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Rapid repellent potential of essential oil from *Etlingera elatior* Jack RM Smith against rice weevils of *Sitophilus oryzae*: A sustainable approach for pest control in stored rice

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ABSTRACT

Aims: Insect infestation of *Sitophilus oryzae* is detrimental for food storage, which has haunted the small-scale farmers for years. Growing resistance of *S. oryzae* against phosphine, restricted use and banning of certain insecticides in some countries have made these problems worse, demanding researchers seek greener ways for pest control. The present study examined the repellent effect of essential oil (EO) from *Etlingera elatior* against *S. oryzae* at concentrations of 2-8 µL/30 cm^2.
Methodology and results: The EO was extracted using the hydro-distillation method and characterised by gas chromatography-mass spectrometry (GC-MS) technique. Repellent assay of EO was investigated against adult *S. oryzae* based on the filter paper impregnation method. Results revealed that *E. elatior* leaf and flower EO demonstrated strong repellent activity towards *S. oryzae* at 2 µL/30 cm^2 after 2 h of exposure ($p < 0.05$). Rapid removal of *S. oryzae* was observed after 1 h exposure to leaf EO at an increased concentration of 8 µL/30 cm^2.
Conclusion, significance and impact of study: The study indicates that *E. elatior* leaf and flower EOs have great potential to be developed as green insecticides for rapid removal of rice weevils in food storage applications. These findings provide important insights into pest control using green insecticides. Their rapid action and natural origin offer an environmentally sustainable approach to managing *S. oryzae* infestations in stored grain, benefiting small-scale farmers and promoting chemical-free pest control.

Keywords: Essential oil, *Etlingera elatior*, rapid repellent, rice weevils, pest control

INTRODUCTION

In the year 2050, the global population is expected to grow to 9.1 billion, causing a big challenge in meeting food demand and sustaining food security (Kumar and Kalita, 2017). Food insecurity and the issue of hunger are among the major concerns in several developing countries with large populations. Approximately 1.3 billion tons of food loss is reported globally every year during the postharvest stage, mainly due to poor storage infrastructure and insufficient technology in developing countries (Kumar and Kalita, 2017). However, food loss in developed countries is relatively low with the availability of efficient storage and handling systems as well as advanced technology.

Cereal grains such as rice, wheat, and maize are staple foods produced in significant amounts in most of the developing countries. These stored grains are susceptible to insect pest attack, particularly in warmer regions, addressing the importance of storage components in the food supply chain (Doherty *et al.*, 2023). Previous studies had estimated that insect infestation during storage is one of the biotic factors contributing to maximum losses in grains between 30-40% (Kumar and Kalita, 2017; Doherty *et al.*, 2023). The rice weevil of *Sitophilus oryzae* is regarded as a destructive primary pest by feeding on grains, not just as adults but also in larval form (Doherty *et al.*, 2023). Adult females of *S. oryzae* are capable of laying eggs up to 400 in their lifetime by making holes in the kernel for egg oviposition. Furthermore, each rice weevil can consume approximately 10-25 g of grains with an average lifespan of between 4-5 months, which is more than adequate to reduce the rice value (Doherty *et al.*, 2023).

At present, pest management and control of stored grains primarily rely on phosphine (hydrogen phosphide,

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PH_3) fumigation in many countries due to its ability to quickly rid of insect pests. The low cost of operation, ease of application, international acceptance as a residual-free treatment, as well as effectiveness against a broad pest spectrum, give added value to phosphine and becomes as popular choice by industry. Over-reliance on phosphine is even greater when the use of methyl bromide and aluminium phosphide as fumigant have been restricted or banned in certain countries due to their negative impact on the environment by capability on depleting the ozone layer (Mehta and Kumar, 2020; Nayak *et al*., 2020). The widespread use of phosphine fumigant has raised concerns over pesticide resistance, with the absence of a comparable substitute fumigant. Several studies have reported that the frequency and strength of phosphine resistance have developed in some insect pest species, including *S. oryzae* (Holloway *et al.*, 2016; Nayak *et al*., 2020).

