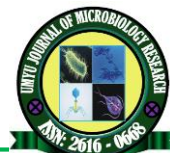




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Entomocidal Effect of Some Essential Oils: An Alternative for Synthetic Pesticides in the Control of *Dermestes maculatus* Degeer 1774 (Coleoptera: Dermestidae)

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Abstract

Realizing the detrimental effect of synthetic pesticides on the environment, non-target organisms, and human health. The scientific community's interest in searching for and providing safe, natural, and effective pesticides is highly attractive. Using the residual contact approach, the essential oils of *Thymus vulgaris* L. and *Syzygium aromaticum* L. (TEO and EOSA) were assessed against *Dermestes maculatus* in a laboratory setting. Steam distillation was used to extract the oils. Four concentrations (2.5, 5, 7.5, and 10%) were prepared using acetone as a solvent and applied individually to 15 g of smoke-dried *C. gariepinus*. For five days, newly emerged adults, third-instar larvae, and newly laid pest eggs were exposed to the treated fish samples. The results showed that both oils had varying larvicidal and adulticidal activities against *D. maculatus*. Similarly, the EOs significantly decreased the pest's ability to lay eggs and hatch. EOSA was the most effective treatment in all cases; it had the lowest LC_{50} and LT_{50} and the most effects at all dosages. Consequently, EOSA and TEO could manage *D. maculatus* infesting smoke-dried *C. gariepinus*.

Keywords: *Clarias gariepinus*, *Dermestes maculatus*, Essential oils, Synthetic pesticides, *Syzygium aromaticum*, *Thymus vulgaris*, Infestation

INTRODUCTION

The most common method fishmongers use in Nigeria to preserve fish is smoking, which is arguably the easiest way because it does not involve complicated machinery or highly experienced workers. Since their nutritional qualities are similar, smoke-dried fish is an excellent substitute for fresh fish (Ajao *et al.*, 2018). *Clarias gariepinus* is the most widely used fish species in Nigeria that has been smoke-dried. It has a distinct taste, is very nutrient-dense, has no saturated fat, and has a high concentration of vitamins, proteins, and minerals (Aremu *et al.*, 2013; Ayelaja *et al.*, 2015). Despite the preservation technique used, in most of Nigeria's producing regions, *Dermestes maculatus* L accounts for around 71.5% of the insect pest infestation of stored smoke-dried *C. gariepinus* (Babarinde *et al.*, 2018; Ayelaja *et al.*, 2020; Indabo and Zakari, 2020). The infestation lowers consumer acceptability and results in 50%-62.5% qualitative and quantitative loss of the stored fish (Babarinde *et al.*, 2018).

Dermestes maculatus is a species of beetle in the family Dermestidae with worldwide distribution (Zakka *et al.*, 2013). Both adults and larvae of this pest are recognized as cosmopolitan pests of stored items, especially

those containing animal protein. They feed on dead and dried animal material such as meat, fish, hide, cheese, feathers, etc. (Charabidze' *et al.*, 2022). Males and females mate multiple times, and the female lays eggs within 24 hours of the first mating. A female requires a continuous supply of water and food to achieve their maximum egg-laying capacities of up to 800 eggs in life. Eggs are laid singly or in small batches on the food source, which hatch within 2 to 4 days (Zakka *et al.*, 2013). The larval body is covered with rows of hairs of different lengths; hence, the underside of the abdomen is typically yellowish-brown, while the dorsal surface is dark brown, usually with a central yellow line (Ismail *et al.*, 2020). The adult is elongated and oval, black or dull, and usually hairy, ranging in size from 5.5 to 10.0 mm. Each side of the thorax has a band of white hairs. The underside of the abdomen is primarily white with black spots at the sides and a large black patch on the last segment. The elytra are dark brown or black, with hairs that are mostly black, yellow, or white. The antennae are short and segmented with a club at the tip. The edges of the abdominal end of the elytra are serrated and end in a small spine projecting straight out. Adult beetles typically live between four to six months (Singh *et al.*, 2018).

