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Bio-insecticidal Potential of Lemongrass (*Cymbopogon citratus*) Essential Oils on Smoke-dry Fish Against Weevils within Storage

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ABSTRACT

This study aims to test the insecticidal effect of two Lemongrass Essential oils (EOs) on two weevils attacking smoke-dry fish within the storage. Fasting capacity, larvicidal and adulticidal properties of EOs on weevils, and the sensorial analysis of fish within storage will be assessed. smoke-dry *Clarias gariepinus* were purchased from the smoker and carried to the laboratory for the study. weevils and EOs were from the Soil Microbiology Laboratory of the University of Yaoundé I. Two species of weevil, and two EOs at three concentrations were used. Fasting capacity was evaluated by exposure of larvae to Eos. Larvicidal and insecticidal capacity was evaluated by exposure of larvae and insect to Eos against control treatment. Emerged insects were count for each treatment after the test. Sensorial property was tested using a panel who scored attributes. The results show that both insects fasted for up to 4 days without death. By contact or fumigation, significant kills of weevil larvae were record in the presence of EOs depending on the exposure time and concentration, with a better efficiency at 5%. Mycorrhizal plant EO causes 83% of death by contact on both insects than none mycorrhizal plant EO causing 75 and 65% of death respectively for *Necrobia rufipes (N. rufipes)* and *Dermestes. Maculatus (D. maculatus)*. Adulcidal test within 42 days shows a significantly greater efficiency of mycorrhizal plant EO accounting for 97% and 92.5% respectively for *N. rufipes* and *D. maculatus* than none mycorrhizal plant EO accounting for 92.5% and 87.5% respectively for *N. rufipes* and *D. maculatus*. EOs have better lavicidal and insecticidal capacity than control treatments ($p < 0.05$). After 42 days, a significantly less emergence rate of larvae was recorded with mycorrhizal plant EO than none mycorrhizal plant EO ($p < 0.05$). sensorial properties of stored fish were significantly good under EOs treatment and bad under control treatments ($p < 0.05$). AM fungi inoculation impact plant metabolism with the accumulation of metabolites geraniol, neral, isoneral and isogeranial which may be responsible for the better biological activities record in this study.

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Introduction

Fisheries and aquaculture are key tools to alleviate food and income in several developing countries, either as a self-activity or in association with others. Both harvesting, selling, and processing fish contribute to food security in several ways. Fisheries sectors and resources are credited with the important feeding capacity of populations worldwide (Prabhakar et al. 2020; Béné et al. 2016). A growing belief progressively supports that fish is the principal source of animal protein for more than 30% of Africa's human population representing more than 200 million people (Tran et al. 2019; Muringai et al. 2022). Freshly captured fish is perishable under inappropriate conservation equipment. Management of post-harvest losses has been the focus of researchers and communities

since decays based on methods including cooling, salting, drying, and smoking. In the coastal areas, more than 50% of caught fish is smoked or dried before bring to the consumers, who are almost far from the catch point (Etchutakang et al. 2023; Ajayi et al. 2006). Those management practices considerably impact the quality of post-harvest fish in coastal areas. Although smoking improved the shelf life of fish, it may be dangerous for living actor's health involved in the value chain steps.

Smoke-dry fish is drastic low water content product, generally subject to contamination by microorganisms and insects, with consequences on the safety and organoleptic properties of the product (Ngo Oum et al. 2021; Taherzadeh-Shalmaei et al. 2021; Molaei et al. 2020; Ndrianaivo et al. 2016). Weevils such as *Dermestes maculatus (D. maculatus)* and *Necrobia rufipes (N. rufipes)* are harmful insects attacking the smoked and smoke-dry fishes during management by traders in markets (Ndrianaivo et al. 2016). They always generate quantitative and qualitative losses (Ngo Oum et al. 2021; Hissein et al., 2018; Ndrianaivo et al. 2016). The preservation of dried foodstuffs is often subject to several management methods, including the use of synthetic pesticides, which unfortunately trigger other limitations, like environmental pollution, remaining pesticide residues in food, and the emergence of resistant pests (Rochester et al. 2015; Rajashekar et al., 2012). Arising concerns about the side effects of synthetic pesticides on human health gradually motivate consumers to pay a premium price for natural and organic fresh products (Rahman et al. 2021). Growing ethnobotanical knowledge continuously shows the relationship between the majority of plant species and the plant use habits of the surrounding population (Phillips et al. 1994; van Andel 2000; Vandebroek et al.2004).

Plant populations worldwide are dense and highly diverse, with relatively less than 10% of these used as foods by human and animal species (Moerman, 1996). Some are essential oils (EOs) producers. This volatile extract is gaining interest as food additives, widely accepted by consumers because of their volatility, and biodegradable nature. More than 17,000 aromatic plant species commonly belong to angiosperms families *Lamiaceae, Rutaceae, Myrtaceae, Zingiberaceae*, and *Asteraceae* (Regnault-Roger et al., 2012). About 60% of essential oil derivatives are credited with fungicidal properties (Wu et al., 2023). Lemongrass (*Cymbopogon citratus)* is an EO producer from approximately 55 species of grasses belonging to the *Poaceae* family. The chemical composition of this plant EO include Néral, Myrcène, Géranial, and Géraniol in majority, and some sesquiterpenes with variable concentrations according to the growing area and conditions of the plant (Fokom et al., 2019; Muturi et al., 2020; Mukarram et al., 2021; El-Kased and Kersh 2022). Lemongrass EOs are credited with microbicidal properties on several disease-causing microorganisms, including bacteria (Farias 2019; Silva 2020), fungi (Lee 2020; Eke et al. 2020; Ngo Oum et al. 2023), and viruses (Silva 2020). Scientists always show EOs and components properties like insecticidal capacity to vary according to plants species and growing ecology whether undergoing fumigation or contact test (Zanuncio et al., 2016). Plant elicitors like Arbuscular mycorrhizal fungi can alter the chemical composition of their extract with extension to its biological properties (Eke et al., 2020; Ngo Oum et al., 2023).

