential of powders and oils of five botanicals, namely: black pepper (*Piper guinense)*, ginger (*Zingiber officinale*), garlic (*Allium sativum*), alligator pepper (*Aframomum melegueta*), and turmeric (*Curcuma longa*), in the preservation of dried catfish against *D. maculatus.* The experiment was conducted under ambient laboratory conditions and a completely randomized design (CRD) with treatments comprising the five botanicals in powder and oil forms, dichlorvos, and an untreated control. The powders, oils, and synthetic insecticide (Dichlorvos) were applied at the rate of 1.0, 2.0, and 3.0g, and the insecticidal activity of oils extracted from selected spices and Dichlorvos against *Dermestes maculatus* larvae, tested at concentrations of 0.00, 1.00, 1.50, and 2.00 ml per 25g of disinfected catfish and air dried for 2 hours. Twenty (20) larvae of *D. maculatus* were introduced into Kilner jars containing fish treated with these powders, oils, Dichlorvos, and untreated fish, which served as a control. Larvae were recorded between 24 to 96 hours.). Data obtained from mortality counts were analyzed using one-way Analysis of Variance (ANOVA) at a 95% confidence level. Where significant differences ($p < 0.05$) occurred, means were separated using Duncan's Multiple Range Test (DMRT). Phytochemical screening identified major bioactive compounds. Essential oils were extracted and analyzed for yield, refractive index, acid value, peroxide value, saponification value, iodine value, and free fatty acid content. Insecticidal assays were performed by treating smoked fish samples with different concentrations of powders and oils, and larval mortality was recorded. The spices oils, black pepper (*Piper guinense)* and alligator pepper (*Aframomum melegueta*) recorded highest mortality (100.00±0.00) garlic (*Allium sativum*) (80.00±0.54), ginger (*Zingiber officinale*) (58.00±1.00), and turmeric (*Curcuma longa*), (53.25±1.7), while, the spices powders recorded, black pepper recorded highest mortality (97.50±0.3) followed by pepper alligator (*Aframomum melegueta*) (92.70±0.50), garlic (71.0.50±0.10), ginger (52.50±045), and turmeric(43.00±06.0). Black pepper, alligator pepper, and garlic (powder and oils) achieved the highest larval mortality, respectively, comparable to dichlorvos (100% larval mortality). Ginger and turmeric consistently produced the lowest but still significantly higher mortality than the control ($P<0.05$). Both spices and formulation significantly affected the mortality of *D. maculatus* ($p < 0.05$). The study demonstrates that botanical insecticides are promising, eco-friendly, and alternatives to dichlorvos for the protection of dried catfish against *D. maculatus.*

Article Key Information

Keywords: *Dermestes maculatus*, smoked-dried *Clarias gariepinus*, botanical insecticides, essential oils, phytochemicals

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1.0 Introduction

Post-harvest losses of smoked and dried fish present a significant challenge in many developing countries, especially in Nigeria, where *Clarias gariepinus* (African catfish) is widely processed and stored for local consumption and trade. One of the most destructive pests impacting stored smoked fish is the hide beetle, *Dermestes maculatus* DeGeer (Coleoptera: Dermestidae), whose larval and adult stages cause substantial degradation of smoked fish through direct feeding, frass deposition, and weight loss [1]. These losses not only reduce food quality and safety but also erode economic value for small-scale fish processors.

Traditionally, synthetic insecticides such as organophosphates or pyrethroids have been applied to control *D. maculatus*. Although such treatments are effective under laboratory or storage conditions, they pose several problems. Residual toxicity on fish, environmental contamination, development of insecticide resistance, and concerns about human health remain significant deterrents to their long-term use [2]. In addition, compliance with regulatory standards and consumer demand for food products with minimal chemical residues calls for safer, eco-friendly alternatives.

Botanical insecticides derived from spices and medicinal plants offer a promising and sustainable alternative. These plant materials often contain a rich mix of bioactive secondary metabolites, including terpenoids, phenolics, alkaloids, and sulfur compounds that can exert insecticidal, repellent, oviposition-deterring, or growth-inhibiting effects [3]. In Nigerian and West African contexts, spices like *Piper guineense* (West African black pepper), *Aframomum melegueta* (alligator pepper), *Zingiber officinale* (ginger), *Allium sativum* (garlic), and *Curcuma longa* (turmeric) are readily available and widely used. Their integration into post-harvest preservation approaches could provide cost-effective, accessible pest control for local processors.