Because of their efficiency and comparatively extended shelf life, synthetic pesticides are the mainstay of management for insect pests in many storage systems (Manuel *et al.*, 2020; Oyinloye *et al.*, 2021). However, studies conducted by scientists have shown that smoke-dried *C. garipepinus* contains pesticide residues over the acceptable level, including Dichlorodiphenyltrichloroethane (DDT), Captan, Hexazinone, and Tecnazene (Adedolapo, 2018; Dauda *et al.*, 2019; Manuel *et al.*, 2020; Oyinloye *et al.*, 2021). According to guidelines from the Food and Agricultural Organization of the United Nations and the World Health Organization (FAO and WHO). Food items deemed fit for human consumption must not contain active pesticide ingredients above the maximum residue limits, nor should they have an off odor, strange color, insect exuvia, or other health risks (Manuel *et al.*, 2020). Because of the severe constraints posed by these pesticides, the scientific community has focused on finding safer alternatives to insecticides that would not harm people, animals, or the environment (Garay, 2020). A noteworthy advancement in recent times has been the utilization of plant-based materials, including powders, extracts, and essential oils (Akinwumi, 2017; Babarinde *et al.*, 2018; Nta *et al.*, 2019; Soe *et al.*, 2020; Indabo and Zakari, 2020; Georgina *et al.*, 2020; Moustapha *et al.*, 2021; Nasiru *et al.*, 2022; Suleiman and Nasiru, 2022).

Essential oils (EOs) are volatile oils found mostly in aromatic plants as secondary metabolites that can be extracted from seeds, buds, stems, leaves, and flowers (Mossa, 2016). They are hydrophobic lipophilic, density is usually lower than water's, and soluble in organic solvents. They comprise a combination of organic chemicals that exhibit a wide range of bio-activities against agriculturally and medically important insect pests. Spanning from sub-lethal effects, including oviposition deterrence, antifeedant, and repellent actions, to toxicity with ovicidal, larvicidal, pupicidal, and adulticidal activities (Campolo, 2018; Ravi *et al.*, 2019). Essential oils can disrupt insects' fundamental metabolic, biochemical, physiological, and behavioral processes. They are selective and have little or no negative effects on the environment, non-target organisms, or human health (Ebadollahi and Mahboubi, 2011). They could be applied as a food preservative to a variety of foods, including dairy products, meat, bread, grains, fruits, and vegetables because they contain Terpenes and terpenoids, which are crucial for human health, food safety and have no appreciable impact on the treated products' quality (Ukoroije and Otoyor, 2020; Sasikala *et al.*, 2019; Owoade *et al.*, 2021).

Consequently, essential oil-based insecticides are very important for the control of storage insects. They are active against insects, fast penetrating, and non-toxic residues in the treated products. It has been reported that due to essential oil, it can be inhaled, ingested, or skin absorbed by insects (Mossa, 2016). The constituents of essential oil are primarily lipophilic compounds that act as toxins, feeding deterrents, and oviposition deterrents to a wide variety of insect pests. This activity is related to their major active compounds and other chemical constituents. Various bioactive constituents of essential oils were reported to be effective against houseflies, red flour beetles, and southern corn rootworms. When tested against *Coptotermes formosanus* (a subterranean termite), eugenol was most effective as a fumigant and feeding deterrent. Orange oil extracted from the citrus peel (containing ~92% d limonene) caused 96 and 68% mortality of subterranean termite, *Coptotermes formosanus* Shiraki, within 5 days, and there was a significant reduction in feeding as compared to controls at 5 ppm concentration (Koul *et al.*, 2008). It has been reported that essential oil obtained from *Artemisia judaica* L repelled *Callosobruchus maculatus* (Fab.). Also, at concentrations of 4.0, 8.0, 15.9, 31.9, and 63.7 µg cmG2, the oil-reduced the pest's egg laying by 12.5, 42.7, 61.8, 86.0, and 92.5%, respectively. Several essential oils are good inhibitors of pest's oviposition. The essential oil of *E. cardamomum* and essential oil obtained from Citrus peels caused a high reduction in oviposition of *C. maculatus*. Meanwhile, both neem and basil oil caused the prolongation of the nymphal duration and reduced the number of adult stages of *A. craccivora* (Koul *et al.*, 2008; Mossa, 2016).