This study aims to test the insecticidal effect of two types of Lemongrass EO on beetles (*D. maculatus* and *N. rufipes*) attacking smoke-dry fish within the storage. Specifically, fasting capacity, larvicidal and adulticidal properties of EOs on weevils, and the sensorial indices of smoke-dry fish within storage with EOs will be assessed.

Materials and Methods

Smoke Dry Fish, Insects and Essential Oils Materials

Smoke-dried fish used were randomly selected and purchased from major smokers who are provider to the retailers, before carried to the Laboratory, weighed, and dehydrated in an oven at 60°C for an hour to kill all possible insect pests and eggs. Finally, samples were allowed to cool at room temperature in the laboratory before used.

Concern insects are *Dermestes maculatus* (*D. maculatus*) and *Necrobia rufipes* (*N. rufipes*), collected from smoke-dry-fish merchants of Yaoundé markets. They are stocked in buckets containing smoke-dry fish at the Soil Microbiological Laboratory, the Biotechnological Center, Nkolbisson of the Yaoundé I University in Cameroon at 28°C, 60% humidity.

Before each experiment, mature insects of each species were collected and introduced in 5l buckets containing safe smoked-dry fish and incubated at ambient temperature until the emergence of young insects. They were collected and used for the biological tests (Delobel and Maurice 1982; Ileke et al. 2021; Nasiru and Suleiman 2024).

Two essential oils (EOs) were obtained from the same Laboratory, including 1 from the none mycorrhizal lemongrass recorded as EO1 and the second from the mycorrhizal lemongrass plant recorded as EO2. Details regarding EOs production and chemical composition is provided in (Figure 7 and 8, Table 1) (Fokom et al., 2019). Ten months old lemongrass leaves growth in field condition was used for the hydro distillation of EO, follow by the GC/MS analysis.

Fasting Capacity of D. Maculatus and N. Rufipes Larvae

Before the test, the natural resistances of insects were asses by exposure of 10 larvae from each species to 7 days fasting period in Petri dishes. During this period, the rate of mortality was evaluated and recorded. Larvae were considered dead if unable to move when hurt with a fine hairbrush.

Essential Oils Effect On D. Maculatus and N. Rufipes Larvae

The effect of EOs on insects was evaluated using the technique described by Plata-Rueda et al., 2020. Screening concentrations from 1% to 10% of EOs led us to select 3%, 4%, and 5% as the test concentrations for this study. This choice was based on the similarities record for their efficiency percentages. Test concentrations of 3%, 4% and 5% were prepared by adding an appropriate amount of EOs in 5% (v/v) Tween 80, gently mixed in a sterile Erlenmeyer to disperse the oil. Tween 80 is prepared at 5% of the highest test concentration. The negative control (NC) were made with the smoke dry fish and insects only.

Table 1. Chemical composition of ten months old lemongrass essential oils from arbuscular mycorhizal and non arbuscular mycorrhizal plant in field. (Fokom *et al*., 2019).

	Compounds	R.t.	NAM (%)	AM (%)
1	6-methyl-5-hepten-2-one	9.750	1.86	1.83
2	Myrcene	10.069	6.44	6.15
5	Alpha- Pinene	11.901	0.15	0.16
6	(E)-, beta- Ocimene	12.350	0.44	0.41
8	6,7-Epoxymyrcene	14.328	0.21	0.18
9	3-(4-methyl-3-pentenyl)-Furan,	14.643	0.08	0.06
10	Linalool	14.828	1.50	1.77
11	3,7-dimethyl-1,6-octadien-3-ol,	15.286	0.07	0.05
13	E-Salvene	16.414	0.17	0.19
14	7-methyl-3-methylene-6-Octenal,	16.772	1.19	1.18
15	Trans-Chrysanthemol	16.934	0.31	0.30
16	Citronellal	17.159	0.32	0.38
17	Isoneral	17.679	2.23	2.43
18	Rose furan oxide	17.977	0.07	0.05
19	Isogeranial	18.591	3.50	3.94
20	3,7-dimethyl-Octa-1,7-dien-3,6-diol	19.043	0.12	0.08
22	cis-p-mentha-1(7),8-dien-2-ol	19.657		0.15
23	Neral	21.770	40.32	42.25
24	Geraniol	22.014	0.33	0.47
25	3-methyl-6-1-methyl 2-cyclohexen-1-one,	22.086	0.13	
26	Geraniol	22.732	2.29	4.98
27	Geranial	23.479	33.16	27.14
28	Citronellylacetone	23.540	0.10	
30	2-Undecanone	23.957	0.84	1.01
31	Geranyl formate	24.077	0.19	
32	2-Hexenyl laurate	25.569	0.68	0.39
34	4,8-Dimethylnona-3,7-dien-2-ol	26.615	0.20	0.20
36	Geranyl acetate	27.499	1.07	1.57
37	(E)-Caryophyllene	29.047	0.16	0.27
38	Trans-.alpha.-Bergamotene	29.678	0.06	0.10
39	Beta-(E)-Farnesene	30 .527		0,06
40	2-tridecanone	32.292	0.55	0.84
41	Alpha(E)-Farnesene	32.635		0,06
42	2-n-dodecylcyclohexanone	33.283		0.07
43	Caryophyllene oxide	35.509	0.10	0.11
44	Selin-6-en-4.alpha.-ol	37.121	0.30	0.42
46	Intermedeol	38.615		0.05
47	2-Pentadecanone	40.029		0.07
Total number of compound			33	37

NAM = none arbuscular mycorhizal, AM = arbuscular mycorhizal, Rt = retention time.