A green approach in developing alternatives to common insecticides is growing tremendously with the availability of encouraging reports against a broad spectrum of stored grain pests. Natural insecticide potential as a stored grain protector has been highlighted from several essential oils (EOs) extracts, and their efficacy was clearly demonstrated. The volatility of EOs in nature gives an added value for their potential apart from their complex chemical components to serve as grain protectants and management of stored grain pests. Cinnamon bark and cloves leaf oil showed strong repellency (90-92%) towards stored maize weevils *Sitophilus zeamais* at the concentration of 10-15% (v/v) after one hour of treatment (Eeisah *et al*., 2022). The EO of *Cinnamomum zeylanicum* contains the highest concentration of (*E*)-cinnamaldehyde (71.50%), which is known to demonstrate insecticidal activity. Other constituents are linalool (7.00%), β-caryophyllene (6.40%), eucalyptol (5.40 %), and eugenol (4.60%). In contrast with clover leaf oil, it is dominated by eugenol (76.8%) followed by other constituents such as β-caryophyllene (17.40%), α-humulene (2.1%), and eugenyl acetate (1.2%). Eugenol is among a broad range of common metabolites of various EOs, including α-pinene, cineole, limonene, terpinolene, citronellol, citronellal, camphor, and thymol that exhibit insect repellent activity (Geetha and Roy, 2014).

Etlingera elatior is a fast-growing plant from the family Zingiberaceae and locally known as Kantan in Malaysia. The use of the flower part is limited as an ingredient for local food preparation, meanwhile the leaf part is only traditionally used as a wound cleaner, body odour remover, and dry skin moisturizer (Shahid Ud-daula and Basher, 2019). Usually, the leaf part of this species is considered unwanted material and is disposed of by local farmers. This species is substantially rich in EO and instantly emits a pleasant smell if the leaf and flower parts are crushed. Its aromatic properties might have potential to repel insect pests of grains in storage warehouses and potentially used as one of the green approaches to reducing food loss during storage, thus increasing the availability of rice. This technique has long been used traditionally by small-scale farmers in the Western Highlands of Cameroon for grain protection by using leaves of wormseed (*Chenopodium ambrosioides*) (Tapondjou *et al*., 2002). However, to our knowledge, no reports are available on the use of *E. elatior* as a repellent agent commercially or traditionally against insect pests of *S. oryzae* for stored product protection.

Therefore, in response to those issues, this study was carried out to evaluate the potential of EOs from *E. elatior* leaf and flower parts against the adult of rice weevil *S. oryzae* for rapid and effective removal of the insect pest from stored products based on the filter paper impregnation assay. The chemical compositions of both EOs were characterised based on the gas chromatography-mass spectrometry (GCMS) analysis.

MATERIALS AND METHODS

Sample collection and preparation

A sample of *E. elatior* was collected from Samarahan Division, Sarawak, Malaysia. The different parts of the plant were separated into leaf and flower. The plant was then cleaned with water and cut into small pieces prior to essential oil extraction. Only a fresh sample of the plant was used for the extraction to maximise the amount of oil yield and to avoid possible loss of any volatile components.

Extraction of essential oil (EO)

Essential oil extraction was performed by using the hydro-distillation method as described by Sim *et al.* (2013) with slight modifications. About 300 g of sample was added into 2 L of round bottom flask containing 1.5 L of distilled water and anti-bumping granules. The flask was then connected to the condenser through the Clevenger apparatus. The mixture was heated to boiling and subjected to the hydro-distillation process for six hours. Essential oil was collected using the Clevenger apparatus. The minor amount of water in essential oil can be removed by adding anhydrous magnesium sulfate. Magnesium sulfate has been proven as more effective drying agent compared to anhydrous sodium sulfate for water removal (Schenck *et al*., 2002). The essential oil was kept in the 2 mL amber glass vial and stored in the refrigerator at 4 °C before analysis.

Repellency test

The repellent activity of *E. elatior* was evaluated towards rice weevil, *S. oryzae*, according to the method described by Khani *et al.* (2017). This test was conducted in a glass Petri dish containing filter paper. The test insects were cultured in uncooked rice at 27 °C under dark conditions for a few days (Jayakumar *et al*., 2017). The sample was prepared at different concentrations by diluting in acetone (2, 4, and 8 $\mu L/30\ cm^2$). Exactly 1 mL of the sample was applied to half-cut of a filter paper by using a micropipette, whereas the other half of the filter paper was treated with

1 mL of acetone. Acetone served as a control. Both filter papers were air-dried for several minutes to remove the solvent before linking them with tape. Ten adults of rice weevil were released at the centre of the filter paper. The number of rice weevils settled on the treated and control areas was recorded every hour up to five hours of treatment. Three replicates were prepared for each treatment. The number of insects observed at the control area (NC) and treated area (NT) was used to calculate the percent repellency (PR) and index of repellency (IR).