Jumbo *et al.* (2018) reported that, in a dosage-dependent manner, the essential oils of *S. aromaticum* and *Cinnamomum zeylanicum* inhibited oviposition, hampered the emergence of offspring, and correspondingly slowed the growth rate of *Callosobruchus maculatus*. Similarly, essential oil extracted from clove leaves displayed strong larvicidal and antifeedant properties against third instar larvae of armyworm (*Spodoptera litura*) at a concentration of 2.0%, with LC₅₀ of 0.09% and LT₅₀ of 24.6 hours (Fateha *et al.*, 2021). Further, 48 hours after treatment, 100% of adult *Sitophilus zeamais* and *A. obtectus* exposed to 17.9 and 35µL g-1 concentrations of clove essential oil were observed killed (Jairoce *et al.*, 2016). Additionally, in laboratory settings, the administration of 1% *Thymus vulgaris* essential oil, commercial thymol, and carvacrol resulted in 50.00%, 86.67%, and 85.00% larval mortality of smaller mealworms (*Alphitobius diaperinus*).

As treatment doses increased to 2%, the mortality rose to 62.5%, 91.67%, and 97.5% (Szczepanik *et al.*, 2012). In addition, *Thymus vulgaris* essential oil reduced adult survival and inhibited oviposition and lifespan of *Acanthoscelides obtectus* using residual contact toxicity in a concentration-dependent manner (Lazarevic *et al.*, 2020). Meanwhile, significant (56%) adult mortality of *Callosobruchus maculatus* was recorded in 0.25 µl of thyme essential. Further increase in concentration to 30 µl resulted in 100% of the pest (Estekhdami *et al.*, 2020). Therefore, this research aimed to compare the entomocidal potential of *Thymus vulgaris* and *Syzygium aromaticum* essential oils against *Dermestes maculatus* infesting smoke-dried *Clarias gariepinus*. By evaluating larvicidal and adulticidal activity, determining

median lethal concentration (LC₅₀) and median lethal time (LT₅₀), and investigating the effect of these essential oils on oviposition and egg hatchability of the pest.

MATERIALS AND METHODS

Collection and Preparation of Plants Materials

The spices utilized in this study (Plate I) were bought at the Fatima Baika Central Market in Katsina. Plant taxonomists at the Department of Biology, Umaru Musa Yar'adua, Katsina (UMYUK), officially recognized the spices and issued voucher numbers (AN001, AN002) to each. The spices were then stored apart in clearly labeled plastic containers after being cleaned with tap water and allowed to air dry for five days in the laboratory under shade (Soe *et al.*, 2020).



Plate I: Spices used for the study (A) *T. vulgaris* leaves; (B) *S. aromaticum* buds

Extraction of the essential oils

The essential oil of each spice was extracted by steam distillation at the Chemistry Laboratory of UMYUK using the Clevenger apparatus with some modifications. A 1000 mL round-bottom flask was filled with 75 g of *T. vulgaris* leaves, *S. aromaticum* buds, and 750 mL of distilled water was added. The flasks were heated on a heating mantle for three hours. Water vapor and the extracted essential oils were evaporated via a connecting tube to the condenser. The top layer of the essential oil remained in the tube after the distillate was collected in a separating funnel and the water was emptied into a beaker. The oils were passed over anhydrous sodium sulfate to remove any excess water, and they were then stored in dark, sealed vials at 4 °C (Ileke *et al.*, 2020).

Collection and Preparation of Fish Sample

Fresh smoke-dried *C. gariepinus*, devoid of any adult or insect pest larvae, was purchased from Fatima Baika Central Market Katsina. The fish

sample was brought to the Postgraduate Laboratory of the Department of Biology, UMYUK, where it was weighed and subjected to a dry air oven at 60°C for 60 minutes to kill all possible insect pests and their eggs. Following this, the sample was allowed to cool at room temperature in the laboratory (Adesina *et al.*, 2015).