The contact toxicity of EOs was done using filter paper as described by Mboussy et al. (2021). A stock solution was prepared by diluting 0.5 ml of essential oil in 2 mL of 5% (v/v) Tween 80 and completing to a volume of 500 mL with distilled water. Practically, 200µL and 1ml of each of the EOs at different concentrations were spread on filter paper discs (Whatman HPL3.1) lining a Petri dishes (9 cm^3 in diameter). Subsequently, ten *N. rufipes* and *D. maculatus* larvae were introduced into the Petri dishes, closed and sealed with parafilm paper. The treatment was incubated at room temperature (28°C) for 96 hours. Three replications were made for each treatment. The experimental design was completely randomized. Dead insects were recorded every 24 hours during four exposure days. larvae were considered dead if unable to walk when prodded with a fine hair brush. Larval mortality was estimated as follow:

Larval Mortality (%) = (Number of Dead Larvae/Number of Larvae Introduced) × 100

Essential Oils Effect On Repellency of D. Maculatus and N. Rufipes Larvae.

The EOs effect on the repellency capacity of *D. maculatus* and *N. rufipes* larvae was evaluated according to the technique of McDonald et al. (1970), using the preferential zone method on filter paper (Mpika et al. 2023). Nine cm of diameter filter paper disks were divided into two equal parts. The solutions of the EOs with respective concentrations were distributed uniformly on half of the disc of filter paper (Whatman HPL3.1). The other half of the paper received 200µl of 5% Tween 80 serving as control. The discs placed in the Petri dishes received 10 larvae of *N. rufipes* and *D. maculatus* at stages 4 of development. Three repetitions were carried out for each treatment. The Petri dishes were incubated at room temperature. The number of insects present on each half-disk in the boxes was recorded every two hours for six hours. The average percentage of repellency for each treatment was calculated and assigned to one of the

different repellent classes (Mc Donald et al. 1970). The percentage of repulsion was calculated according to the formula (1).

$$PR(\%) = \frac{Nc-Nt}{Nc+Nt} \times 100 \quad (1)$$

Nc : number of insects present on the part of the disc treated only with tween 80 at 5%;

Nt : number of insects present on the part of the disc treated with essential oil solutions.

PR : percentage of repulsion.

Fumigantion Test of Essential Oils On D. Maculatus and N. Rufipes Larvae

Fumigant effect of EOs on D. *maculatus* and *N. rufipes* larvae was evaluated according to the technique of Mboussy et al. 2021. In glass jars of 270 cm^3 with tight lids, 10 imagos of *D. maculatus* and *N. rufipes* of mixed sexes were introduced. Discs of filter paper (Whatman HPL3.1) with a surface of 9 cm^3 were fixed using a black wire at the centre of the inner face of the lids so that they took up half the height of the jars. 1ml of essential oils of 3%, 4% and 5% concentrations were spread on the filter paper discs. The control treatment with 1ml of solvent without essential oils (tween 80 and water) was made. Each treatment was repeated three times. All treatments were incubated at room temperature (28°C) and 80% relative humidity for 96 hours. Every 24 hours, the number of dead insects were recorded in each treatment. The larva was declared dead when they did not react to an abdominal pain-punch.

Test of Conservation with Eos on Smoked-Dry-Fish Against N. Rufipes and D. Maculatuse

Three smoked dry fish of 200 g were sprayed with 1.5 ml of 5% EO and introduced in 5L plastic buckets. Ten young adults of *D. maculatus* and *N. rufipes* were introduced in buckets and covered with a porous fabric. The control batch received the same treatment except that only 5% of Tween 80 was sprayed on the smoke-dry fish. The negative control did not receive any treatment. All treatments were made in three repetitions. The experimental device was factorial with 6 treatments including 2 EOs, 2 insects and 2 controls all arranged according to a randomized complete block design. All treatments were incubated within 42 days at room temperature (28°C), and relative humidity (80%). The number of dead insects was recorded at 14, 28 and 42 days after incubation. A dead insect was found in a dorsal or ventral position with body stiff, immobile legs and antennae after stimulation with forceps. After 42 days of incubation, the fish were crumbled and the emerging larvae were counted for each treatment and recorded (Ndrianaivo et al. 2016).

Kinetic of Smoke-Dry Fish Sensory Quality Within the Storage

Smoke-dry fish from each treatment were subject to sensorial analysis every 14 days using 30 untrained panels of 25 to 40-year-olds. The panel members were familiar with smoked fish because they almost eat it every week, allowing them to smell and appreciate the color and texture of smoked fish. Panelists were asked to evaluate the attributes of odor, color, and texture. Prior to the test, a brief explanation of each attribute was provided to enhance their ability to assess these qualities. The evaluation was conducted using a 7-point hedonic scale, where 1 indicates "poor" and 7 indicates "excellent" (Eyo, 2001). Each fish sample from the different treatments was presented sequentially to the panelists at each evaluation period. Before the sensory analysis began, consent was kindly requested and obtained from each panelist as a mandatory requirement for participation.

Statistical Analysis

Data collected were range according to treatments and subjected to analysis of variance test (ANOVA), Using statistical package for the social science (SPSS) using computer software version 22.0. Comparisons among treatment was carried out by Tukey Multiple Range Test at a significance level of 0.05

Results

Fasting Capacity of N. Rufipes and D. Maculatus Larvae

The larvae of both insect species can withstand absolute fasting for up to 4 days. Deaths are noted between the fourth and seventh days without exceeding 25% of the whole population (Figure 1).