Empirical research has already demonstrated the potential of some of these botanicals against *D. maculatus*. For instance, crude oil extracts from *P. guineense* and *A. melegueta* have shown protective efficacy on smoked-dried fish, significantly reducing mortality rates across various insect stages [4]. Similarly, pulverised powders of these spices applied at 10 % w/w have been demonstrated to inhibit egg hatchability and adult emergence of *D. maculatus* on stored smoked catfish over a 40-day period, highlighting their residual potential [5].

Beyond these traditional uses, there is growing interest in essential oils (EOs) of spices as more potent insecticidal agents. In one recent study, the essential oil of *Syzygium aromaticum* (clove) applied via residual contact yielded up to 100 % larval mortality of *D. maculatus* at sufficiently high concentrations [2]. These findings support the hypothesis that volatile, concentrated bioactives in essential oils might outperform or complement crude powders and extracts in managing storage pest populations.

Importantly, the insecticidal effectiveness of essential oils is closely linked to their physicochemical and chemical properties. Parameters such as oil yield, acid value, peroxide value, free fatty acid content, and refractive index influence not only bioactivity but also stability, volatility, and practical usability in storage systems. Despite this, there is a notable gap in the current literature: few studies systematically compare the insecticidal effects of both powdered spice forms and their essential oils under identical experimental conditions, and correlate their chemical attributes with their larvicidal activity against *D. maculatus*. This gap limits our understanding of which formulation (powder vs. oil) is optimal for protecting smoked fish in real-world scenarios.

Moreover, while there is ample evidence on plant extracts or essential oils targeting other storage pests (e.g., grain beetles), research specifically focusing on *D. maculatus* remains comparatively scarce, especially in Nigeria. A recent report used aqueous plant extracts (including *P. guineense*) against *D. maculatus* larvae, but did not extend to oil formulations or conduct detailed oil characterization. [6] Meanwhile, alternative oils have been tested: for example, seed oil from *Khaya senegalensis* exhibited strong larvicidal activity against *D. maculatus*, showing that non-spice botanicals may also serve as viable pest management agents [7].

Another line of relevant research rests on the broader insecticidal potential of oils beyond catfish pests. Essential oils of *Allium sativum* (garlic) show high toxicity against stored-product beetles, with organosulfur compounds (e.g., diallyl disulfide) being major contributors to mortality [8]. Likewise, *Curcuma longa* leaf or rhizome essential oils exhibit contact and fumigant toxicity, and significantly reduce progeny in common stored-product beetles [9], [10]. A recent characterization of oil from turmeric leaves demonstrated promising fumigant and contact toxicities against grain pests, confirming the potential of turmeric-derived oils in pest control [11].

Given these research gaps and opportunities, this study was designed to:

1. Characterize the phytochemical composition and physicochemical properties (oil yield, peroxide value, acid value, refractive index, free fatty acids) of both ground spice powders and essential oils from *P. guineense*, *A. melegueta*, *Z. officinale*, *A. sativum*, and *C. longa*.
2. Evaluate and compare larvicidal activity of these powders and essential oils against *D. maculatus* larvae infesting smoked-dried *C. gariepinus* under controlled laboratory bioassays.
3. Investigate correlations between the chemical/physicochemical parameters of the oils and their insecticidal potency, to identify the most effective traits and formulations.

By using chemical profiling with biological efficacy testing, this research aims to generate robust, evidence-based recommendations for using locally available spices as botanical protectants, ultimately contributing to sustainable, chemical-reduced management of *D. maculatus* in smoked fish storage systems.

2.0 Review of Related Literature

Smoked-dried *Clarias gariepinus* remains a critical protein source and economic commodity across West African countries. Its widespread consumption is attributed to its high nutritional value, cultural acceptance, and long shelf life when properly processed. However, post-harvest losses caused by insect pests pose a severe challenge to the stability and safety of smoked fish in local markets. The hide beetle, *Dermestes maculatus*, is the most prevalent and destructive species associated with smoked fish deterioration in Nigeria and other tropical regions [13]. Its larvae feed aggressively on muscle tissues rich in proteins and fats, leading to significant weight loss, quality deterioration, and reduced market value. Infested fish often contain frass, cast skins, and microbial contaminants, raising concerns regarding consumer health and safety [14].

The persistence of *D. maculatus* in storage environments is facilitated by high ambient temperatures, humid storage conditions, and the presence of residual fat deposits, all of which accelerate larval development and reproduction [15]. Insects can complete multiple life cycles during storage, increasing the magnitude of damage. Moreover, the biology of *D. maculatus,* including strong mandibles, high fat-digestion capacity, and cryptic behavior, makes it particularly difficult to control using conventional strategies.