Percent Repellency (PR) was calculated based on the given formula:

$$\text{Percent Repellency (\%)} = \left[\frac{NC\text{-}NT}{NC+NT}\right] x\ 100$$

Index of repellency (IR) was calculated using the following formula:

$$\text{Index of Repellency (\%)} = \left[\frac{2NT}{NT+NC}\right] x\ 100$$

IR values were categorised as repellent (IR < 1), neutral (IR=1), and attractant (IR > 1) (Gitahi *et al*., 2021). The class of repellents can be categorised based on percent repellency as shown in Table 1 (Murugesan *et al*., 2021). Data was analysed using one-way ANOVA and the Tukey test. Mean values of all treatments were given as mean ± SE, and the differences between treatments were considered significant if $p < 0.05$.

Table 1: Class of repellent.

Class	Percent repellency (%)
0	0-0.1
I	0.1-20
II	20.1-40
III	40.1-60
IV	60.1-80
V	80.1-100

Gas chromatography–mass spectrometry (GCMS) analysis

Identification of chemical components in the essential oil was determined using GCMS Model SHIMADZU Nexis GC-2030, fused with a silica capillary BPX-5 column (30.0 m x 0.25 mm internal diameter; 0.25 µm film thickness). Temperatures for the injector and detector were set at 280 °C and 300 °C, respectively. The initial temperature of the GC programme was set at 50 °C for 1 min and then increased to 280 °C at a rate of 5 °C/min with holding times of 10 min. The sample was prepared by diluting 1 mg of the sample into 1 µL of hexane. About 1 µL of sample was injected to GCMS via splitless injection mode. The sample was analysed for 60 min.

Kovats indices

A series of *n*-alkane standards (C_9-C_{30}) has been analysed on GCMS. The temperature programme used was identical to the sample. The retention times of each standard peak have been recorded for the calculation of Kovat Indices (KI) (Figure 1).

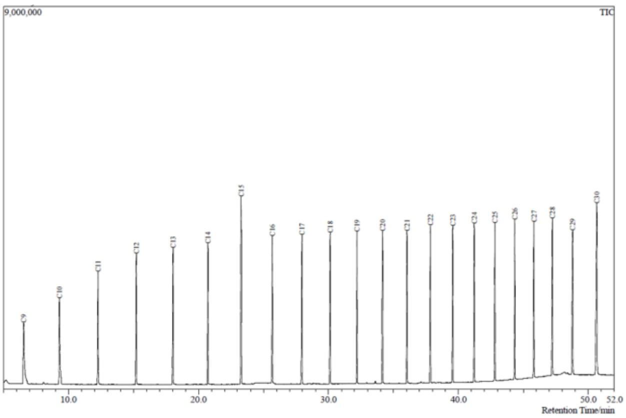

Figure 1: GCMS Chromatogram of *n*-alkane standards (C_9-C_{30}).

The KI value of samples for the temperature programming measurement was calculated based on the following formula:

$$I_x = 100n + \left[\frac{100\ (t_x - t_n)}{t_{n+1} - t_n}\right]$$

Where n is the number of carbon, t_n and t_{n+1} are net retention times of the reference *n*-alkane hydrocarbon eluting before and after compound X, and t_x is the retention time of compound X (Babushok *et al*., 2011).

The chemical compositions of essential oil were identified by comparing their Kovat's retention indices with literature values and their mass spectral data with those from the National Institute of Standards and Technology mass spectral database (Adams, 2007; Babushok *et al*., 2011). Only 0-2 differences between calculated and reported KI were acceptable for compound identification within a range of KI between 850 and 1900. For very early and late eluting compounds with KI less than 850 and more than 1900, respectively, the KI differences up to 5 units were acceptable for compound identification (Lucero *et al*., 2009).