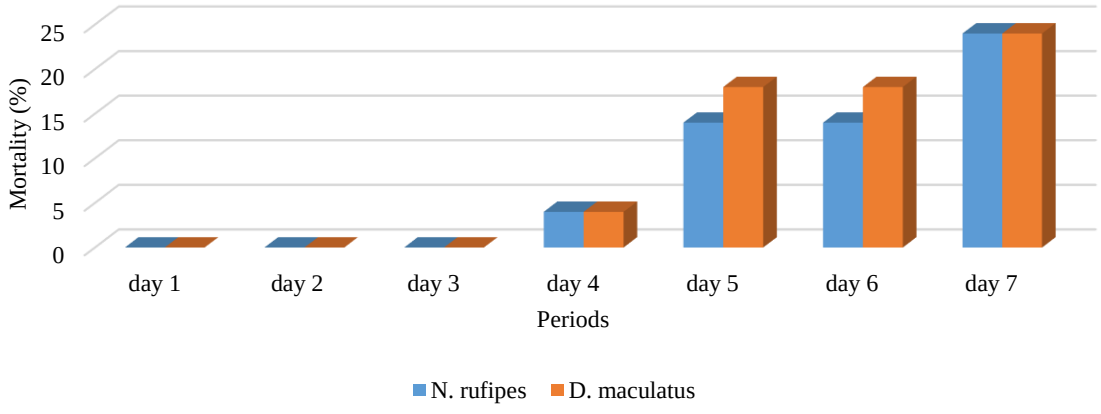

Figure 1. Fasting capacity of *N. rufipes* and *D. maculatus* larvae

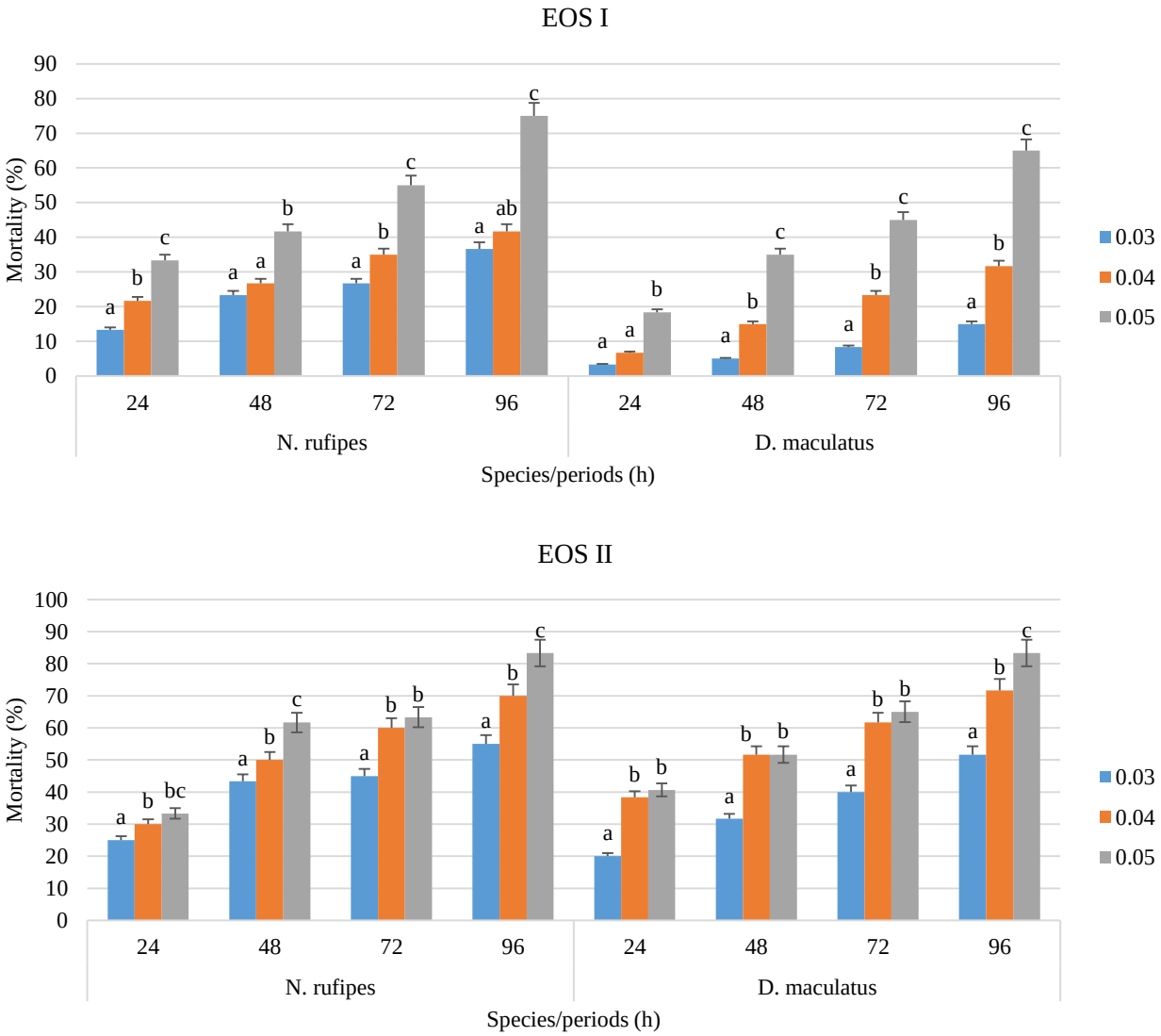

Figure 2. Influence of lemongrass EOs on *N. rufipes* and *D. maculatus* larvae by contact on filter paper. a) is none mycorrhizal EO concern, b) is mycorrhizal EO concern. 0.03, 0.04, and 0.05 are EOs concentrations in %. For each insect species at each storage period, bars assigned different letters significantly different ($p < 0.05$).