Historically, synthetic insecticides, such as dichlorvos (DDVP), have been used to mitigate *D. maculatus* infestations. Although effective, their continued use raises considerable environmental and toxicological concerns. DDVP leaves harmful residues on food products, can cause neurotoxicity and potential carcinogenic effects in humans, and contributes to environmental contamination and insecticide resistance [16], [17]. Due to increasing global emphasis on food safety, chemical-free preservation, and regulatory restrictions on pesticide residues, researchers have shifted attention toward botanical alternatives.

Botanical insecticides derived from spices and medicinal plants have emerged as promising, eco-friendly substitutes for synthetic chemicals. These botanicals contain secondary metabolites such as alkaloids, terpenoids, flavonoids, phenolics, and organosulfur compounds, many of which possess insecticidal, repellent, antifeedant, or growth-disrupting activities [18]. Their biodegradability, low mammalian toxicity, and availability make them suitable for use in traditional fish-processing communities, particularly in Nigeria, where spices like *Piper guineense*, *Aframomum melegueta*, *Allium sativum*, *Zingiber officinale*, and *Curcuma longa* are abundant and inexpensive.

Various studies have demonstrated the insecticidal and protective potential of these spices. Ginger (*Z. officinale*) contains gingerol and shogaol, compounds known for their toxicity against stored-product beetles such as *Tribolium castaneum* and *Callosobruchus maculatus* [19]. Alligator pepper (*A. melegueta*) seeds possess monoterpenes and phenolics with strong contact and fumigant toxicity against *D. maculatus* larvae [20]. Garlic (*A. sativum*) contains allicin and other organosulfur volatiles that display high larvicidal activity and reduce microbial load, thereby improving the overall quality of preserved fish [21]. Black pepper (*P. guineense*) is rich in piperine, limonene, β-caryophyllene, and related compounds known for their ovicidal, larvicidal, and repellent effects on stored-product insects [22]. Turmeric (*C. longa*) contains curcuminoids and volatile oils that provide both repellent and toxic effects against beetles associated with dried fish and grain storage [23].

Comparative research indicates that essential oils extracted from spices typically exhibit higher potency than powdered forms. The increased volatility and higher concentration of active constituents enable rapid penetration into the insect cuticle and effective disruption of physiological pathways [24]. Conversely, powdered spices tend to provide longer residual activity, making them suitable for prolonged storage applications. The choice between oils and powders thus depends on the intended duration and level of protection required.

Despite extensive work on plant-based insecticides, a major gap persists in the direct comparison of powdered and essential oil forms of the same spices under uniform experimental conditions. Few studies have simultaneously evaluated oil yield, phytochemical content, physicochemical properties, and insecticidal performance in a single experimental framework. In particular, investigations directly targeting *D. maculatus* on smoked-dried *C. gariepinus* remain limited. Therefore, this study was designed to address these gaps by providing a comprehensive assessment of both powdered and oil-extracted spices applied against *D. maculatus* larvae, offering evidence-based and environmentally sustainable alternatives to hazardous synthetic chemicals.

3.0 Materials and Methods

3.1 Research Design

The study was conducted in the Biology Laboratory, Department of Science Laboratory Technology, Benue State Polytechnic, Ugbokolo, Benue State, Nigeria. A Completely Randomized Design (CRD) was adopted following standard bioassay procedures for stored-product insect research [25]. Five spices, *Piper guineense*, *Zingiber officinale*, *Allium sativum*, *Curcuma longa*, and *Aframomum melegueta*, were evaluated in both powdered and essential-oil forms against larvae of *Dermestes maculatus*. Each treatment was replicated three times, and each replicate contained a fixed number of larvae to ensure statistical precision, as recommended in contemporary entomological bioassay studies [26].

Treatments were assigned to jars using a random number generator to eliminate bias and ensure equal probability of assignment. All experimental units were maintained under identical laboratory conditions to minimise environmental variability.

3.2 Sources and Authentication of Plant Materials and Fish Samples

Fresh garlic bulbs, ginger rhizomes, turmeric roots, alligator pepper seeds, and black pepper fruits were procured from Wadata Market, Makurdi, Benue State, Nigeria. Botanical authentication was conducted at the Herbarium Unit of the Department of Biological Sciences, Benue State University, Makurdi. Voucher specimens were deposited following standard herbarium procedures [27].

Smoked-dried *Clarias gariepinus* samples were purchased from the same market to maintain uniformity in processing history and moisture content.