Rearing of *Dermestes maculatus*

The source of *D. maculatus* (Hide Beetle) employed in this investigation was smoke-dried *C. gariepinus* (African Cat Fish) that was naturally infested, and from wall crevices in stores that sold dried fish. The beetles were transported to the Postgraduate Laboratory of the Department of Biology at UMYUK in plastic jars covered with muslin cloth. Twenty pairs of adult *D. maculatus* that had been positively identified were placed into three distinct raising containers with 50 g of smoke-dried *C. gariepinus* and cotton wool soaked in water.

To provide the beetles with a food source and the water they need for oviposition. Afterward, muslin material was placed over the containers to keep insects inside and/or others from entering. The setup was maintained in an incubator for three weeks at $28 \pm 20^\circ\text{C}$ and $65 \pm 5\%$ relative humidity (R.H.) to facilitate oviposition and larval emergence. The new generation was prepared by removing newly emerged larvae from the stock culture and placed on another prepared setup (Ileke *et al.*, 2021).

Larvicidal Bioassay

The residual contact approach, adopted by Soe *et al.* (2020), was used to investigate the larvicidal efficacy of the chosen essential oils against *D. maculatus*. Five milliliters (ml) of the produced essential oil concentrations (2.5, 5.0, 7.5, and 10%) were sprayed separately and thoroughly on fifteen grams of smoke-dried, de-infested *C. gariepinus* contained in labeled transparent plastic containers. The control consisted of the same grams of smoke-dried *C. gariepinus* that had been treated with acetone only. Ten *D. maculatus* third-instar larvae were released over each treated fish flesh in the containers. The treated and control samples were left to air dry for two hours to enable solvent evaporation. The lids were punctured and covered with muslin material to provide aeration and prevent the introduced larvae from leaving the container or certain insects from entering. Three duplicates of each treatment and control were maintained in an incubator at 28°C and $65 \pm 5\%$ relative humidity. Mortality was noted every 24 hours for four days. The larva was declared dead when it did not react to an abdominal pin-punch, and the mean percentage of larval mortality was computed using the formula below:

Larval Mortality (%)

$$= \frac{\text{Number of Dead Larvae}}{\text{Number of Larvae Introduced}} \times 100$$

Adulticidal bioassay

The residual contact approach employed by Soe *et al.* (2020) evaluated the toxicity of essential oils of *S. aromaticum* and *T. vulgaris* against adult *D. maculatus*. Five milliliters (5 ml) of the essential oil stock solution was thoroughly sprayed over fifteen grams (15 g) of de-infested, seasoning- and treatment-free smoke-dried *C. gariepinus*, placed in eight labeled transparent plastic containers. The same grams of smoke-dried fish were also used to make a control

sprayed with 5 ml acetone. There were three duplicates of each treated and the control. The solvent was allowed to evaporate by air-drying the treated and the control samples for two hours. Five pairs of recently emerging adult *D. maculatus* (aged 0-24 hours) were released within each container. A cotton wool that had been soaked in water was inserted into each container to satisfy the oviposition requirement. The lids were perforated and equipped with a net to allow air to circulate, keep insects from escaping, and prevent outside insects from invading. The containers were then kept in a laboratory environment for five days. Upon not responding to a pin probe, the beetles were considered dead. Mortalities were recorded every 24 hours, and the proportion of deaths was calculated using the formula below:

Adult Mortality (%)

$$= \frac{\text{Number of dead Adults}}{\text{Number of Adults introduced}} \times 100$$

Oviposition and egg-hatching bioassay

Adesina *et al.* (2016) approach was adopted to investigate the impact of *Thymus vulgaris* and *Syzygium aromaticum* essential oils on the Oviposition and egg hatchability of *D. maculatus*. Two groups of experimental setup, each consisting of eight labeled transparent plastic containers, were organized. Fifteen grams (15 g) of disinfested smoke-dried *C. gariepinus* were treated with 5 ml concentrations (2.5%, 5.0%, 7.5%, and 10%) of the selected essential oils and placed in each container. The same weight of smoke-dried *C. gariepinus* treated without any treatment serves as a control. The treated and control containers were replicated three times.