Larvicidal Effect of Eos by Contact on Filter Paper

Assessment of the larvicidal effect by contact of EOs on *N. rufipes* and *D. maculatus* larvae was evaluated (Figure 2). Upon contact with the EO1, the mortality of the larvae of both insects was recorded, with a greater effect on the *N. rufepes* than *D. maculatus* species. The mortality rate varied according to the exposure time, with the best rates recorded at the concentration of 5% ranging from 35% after 24 hours to 75% after 96 hours for *N. rufepes* and from 18% after 24 hours to 65% after 96 hours for *D. maculatus* (Figure 2a). Related to the EO2, the death of the larvae of both insects was also recorded, with a greater effect on the *D. maculatus* than the *N. rufepes* species. This mortality varied according to the exposure time, with the best rates recorded at 5% concentration, ranging from 34% after 24 hours to 83% after 96 hours for *N. rufepes* and from 40% after 24 hours to 83% after 96 hours for *D. maculatus* (Figure 2b). Significant differences ($P<0.05$) were recorded with respect to EO concentration used and the exposure time of insects (Figure 2).

Fumigation Test of Eos Against N. Rufipes and D. Maculatus Larvae.

Test of the larvicidal effect by fumigation of EOs on *N. rufipes* and *D. maculatus* larvae was evaluated (Figure 3). The fumigation effect of EO1 led to the continuous death of larvae of each insect involved in this study, with a greater action on the *N. rufipes* than on *D. maculatus* species. The mortality rate varied according to the exposure time, with the best rates recorded at the concentration of 5% of EO1, ranging from 40% after 24 hours to 75% after 96 hours for *N. rufipes* and from 15% after 24 hours to 75% after 96 hours for *D. maculatus* (Figure 3a). Simultaneously the death of both insect larvae was also recorded with the EO2, with a greater effect on the *N. rufipes* than the *D. maculatus* species. This mortality varied according to the exposure time, with the best rates recorded at 5% concentration, ranging from 25% after 24 hours to 75% after 96 hours for *N. rufipes* and from 15% after 24 hours to 60% after 96 hours for *D. maculatus* (Figure 3b).