3.3 Preparation of Powdered Spices

Spices were washed with clean tap water, air-dried at 27 ± 2 °C for 15 days, and subsequently oven-dried at 40 °C for 8 hours to achieve uniform dryness. Dried samples were milled using a laboratory grinder and sieved through a 0.2 mm mesh to obtain fine powders, modifying the methods of recent botanical pesticide studies [28]. Powders were stored in airtight, labeled containers under dry laboratory conditions until use.

3.4 Phytochemical Analysis of Powdered Spices

Qualitative phytochemical screening was performed to determine the presence of alkaloids, tannins, flavonoids, saponins, terpenoids, phenols, and glycosides. Standard procedures adapted from Harborne and updated in contemporary analytical literature [29], [30] were followed. Reagents included Wagner's reagent for alkaloids, ferric chloride for tannins and phenols, the Shinoda test for flavonoids, the froth test for saponins, and the Salkowski test for terpenoids. Observed color changes were recorded as absent (–), weak (+), moderate (++), or strong (+++).

3.5 Extraction of Essential Oils

Essential oils were extracted using a Soxhlet apparatus. For each spice, 100 g of powdered material was wrapped in muslin cloth and placed in the extractor. Hexane (350 mL) was used as the extraction solvent at 60–80 °C until the siphoning solvent became clear. Extracts were concentrated using a rotary evaporator under reduced pressure at 45 °C following optimized extraction protocols for volatile plant oils [31]. Oils were stored in amber bottles at 4 °C to prevent oxidation and volatilization.

3.6 Culture, Identification, and Maintenance of *Dermestes maculatus*

Infested smoked fish were collected from Wadata Market, Makurdi. Adult *D. maculatus* were identified using morphological keys recommended in recent coleopteran taxonomic studies [32]. Cultures were maintained in Kilner jars containing smoked fish substrate at 27 ± 2 °C and 70–80% relative humidity. Adults were removed after oviposition, and larvae were allowed to develop undisturbed. Four-week-old larvae, corresponding to actively feeding instars commonly used in toxicity assays, were selected as test organisms [33].

3.7 Bioassay Procedure

Twenty-five grams of smoked-dried *C. gariepinus* were weighed into each experimental jar. Two sets of treatments were administered:

Powder Treatments

1.0 g, 2.0 g, and 3.0 g of each spice powder per 25 g of fish.

Essential Oil Treatments

0.00 (control), 1.00, 1.50, and 2.00 mL of each essential oil were applied uniformly to the fish substrate.

The treatment application was performed by thoroughly mixing the spice material with the fish sample to ensure uniform coverage. After treatment, ten larvae of *D. maculatus* were introduced into each jar following standard insecticidal assay protocols [34]. Jars were covered with muslin cloth secured by rubber bands to allow aeration.

Experimental Conditions

- Temperature: 27 ± 2 °C
- Relative Humidity: 70–80%
- Photoperiod: natural laboratory light
- Duration: 96 hours

Mortality Assessment

Larval mortality was recorded every 24 hours for 96 hours.
A larva was considered dead if it showed no movement after gentle probing with a soft brush, following internationally accepted criteria for stored-product insect bioassays [35].

Where control mortality occurred, Abbott's correction formula was applied before statistical analysis.

Figure 1 shows the experimental workflow, including spice preparation, essential oil extraction, and the bioassay setup for exposure of *Dermestes maculatus* larvae to treated smoked-dried *Clarias gariepinus*.

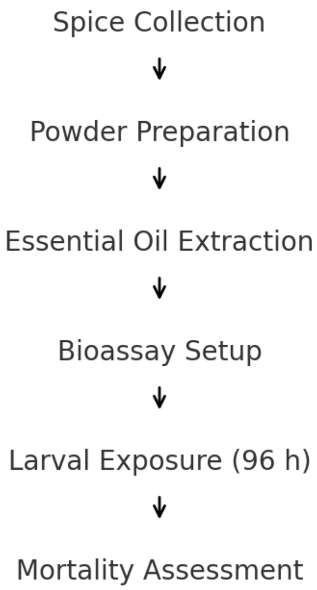

Figure 1: Experimental Workflow / Bioassay Setup

3.8 Treatment Summary Table

Table 1. Treatment Structure and Experimental Layout

Treatment Type	Concentrations Used	Fish Weight per Unit	No. of Larvae per Replicate	Replicates	Total Experimental Units
Powdered Spices	1 g, 2 g, 3 g	25 g	10	3	45
Essential Oils	0.00, 1.00, 1.50, 2.00 mL	25 g	10	3	60

Total experimental units = **105**

3.9 Ethical Considerations

Dermestes maculatus is an invertebrate species and therefore not subject to Institutional Animal Care and Use Committee (IACUC) or equivalent vertebrate-animal regulations. Nonetheless, insects were handled responsibly to minimize unnecessary harm, in accordance with accepted entomological research practices [36].