In the first group of the experimental set up, ten pairs of newly emerged (0 -24 hours) *D. maculatus* adults were introduced into each container. A water-soaked cotton wool was placed to meet the water requirement for Oviposition. To allow aeration and prevent the escaping of the beetles and or intrusion of other insects from outside, the containers were covered with a perforated lid fitted with a net. Using a hand lens and soft entomological brush, the number of eggs laid was counted after 24, 48, and 72 hours. Following this, all adult beetles, dead and alive, were removed from the treated and control containers. The percentage reduction of eggs laid was computed using the formula applied by Adesina *et al.* (2016)

$$\text{Oviposition Deterrence (\%)} = \frac{\text{NEC} - \text{NET}}{\text{NEC}} \times 100$$

Where: NEC = Number of eggs laid in the control and NET = Number of eggs laid in the treated samples.

In the second setup, forty (40) recently deposited eggs were placed on the treated smoke-dried *C. gariepinus* in each container and maintained under laboratory conditions. The number of eggs hatched was counted at 48, 72, and 96 hours after exposure to the treated fish samples. Percentage egg hatchability was calculated using the formula applied by Adesina et al. (2016).

$$\text{Egg Hatchability (\%)} = \frac{\text{Number of Eggs Hatch}}{\text{Number of Eggs Introduced}} \times 100$$

Data analysis

A one-way Analysis of Variance (ANOVA) at P<0.05 was applied to the mortality data to identify any significant differences between *Thymus vulgaris* and *Syzygium aromaticum* essential oils. The means were separated using Tukey HSD. Probit Analysis was used to establish the median lethal concentration (LC₅₀) and lethal time (LT₅₀) of the essential oils based on

mortality data from all the oils using the SPPS 23 version.

RESULTS

Larvicidal effect of the tested essential oils against *Dermestes maculatus*

Results of larval mortalities of *D. maculatus* exposed to *C. gariepinus* treated with varying concentrations of the essential oils of *Syzygium aromaticum* (EOSA) and *Thymus vulgaris* were presented in Table 1. The result shows that, 24 hours after exposure, higher (80.00%) larval mortality was recorded in both 7.5 and 10.0% concentrations of EOSA, while lower (10% and 20%) mortalities were observed in the same concentrations of TEO. The result further expressed that, larval mortality increased to 90% and 100% on *C. gariepinus* treated with 7.5 and 10% concentrations of EOSA, 48 HAE. This significantly differs from the 40% and 50% mortality recorded in TEO at the same concentration and exposure hours. Moreover, the Table further revealed that, with an extension of the exposure hours to 96, the mortality increased to 80% and 93.33% in 7.5 and 10% concentrations of TEO, respectively.

Table 1: Larval Mortality of *D. maculatus* in varying concentrations of EOSA and TEO

Concentrations (%)	Essential Oils	Mean % larval Mortality ± S.E			
		24 hours	48 Hours	72 hours	96 hours
2.5	EOSA	23.33±0.67	40.00±0.00	50.00±0.00	60.00±0.00
	TEO	00.00±0.00	0.00±0.00	6.67±0.33	13.33±0.67
5.0	EOSA	40.00±0.00	70.00±0.00	83.33±0.67	83.33±0.67
	TEO	0.00±0.00	10.00±0.00	23.33±0.67	30.00±0.00
7.5	EOSA	80.00±0.00	90.00±0.00	100.00±0.00	100.00±0.00
	TEO	10.00±0.00	40.00±0.00	70.00±0.00	80.00±0.00
10	EOSA	80.00±0.00	100.00±0.00	100.00±0.00	100.00±0.00
	TEO	20.00±0.00	50.00±0.00	80.00±0.00	93.33±0.67
Control	0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