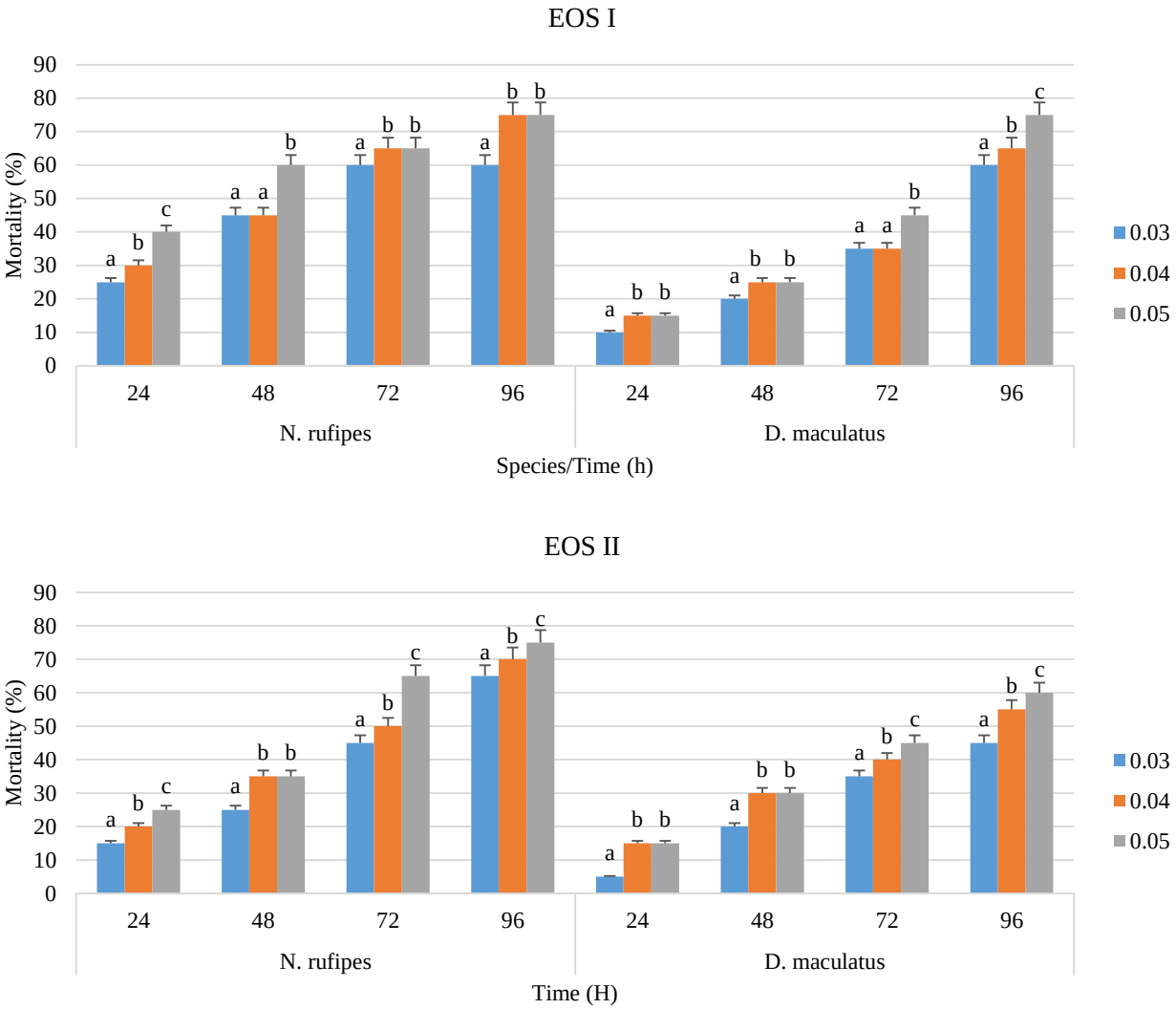

Figure 3. Influence of lemongrass *EOs* on *N. rufipes* and *D. maculatus* imagos by fumigation in vitro. a) is none mycorrhizal EO concern, b) is mycorrhizal EO concern. 0.03, 0.04, and 0.05 are EOs concentrations in %. For each insect species at each storage period, bars assigned different letters significantly different ($p < 0.05$)

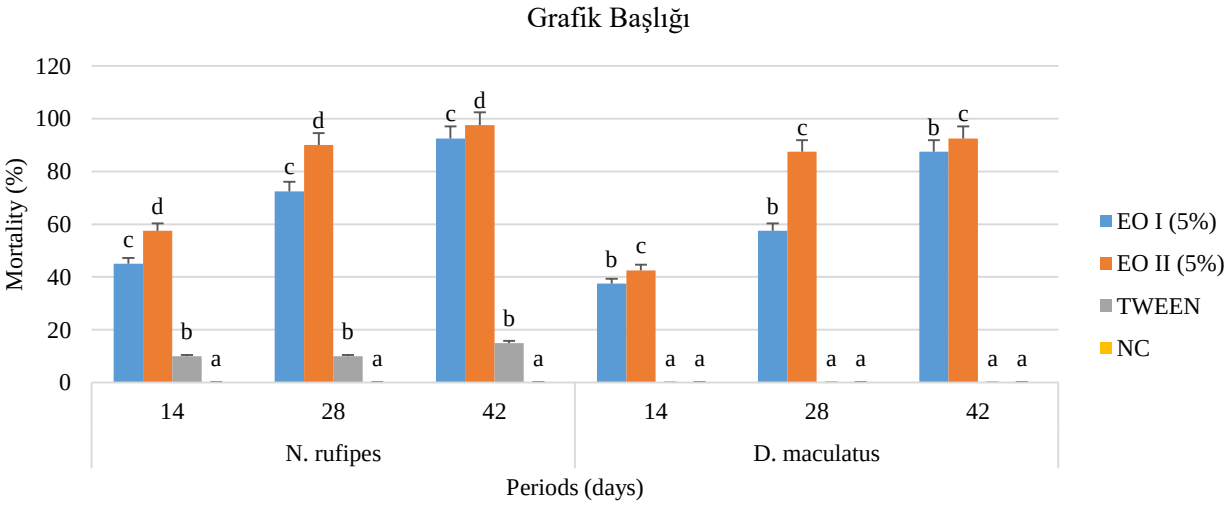

Figure 4. insecticidal capacity of EOs on *N. rufipes* and *D. maculatus* within smoke-dry fish storage. EO1 and EO2 are non-mycorrhizal and mycorrhizal essential oils concern respectively. TWEEN refer to treatment with 5% tween 80; NC: control treatment containing fish and insects only. For each species at each storage period, bars assigned different letter are significantly different ($p < 0.05$)

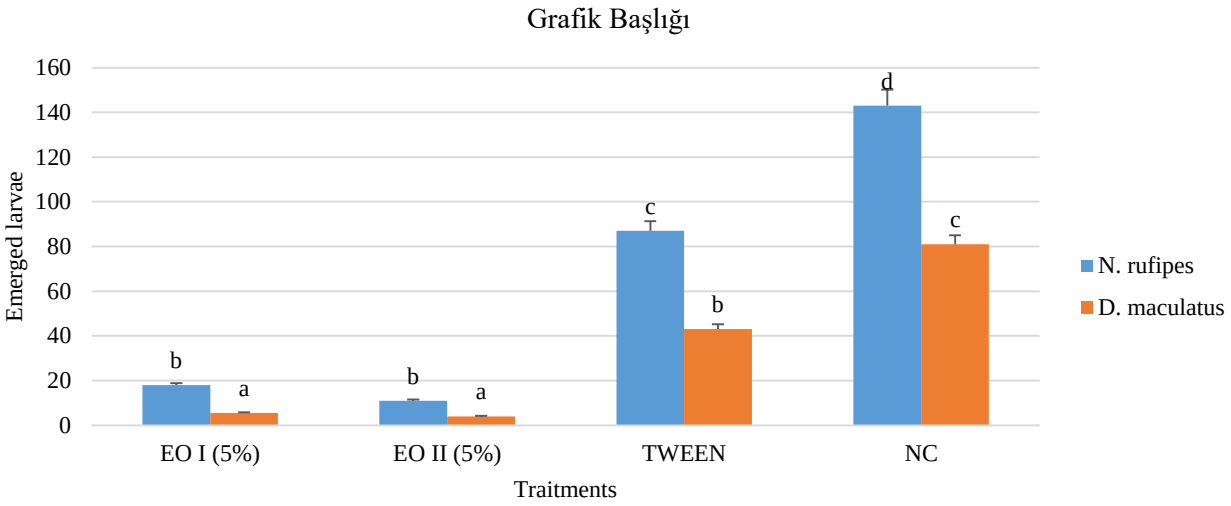

Figure 5. The influence of lemongrass EOs on the emergence capacity of: *N. rufipes* and *D. maculatus* after 42 days. EO1 and EO2 are non-mycorrhizal and mycorrhizal essential oils concern respectively. Tween refer to treatment with 5% tween 80; NC: negative control treatment containing fish and insects only. For each treatment, bars assigned different letter significantly different ($p < 0.05$).