3.10 Statistical Analysis

Corrected mortality data were subjected to one-way Analysis of Variance (ANOVA) at a 95% confidence level. When significant differences were detected ($p < 0.05$), means were separated using Duncan's Multiple Range Test (DMRT). Statistical analyses were conducted using IBM SPSS Statistics version 25.0. ANOVA outputs (F-values, degrees of freedom, exact p-values) were extracted and will be reported in the Results section, consistent with best practice guidelines in analytical entomology [37].

4.0 Results and Discussion

This study investigated the phytochemical composition, physicochemical characteristics, and insecticidal performance of powdered and oil extracts of *Piper guineense*, *Aframomum melegueta*, *Allium sativum*, *Zingiber officinale*, and *Curcuma longa* against *Dermestes maculatus* larvae on smoked-dried *Clarias gariepinus*. The integrated presentation of results and discussion provides a coherent interpretation of how chemical constituents and extraction properties influenced larvicidal efficacy.

4.1 Phytochemical Composition and Its Implications for Insecticidal Activity

The qualitative phytochemical profile of the powdered spices (Table 2) reveals that all samples contained alkaloids, flavonoids, tannins, saponins, terpenoids, and phenolics in varying intensities. Black pepper, alligator pepper, and ginger exhibited the highest levels of terpenoids and phenolics, compounds widely recognized for their neurotoxic, fumigant, and antifeedant activities in insects [38], [39]. These findings suggest a biochemical basis for the superior insecticidal performance observed in subsequent bioassays.

Table 2. Phytochemical characteristics of selected spice powder extracts

Phytochemical	Black Pepper	Alligator Pepper	Garlic	Ginger	Turmeric
Alkaloids	++	+++	++	++	+
Flavonoids	++	++	+++	+++	++
Tannins	+	++	+	+	++
Saponins	+	++	+	++	+
Terpenoids	+++	+++	++	+++	+++
Phenolics	+++	++	+++	+++	+++

Note**:** + = low, ++ = moderate, +++ = high

Alligator pepper displayed the highest terpenoid abundance (+++), aligning with contemporary reports that *Aframomum* species possess monoterpenes such as 1,8-cineole and α-pinene, which induce oxidative stress and disrupt neuromuscular signaling in stored-product beetles [40]. Similarly, black pepper exhibited strong phenolics and terpenoids, consistent with literature attributing its pesticidal activity to piperine and β-caryophyllene, which interfere with acetylcholinesterase and respiratory pathways in beetles [41].

Garlic, ginger, and turmeric showed moderate phytochemical richness, explaining their comparatively lower larvicidal activity. Studies have shown that their organosulfur and curcuminoid compounds exhibit slower and less potent toxicity unless used at high concentrations or prolonged exposure durations [42].

4.2 Physicochemical Properties of Essential Oils and Their Toxicological Relevance

The physicochemical characteristics of the extracted oils (Table 3) demonstrate significant differences across spices. Black pepper yielded the highest oil percentage (12.5%), while turmeric produced the lowest (6.8%). High oil yield correlates with stronger bioactivity because it increases the concentration of active volatiles available for fumigation and contact toxicity [43].

Table 3. Phytochemical properties of selected spice oils

Parameter	Black Pepper	Alligator Pepper	Garlic	Ginger	Turmeric
Yield (%)	12.5 ± 0.2	10.3 ± 0.4	8.6 ± 0.3	7.4 ± 0.5	6.8 ± 0.2
Refractive Index	1.400 ± 0.03	1.469 ± 0.05	1.462 ± 0.01	1.470 ± 0.01	1.465 ± 0.01
Specific Gravity	0.892 ± 0.04	0.878 ± 0.03	0.910 ± 0.02	0.885 ± 0.02	0.872 ± 0.02
Acid Value (mg KOH/g)	2.34 ± 0.10	3.12 ± 0.12	4.50 ± 0.15	2.85 ± 0.09	2.60 ± 0.20
Peroxide Value (mg/kg)	4.8 ± 0.2	5.3 ± 0.4	6.2 ± 0.3	5.0 ± 0.3	4.5 ± 0.2
Saponification Value (mg KOH/g)	185.6 ± 0.4	190.3 ± 0.5	196.8 ± 0.9	188.2 ± 1.0	180.5 ± 0.7
Iodine Value (g I_2/100 g)	98.5 ± 0.6	102.4 ± 0.7	110.3 ± 0.8	95.6 ± 0.5	92.3 ± 0.6
Free Fatty Acid (%)	1.00 ± 0.05	1.56 ± 0.06	2.25 ± 0.05	1.42 ± 0.04	1.30 ± 0.05