Percentage of individual chemical components

The relative percentage of individual chemical components was determined based on the relative area method on GCMS chromatogram according to Chamorro *et al*. (2012). The percentage was calculated using the following equation:

$$\text{Percentage relative of the component (\%)} = \frac{\text{Component area}}{\text{Total area}}$$

RESULTS AND DISCUSSION

In this study, the EO from the leaf and flower parts of *E. elatior* was tested against rice weevil of *S. oryzae* at the concentrations of between 2-8 µL/30 cm^2 for up to 5 h. The findings showed EO of *E. elatior* leaf and flower strongly repelled *S. oryzae* between 2-8 µL/30 cm^2 at and above 80% repellency after 2 h of treatment. The 2 h repellency effect was significantly different from 1 h of exposure ($p < 0.05$; Table 2), suggesting the maximum duration of 2 h of exposure would be more than sufficient to get rid of most of the rice weevils from stored products. At this point, referring to the percentage of repellency, both leaf and flower EO can be categorised as a class V repellent (Table 2). Even from the first hour of treatment, the percent repellency has reached 60.00 and 66.67% for flower and leaf EO, respectively, at a minimum concentration tested (2 µL/30 cm^2). After 1 hour exposure of leaf and flower EO to rice weevils, doses of 2, 4, and 8 µL/30 cm^2 were comparable to each other ($p > 0.05$; Table 2).

Rapid removal of rice weevils during the first two hours indicated that both leaf and flower parts of EO have great potential to be applied for quick and effective removal of weevils from grain products. Exactly 100% repellency was achieved after 2 h of treatment for both plant parts of EO at 4 µL/30 cm^2 (leaf) and 8 µL/30 cm^2 (flower). Both EOs were comparable ($p > 0.05$; Table 2) in manifesting repellency activity. Within five hours of the experimental period, the repellency effect of both EOs towards rice weevils ranged between 66.67-100% (leaf EO) and 60.00-100% (flower EO). The repellent potential of both EOs can be classified to the highest-class V between 2-8 µL/30 cm^2 at all tested concentrations after five hours. Both EOs manifested repellency effects, which were significantly different from the negative control ($p < 0.05$). Additionally, the index of repellency (IR) of both EOs against rice weevils was lower than 1, and thus further classified those EOs as insect repellents, non-insect attractants (Figures 2 and 3) (Gitahi *et al*., 2021).

This present finding is consistent with the recent reported research for flower EO of *E. elatior* that also demonstrated insecticidal activity against different species of insect pest, maize weevil, *S. zeamais* (De Lira *et al*., 2023). This insect is capable of causing 15-40% loss of corn kernels during storage or in the field, suggesting the potential of *E. elatior* EO as a natural insecticide for this pest.

From the bar graph, ascending trends were observed in the repellency percentage of both EOs at all tested concentrations between 1-2 h of exposure. Both EOs demonstrated strong (high) weevil-repelling potential from 2 h of exposure until the final hours of the experiment (Figures 2 and 3). The flat trend with exposure time beginning at 2 h suggests that the rice weevils are very sensitive to the smells attributed to both EOs of *E. elatior,* even at low concentrations. This observation is similar to other studies indicating repellent activity is independent of exposure time, adding more support for the use of EO as a rapid method for the management and control of rice weevils during storage (Gitahi *et al*., 2021). In addition, no weevil's death was observed at all concentrations of tested EO, suggesting the chemical constituents of both EO did not induce any poisoning symptoms (Gaire *et al*., 2019). Zero mortality of insects from this approach would facilitate the management and packaging of stored products, as it could skip the process for dead weevils' removal, resulting in good acceptance by consumers.

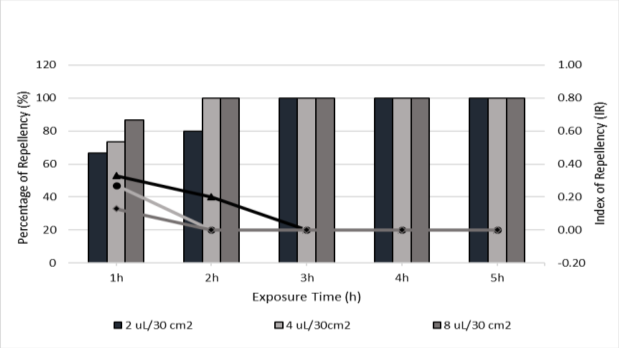

Figure 2: Percent repellency (%) of *E. elatior* leaf EO against *S. oryzae*.