Insecticidal Capacity of Essential Oils on Smoke-Dry Fish Within the Storage.

The evaluation of the insecticidal capacity of EOs on smoke-dry fish-destroying insects in storage was carried out for 42 days (Figure 4). The results show an increasing mortality of the two weevil species with time and the type of EO. For EO 1, the mortality rate varied from 42% to 92% respectively at 14 and 42 days of storage for the species *N. rufipes* and from 57.5% to 97.5% respectively at 14 and 42 days of storage for the species *D. maculatus*. Regarding EO2, mortality varies from 57.5% to 97.5% respectively at 14 and 42 days of storage for the species *N. rufipes*, and from 42.5% to 92.5% respectively at 14 and 42 days of storage for the species *D. mculatus*. A significant difference was recorded in viewing the efficacy of EOs compared to the controlled treatments, and the type of EO, with EO2 being more efficient than EO1 ($P<0.05$).

Emergence of N. rufipes and D. maculatus Adult On Smoked–Dry Fish After 42 Days

After 42 days of preserving smoked dry fish under different treatments, the number of emerging insects was evaluated (Figure 5). The results show that: EOs at 5% causes a highly significant reduction in the number of emerging insects compared to the control treatment whether positive or negative. This reduction is more pronounced with the species *D. maculatus* than *N.rufipes*. Also, a better reduction of emerging insects of both species was recorded with EO2 compared to EO1.

Sensory Indices of Smoked Fish During 42 Days of Storage

In addition to evaluating storage under different treatments, the sensory profile of the smoked dried fish was assessed every 14 days based on specific attributes (see Figure 6). The results indicate that the scores for various attributes of the smoked fish gradually decrease over time across all treatments. However, despite this decline, the fish treated with essential oils (EOs) remain more acceptable than those from the negative control treatments, which show a significant drop in appreciation after 42 days of storage. Each attribute contributes to the sensory profile of the fish, following a similar rate of decline.

Discussion

Fish and fish products are excellent sources of protein, providing sustenance for over 30% of the African population (Tran et al. 2019; Muringai et al. 2022). However, the perishable nature of fresh fish has led to the development of various preservation methods, including smoking, which is commonly used in this sector. While smoking improves the shelf life of fish, smoked and dried fish faces several challenges, particularly from insect infestations. The insects *D. maculatus* and *N. rufipes* are among the most harmful pests attacking smoked and dried fish, leading to both quantitative and qualitative losses (Ndrianaivo et al. 2016; Ngo Oum et al. 2021). Research has shown that both the adult and larval stages of *D. maculatus* and *N. rufipes* can cohabit, feed on, and damage the same dried fish products (Richard and Davies 1977). The study found that these insects can survive for up to four days without food and can endure seven days with minimal food supply, resulting in less than 25% mortality (Figure 1). This highlights their resilience and significant potential for causing damage to smoke-dried fish.

Upon contact with lemongrass essential oils (EOs) through physical application or fumigation, the mortality rate of *D. maculatus* and *N. rufipes* larvae increased gradually with time and concentration. The highest death rate was observed at a 5% concentration after 96 hours, regardless of the type of essential oil used (figures 2a, 2b, 3a, and 3b). This finding supports other research that highlights the larvicidal effectiveness of lemongrass EOs against various larval species. Additionally, a separate study demonstrated the significant insecticidal properties of essential oils from *Corchorus olitorius*, *Solanum nigrum*, *Lycopersicon esculentum*, and *Telfairia occidentalis* on *D. maculatus* larvae infesting smoked dry fish during storage (Nta et al. 2019).