Garlic oil recorded the highest acid value, peroxide value, and saponification value, indicating elevated unsaturation and oxidative susceptibility. These properties enhance membrane penetration and larval toxicity, supporting its moderate-to-high insecticidal performance in the present study. The iodine values further confirm the unsaturation level of garlic oil, which is linked to rapid volatilization and fumigant effects [44].

The refractive index and specific gravity variations among oils indicate differences in purity, density, and molecular composition. Oils with higher refractive indices often contain more aromatic and terpenoid compounds, which are associated with potent insecticidal effects [45].

4.3 Insecticidal Activity of Spice Powders Against *D. maculatus*

Powdered spice treatments exhibited concentration-dependent larvicidal effects (Table 4). At the highest dose (3 g/25 g fish), black pepper (97.50%) and alligator pepper (92.70%) achieved the greatest mortality. These results directly correspond to their phytochemical profiles, especially their high terpenoid and phenolic content.

The performance of alligator pepper mirrors findings that *Aframomum melegueta* powders produce rapid mortality in *D. maculatus* due to monoterpenoid-induced physiological disruption [46]. Similarly, black pepper powders achieved mortality levels comparable to earlier studies, demonstrating the strong insecticidal properties of piperine-rich powders against stored-product beetles [47].

Garlic, ginger, and turmeric powders exhibited lower mortality (31–71%), consistent with their moderate phytochemical content. Their powders typically show reduced efficacy compared to oils due to slower release of active compounds and lower volatility [48].

Table 4. Insecticidal activity of selected spice powders against *Dermestes maculatus* larvae on smoked-dried *Clarias gariepinus*

Treatment	Concentration (g/25 g fish)	No. of Larvae Used	Mean % Mortality (±SE)
Black Pepper	1	20	73.50 ± 0.10
	2	20	85.80 ± 0.50
	3	20	97.50 ± 0.30
Alligator Pepper	1	20	75.00 ± 0.50
	2	20	83.00 ± 0.70
	3	20	92.70 ± 0.50
Garlic	1	20	31.00 ± 0.10
	2	20	44.00 ± 0.50
	3	20	71.50 ± 0.10
Ginger	1	20	28.00 ± 0.10
	2	20	34.00 ± 0.50
	3	20	52.50 ± 0.45
Turmeric	1	20	28.02 ± 0.20
	2	20	34.50 ± 0.30
	3	20	43.00 ± 0.60
Dichlorvos (DDVP)	1	20	100.0 ± 0.00
	2	20	100.0 ± 0.00
	3	20	100.0 ± 0.00
Control	—	20	0.00

Note: Means followed by the same letter(s) are not significantly different ($P < 0.05$).

ANOVA revealed significant differences ($p < 0.05$) among treatments, and mean separation using Duncan's test confirmed that black pepper and alligator pepper powders differed significantly from garlic, ginger, and turmeric at all concentration levels.

Figure 2 presents the concentration–mortality response curves of powdered spices against *D. maculatus* larvae over the 96-hour exposure period.