Adulticidal effect of the tested Essential Oils against *Dermestes maculatus*

Table 2 presents the mortality result of adults *D. maculatus* in contact with *C. gariepinus* treated with varying concentrations of EOSA and TEO. The Table shows that the mortality was concentration and period of exposure dependent. At a concentration of 2.5%, EOSA and TEO resulted in 50% and 10% mortalities, 24 HAE. Meanwhile, during the same Exposure period, 100% and 90% of the exposed beetles died in 10% concentrations of both essential oils, respectively. Further, 48 HAE, EOSA, and TEO recorded 100% mortalities at 7.5% and 10% concentrations.

Table 2: Adult Mortality of *D. maculatus* in varying concentrations of EOSA and TEO

Concentrations (%)	Essential Oils	Mean % Adult Mortality ± S.E			
		24 hours	48 Hours	72 hours	96 hours
2.5	EOSA	50.00±0.00	70.00±0.00	86.67±0.33	100.00±0.00
	TEO	10.00±0.00	30.00±0.00	40.00±0.33	70.00±0.00
5.0	EOSA	70.00±0.00	76.67±0.33	96.67±0.33	100.00±0.00
	TEO	20.00±0.00	50.00±0.00	60.33±0.33	83.33±0.67
7.5	EOSA	86.67±0.33	100.00±0.00	100.00±0.00	100.00±0.00
	TEO	80.00±0.00	100.00±0.00	100.00±0.00	100.00±0.00
10	EOSA	100.00±0.00	100.00±0.00	100.00±0.00	100.00±0.00
	TEO	90.00±0.00	100.00±0.00	100.00±0.00	100.00±0.00
Control	0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00

Median lethal concentration (LC₅₀) and lethal time (LT₅₀) of EOSA, TEO against *D. maculatus*
The essential oil concentration needed to kill 50% of adult *D. maculatus* (LC₅₀) varied significantly among the EOs tested. EOSA had the lowest LC₅₀ of 2.72, 1.80, and 0.99%, while TEO exhibited higher LC₅₀ of 5.71, 3.74, and 3.43% concentrations at 24, 48, and 72 hours, respectively. Similarly, the LC₅₀ of the EOs against larva of *D. maculatus* is lower (4.87, 3.14, and 2.60%) in EOSA and higher (13.93, 9.66 and 6.30% in TEO, at the same period (Table 3). The findings indicated that EOSA exhibited LT₅₀ values of 24.04, 17.15, 10.94, and 7.00 hours for achieving 50% mortality of adult *D. maculatus* at concentrations of 2.5%, 5.0%, 7.5%, and 10%, respectively. In contrast, at corresponding concentrations, TEO demonstrated LT₅₀ values of 73.43, 49.55, 13.55, and 9.63 hours. Similarly, for 50% mortality of *D. maculatus* larvae, EOSA required 69.04, 29.70, 13.10, and

7.00 at the specified concentrations, while TEO demanded 158.01, 131.24, 54.56, and 43.87 hours (Table 4)

Effect of the tested Essential Oils on Oviposition and Eggs Hatchability of *D. maculatus*

Table 5 shows the result of Oviposition and egg hatchability of *D. maculatus* exposed to varying concentrations of the two selected essential oils. From the table, 2.5% and 5.0% concentrations of both EOSA and TEO resulted in 82.40% - 92.41% oviposition deterrence. Meanwhile, total (100%) oviposition deterrence was recorded on smoke-dried *C. gariepinus* treated with 7.5 and 10% concentrations of both essential oils. Moreover, the table presented that few eggs could hatch in 2.5% and 5.0% concentrations of both essential oils. While egg hatchability was completely (100%) halted in 7.5% and 10% concentrations of these EOs.