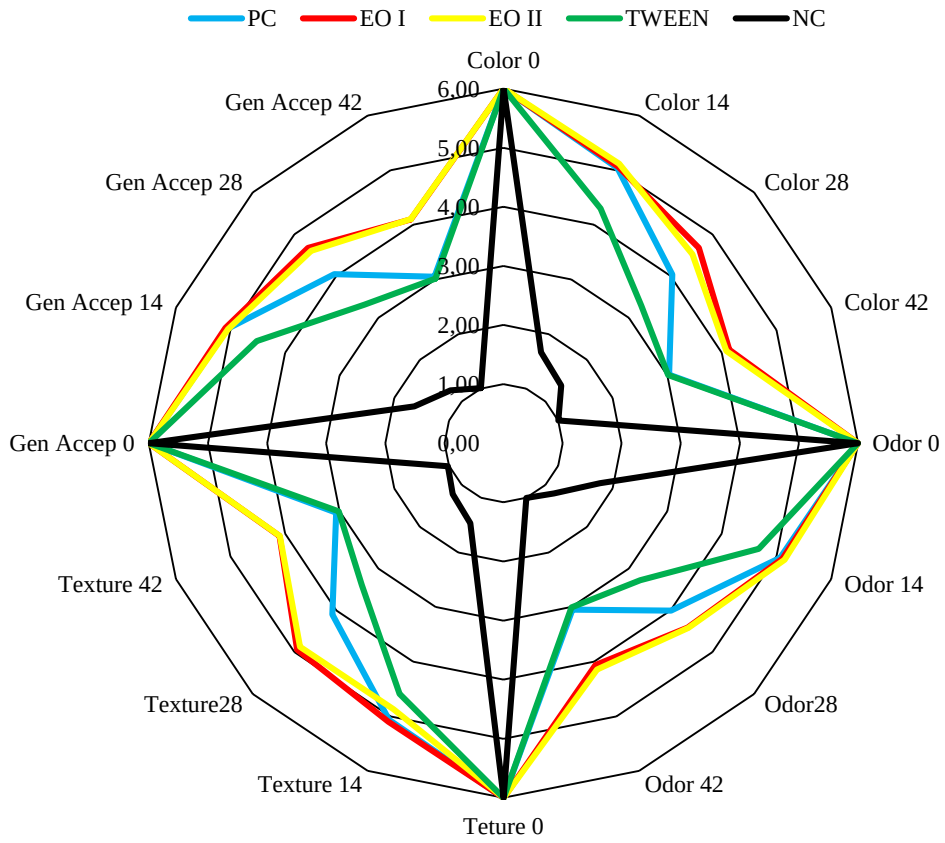

Figure 6. Kinetics variation of smoke-dry fish quality within 42 days under EOs protection against weevils. EO1 and EO2 are non-mycorrhizal and mycorrhizal essential oils concern respectively. Tween refer to treatment with 5% tween 80; NC: negative control treatment containing fish and insects only. PC: positive control containing fish only. Gen Accep refer to general acceptability. Each attribute is follow by a number refer to the period of storage.

Both fumigation and contact tests on the larvae of two insect pests attacking smoked-dried fish demonstrate a higher mortality rate for lemongrass oils on the species *Nezara rufipes* compared to *Dermestus maculatus*, regardless of the essential oil (EO) quality (see figures 2a, 2b, 3a, and 3b). This observation may be related to the physiological and genetic characteristics of the species. Although larval mortality observed in fumigation tests did not show significant differences with EO type, the contact tests revealed differences in larval mortality for both insect species and the EO type. Non-mycorrhizal essential oil (EOI) resulted in lower larval mortality compared to mycorrhizal essential oil (EOII) ($P \leq 0.05$). This difference may be attributable to the chemical composition of the EOs, as previous studies indicated that arbuscular mycorrhizal fungi can modify the metabolism of their host plants and the chemical composition of their volatile extracts (Maycow Marcos et al. 2024; Oliveira et al. 2019; Fokom et al. 2019; Fontana et al. 2009). These modifications affect the biological properties of the EO like the bio-protection of seeds against Fusarium species (Kanko et al. 2017; Eke et al. 2020; Ngo Oum et al. 2023).

A test evaluating the effectiveness of lemongrass essential oils (EOs) in controlling adult weevils during the storage of smoked-dried fish demonstrated that these oils not only significantly eliminate weevils throughout the storage period, but also that the type of essential oil plays a crucial role in the level of weevil destruction. Specifically, EOII exhibited greater activity than EO1. Furthermore, it was observed that the *N. rufipes* species is more sensitive to essential oils, regardless of the type, compared to the *D. maculatus* species (Figure 4). After the preservation period, the emergence test indicated a significant reduction in larvae among the treatments with essential oils compared to the control group. Furthermore, smoke-dried fish preserved with EOII exhibited a significant reduction in the population of emerged larvae compared to those preserved with EO1 (see Figure 5). The insecticidal activity of EOs on insect-infested dried food during storage has been consistently reported in various studies (Doumbia et al., 2014; Nta et al., 2019; Lazarević et al., 2020; Plata-Rueda et al., 2020). Case studies on lemongrass EOs highlight the insecticidal effects of both the entire oil and its individual chemical compounds, with similar observations noted for insects such as *D. maculatus* (Ikawati et al., 2021; Nta et al., 2019). To emphasize the significance of essential oil (EO) potential in relation to the growth conditions of the plant, a study was initiated to test the inoculation with arbuscular mycorrhizal fungi and its impact on EO composition. This is one of the first study exploring the development of bio-insecticidal products from inoculated plants, specifically aimed at managing insect pests that of dry fish. Over a 42-day analysis, fish infested with two types of weevils exhibited a decline in sensory quality, which initially very good, deteriorated to an unacceptable level when no essential oils (EOs) were used. In contrast, fish stored with EOs maintained acceptable sensory scores throughout the entire study (Figure 6). The inoculation of lemongrass plants with arbuscular mycorrhizal fungi resulted in metabolic changes that influenced the

chemical composition of their EO extracts. Notably, the concentrations of compounds such as geraniol, neral, and isoneral increased, and the total number of compounds present following bio-f ertilization (Table 1). Such modifications of EO composition may support the larvicidal insecticidal and low emergence of weevils bearing EO record in this study, as well as the good sensorial quality of smoked dry fish record following storage. Previous studies record citral (geranial and neral mixture) as the insecticidal compounds of the lemongrass plant (Eden et al., 2020). Additionally, the increased concentrations of citral and isoneral, along with the total number of compounds following the inoculation of lemongrass plants with mycorrhiza, may have enhanced the neurotoxicity of the essential oil, resulting in improved activity.

Conclusion

This study revealed that lemongrass EOs are credited with insecticidal and larvicidal properties against *D. maculatus* and *N. rufipes* insects regardless of the type. The efficiency is better with EOII compared to EO1. The rate of mortality is higher with *N. rufipes* species than *D. maculatus*. Fish stored within 42 days in the EOs area show better sensorial indices than control treatments. The plant growth conditions for EOs production should be considered to improve their properties.

Declarations

Author Contribution Statement

MAG, NOTJ, MMGG, WR, GP, EP, FR, AS: Data collection, investigation, formal analysis, and writing the original draft. SS, HV, SKA, ND, FBF, FR, EP, MAG, NOTJ: Project administration, supervision, conceptualization, methodology, review and editing. FR, MAG, EP, NP, WR: Data collection and investigation

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Conflict of Interest

"The authors declare no conflict of interest."

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