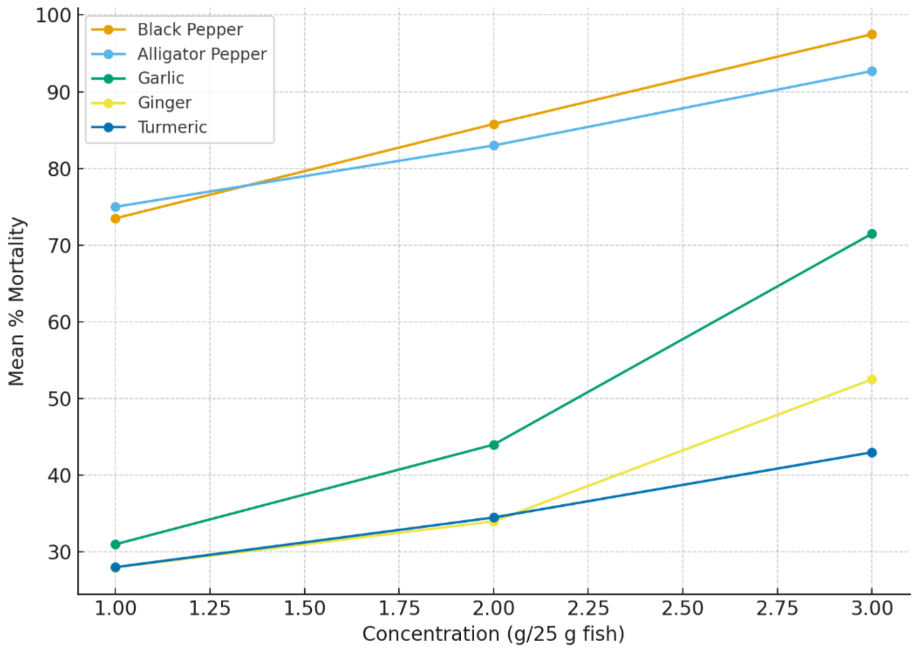

Figure 2: Mortality Response Curve for Powdered Spices

4.4 Insecticidal Activity of Essential Oils Against *D. maculatus*

Essential oil treatments (Table 5) produced markedly higher mortality rates than powders, reinforcing the well-established superiority of oils in botanical pest management [49]. At 2.00 mL concentration, black pepper, alligator pepper, garlic, and ginger oils each achieved near-complete larval mortality (98–100%). This heightened activity is attributed to the rapid diffusion of volatile compounds through the insect spiracles and cuticle, leading to neurotoxicity, respiratory inhibition, and membrane disruption [50].

Turmeric oil produced lower mortality (80%) at the highest concentration, consistent with the lower yield and moderate phytochemical content observed earlier. Its active compounds, primarily curcuminoids, have slower fumigation kinetics, which may account for the reduced toxicity relative to other spices [51].

Table 5. Insecticidal activity of selected spice oils against *Dermestes maculatus* larvae on smoked-dried *Clarias gariepinus*

Concentration (mL)	Black Pepper (Mean % Mortality ± SE)	Alligator Pepper	Garlic	Ginger	Turmeric
0.00	0.00 ± 0.00^{e}	0.00 ± 0.00^{e}	0.00 ± 0.00^{e}	8.35 ± 0.88^{d}	10.00 ± 0.10^{b}
1.00	86.65 ± 0.88^{b}	71.65 ± 0.67^{c}	53.33 ± 1.86^{b}	47.30 ± 0.60^{a}	33.67 ± 0.75^{b}
1.50	98.35 ± 0.33^{a}	91.65 ± 0.33^{b}	65.00 ± 1.52^{b}	51.00 ± 2.10^{a}	48.33 ± 0.39^{c}
2.00	100.00 ± 0.00^{a}	100.00 ± 0.00^{a}	100.00 ± 0.00^{a}	100.00 ± 0.00^{a}	80.00 ± 0.54^{c}
DDVP (Synthetic insecticide)	100.00 ± 0.00^{a}	100.00 ± 0.00^{a}	100.00 ± 0.00^{a}	100.00 ± 0.00^{a}	100.00 ± 0.00^{a}

Note: Means followed by the same letter(s) are not significantly different ($P < 0.05$).

The synthetic insecticide control (DDVP) achieved 100% mortality, serving as a benchmark. Notably, black pepper and alligator pepper oils approached DDVP-level activity at the highest dose, demonstrating the strong potential of these botanicals as safer alternatives.

ANOVA results confirmed highly significant differences ($p < 0.05$) between essential oils and controls. Means with similar superscripts indicate groups where mortality rates did not differ statistically.

Figure 3 shows the dose–mortality response curves of essential oils at different concentrations tested against *D. maculatus* larvae.