Table 3: Median Lethal Concentration (LC₅₀) and Lethal Time (LT₅₀) of EOSA and TEO against Adult *D. maculatus*

Essential Oils	LC ₅₀ (%)			LT ₅₀ (Hours)			
	Exposure Period (Hours)			Concentrations (%)			
	24	48	72	2.5	5	7.5	10
EOSA	2.72	1.80	0.99	26.40	17.15	10.94	7.00
TEO	5.71	3.74	3.34	73.43	49.55	13.55	9.63

Table 4: Median Lethal Concentration (LC₅₀) and Lethal Time (LT₅₀) of EOSA and TEO against *D. maculatus* Larva

Essential Oils	LC ₅₀ (%)			LT ₅₀ (Hours)			
	Exposure Period (Hours)			Concentrations (%)			
	24	48	72	2.5	5	7.5	10
EOSA	4.87	3.14	2.60	69.04	29.70	13.10	13.50
TEO	13.93	9.66	6.30	158.01	131.24	54.56	43.87

KEY: EOSA= Essential oil of *S. aromaticum*, TEO= *T. vulgaris* Essential oil

Table 5: Effect of the tested Essential Oils on Oviposition and Eggs hatchability of *D. maculatus*

Concentrations (%)	Essential oils	NO. of eggs laid	Oviposition deterrence (%)	NO. of eggs Hatched	Egg Hatchability (%)
2.5	EOSA	9.67±0.33 ^a	89.96	2.67±0.33 ^a	6.68
	TEO	17.00±0.58 ^a	82.40	3.33±0.67 ^a	8.33
5.0	EOSA	7.33±0.67 ^a	92.41	2.00±0.00 ^a	5.00
	TEO	7.67±0.33 ^a	92.06	3.00±0.00 ^a	7.50
7.5	EOSA	0.00±0.00 ^a	100.00	0.00±0.00 ^a	0.00
	TEO	0.00±0.00 ^a	100.00	0.00±0.00 ^a	0.00
10.0	EOSA	0.00±0.00 ^a	100.00	0.00±0.00 ^a	0.00
	TEO	0.00±0.00 ^a	100.00	0.00±0.00 ^a	0.00
	Control	96.56±0.64 ^c	3.00	39.56±0.14 ^c	98.9

Means followed by the same letter(s) in the same column are not significantly different (P > 0.05) from each other using Turkey's HSD Test.

DISCUSSION

The findings of this study demonstrated the entomocidal potential of the essential oils of *S. aromaticum* and *T. vulgaris* against *D. maculatus*. Both essential oils were effective at all concentrations with low LC₅₀ and LT₅₀ against adults and larvae of the pest. The oils also deterred oviposition and inhibited egg hatching of the beetle. The adulticidal and larvicidal effect of the selected essential oils confirmed the findings of Wilane *et al.* (2014), who reported 70% and 90% mortality of 1st instar larvae of *D. maculatus* and *D. frischii* exposed to 0.064µl/ml and 0.512µl/ml concentrations of *Mentha spicata* using fumigation method 24 hours of exposure. The findings also support the report of Estekhdami *et al.* (2020) that 0.25 µl of thyme essential oil resulted in significant (56%) mortality of adult *Callosobruchus maculatus* and further increase in concentration of the oil to 30 µl resulted in 100% of the pest. In addition, the result also supported the findings of Jumbo *et al.* (2018), who reported

proportional delay in growth rate, oviposition deterrence, and significant impairment of offspring emergence of *Callosobruchus maculatus* exposed to LD₂₀ of the essential oils of *S. aromaticum* and *Cinnamomum zeylanicum*. Similarly, the findings are in agreement with the report of Lazarević *et al.* (2020) that the essential oil of *Thymus vulgaris* resulted in the reduction of adult survival, deterred oviposition and longevity of *Acanthoscelides obtectus* in a concentration-dependent manner using residual contact toxicity.

CONCLUSION

Based on the findings of this study, it could be inferred that *Thymus vulgaris* and *Syzygium aromaticum* essential oils have effective insecticidal properties against adult, larva, oviposition, and egg hatchability of *D. maculatus*. Lower LC₅₀ of EOSA revealed it is high efficiency against the pest. Therefore, the tested essential oils could play a vital role in the management and control of *D. maculatus* infesting smoke-dried *C. gariepinus*.

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