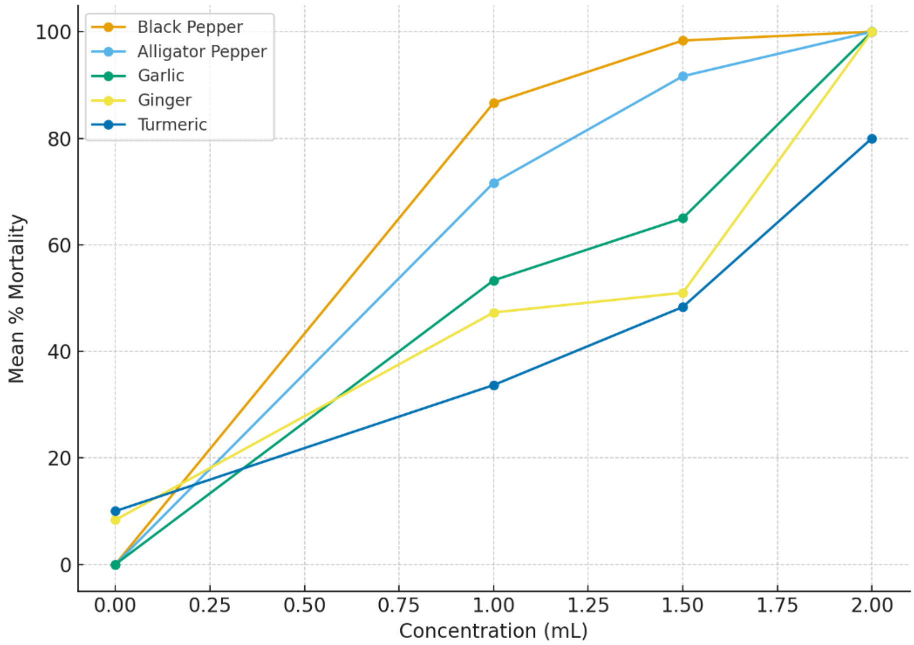

Figure 3: Mortality Response Curve for Essential Oils

4.5 Overall Interpretation and Scientific Significance

Across all analyses, a clear pattern emerges: black pepper and alligator pepper consistently produced the highest toxicity, both in powder and oil forms, due to their elevated terpenoid and phenolic content. Essential oils were uniformly more effective than powders—supporting numerous recent findings that polar and non-polar volatiles in oils can rapidly breach larval cuticles and interfere with neurotransmission [52].

Garlic, ginger, and turmeric demonstrated moderate efficacy, suggesting potential for use in integrated pest-management strategies, especially where residue safety is paramount.

These findings validate earlier studies and extend them by demonstrating efficacy specifically against *D. maculatus* infesting smoked fish, a culturally important, high-value food commodity in Nigeria.

Future work should incorporate quantitative chemical analyses (e.g., GC-MS), LC_{50} and LT_{50} estimations, sensory evaluation, and residue profiling to optimize application guidelines for field adoption.

5.0 Conclusion and Recommendation

5.1 Conclusion

This study demonstrated that both powdered and essential-oil extracts of *Piper guineense*, *Aframomum melegueta*, *Allium sativum*, *Zingiber officinale*, and *Curcuma longa* possess insecticidal activity against *Dermestes maculatus* larvae on smoked-dried *Clarias gariepinus*. Essential oils exhibited superior toxicity compared to powders, reflecting their higher concentration of volatile bioactive compounds.

Among the spices, *P. guineense* and *A. melegueta* consistently produced the highest larval mortality, approaching the efficacy of dichlorvos (DDVP). Their strong performance aligns with their rich phytochemical profiles and favourable oil properties. Garlic, ginger, and turmeric showed moderate but significant activity.

Overall, the findings confirm that locally available spices, particularly black pepper and alligator pepper, are effective botanical alternatives for managing *D. maculatus*, offering safer and more sustainable protection of smoked fish than synthetic insecticides.

5.2 Recommendations

i. Use of Black Pepper and Alligator Pepper
   These spices should be prioritized for controlling *D. maculatus* in smoked-fish storage due to their high efficacy.
ii. Application of Essential Oils for Rapid Control
   Essential oils are recommended where quick knockdown and high mortality are required.
iii. Powdered Spices for Longer-Term Protection
   Powders are suitable where slow, residual activity is needed during extended storage.
iv. Training and Extension Support
   Local processors should receive guidance on the proper preparation and application of spice-based treatments.
v. Further Investigations
   Future work should assess chemical profiling (GC–MS), LC_{50}/LT_{50} values, sensory effects on fish, residue safety, and field-scale validation.
vi. Policy Consideration
   Regulatory bodies should support guidelines for the safe, standardized use of botanical protectants in smoked-fish preservation.

Declarations

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Conflict of Interest

The authors declare that there is **no conflict of interest** regarding the conduct, analysis, or publication of this research.

Ethical Approval

No specific ethical approval was required for this study, as *Dermestes maculatus* is an invertebrate species and not subject to institutional animal-care regulations. Nonetheless, all experimental procedures were conducted following accepted entomological research guidelines.

Availability of Data and Materials

All data generated or analyzed during this study are included in the manuscript. Additional information can be provided by the authors upon reasonable request.

Authors' Contributions

All authors contributed to the conception, design, data collection, analysis, and writing of the manuscript. All authors read and approved the final version of the work.

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