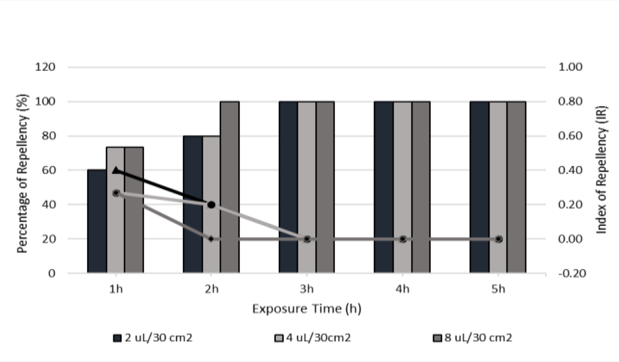

Figure 3: Percent repellency (%) of *E. elatior* flower EO against *S. oryzae.*

The chemical compositions of EOs from *E. elatior* have been identified and quantified based on GCMS analysis (Table 3, Figures 4 and 5). A total of thirty-six chemical components were identified from the leaf and flower parts of EO. Based on the analysis, the leaf EO was shown to be rich in hexyl benzoate (14.82%), α-cadinene (9.63%), salvial-4(14)-en-1-one (8.9%), β-cedrene (6.63%), and prenyl hexanoate (5.12%). The major components of the flower EO were (*Z*)-ligustilide (13.25%), oroselone (10.01%), tetradecanal (9.27%), 3*α*-14,15-dihydromanool oxide (7.71%), and α-copaen-11-ol (5.72%). Several similar compounds that are present in both EOs were citronellic acid (0.13-1.46%), β-cedrene

Table 2: Repellent activity of leaf and flower EO from *E. elatior* against rice weevil of *S. oryzae.*

Plant part	Concentrations (µL/30 cm^2)	Repellency (%)				
		1 hour	2 hours	3 hours	4 hours	5 hours
Leaf	2	66.67 ± 6.67 (0.33)	80.00 ± 0.00 (0.20)	100.00 ± 0.00 (0.00)	100.00 ± 0.00 (0.00)	100.00 ± 0.00 (0.00)
	4	73.33 ± 6.67 (0.27)	100.00 ± 0.00 (0.00)	100.00 ± 0.00 (0.00)	100.00 ± 0.00 (0.00)	100.00 ± 0.00 (0.00)
	8	86.67 ± 6.67 (0.13)	100.00 ± 0.00 (0.00)	100.00 ± 0.00 (0.00)	100.00 ± 0.00 (0.00)	100.00 ± 0.00 (0.00)
Flower	2	60.00 ± 0.00 (0.40)	80.00 ± 0.00 (0.20)	100.00 ± 0.00 (0.00)	100.00 ± 0.00 (0.00)	100.00 ± 0.00 (0.00)
	4	73.33 ± 6.67 (0.27)	80.00 ± 0.00 (0.20)	100.00 ± 0.00 (0.00)	100.00 ± 0.00 (0.00)	100.00 ± 0.00 (0.00)
	8	73.33 ± 6.67 (0.27)	100.00 ± 0.00 (0.00)	100.00 ± 0.00 (0.00)	100.00 ± 0.00 (0.00)	100.00 ± 0.00 (0.00)

(0.1-6.63%), 1-*epi*-cubenol (0.74-1.13%), β-bisabolenal (1.24-1.46%), and hexadecanal (0.17-1.29%).

The strong repellency activity demonstrated by leaf and flower EO is most likely attributed to the presence of several insecticidal agents such as β-cedrene and citronellic acid (Figure 6). β-cedrene is a sesquiterpene hydrocarbon and also one of the major components of the herbaceous plant of *Bidens frondosa,* which is commonly known as beggar-ticks (Li *et al*., 2017). This component has been reported to exhibit acute toxicity against the grain storage insect of *Liposcelis bostrychopila* at LC_{50} value of 458.79 µg/cm^2 (Li *et al*., 2017). The study highlighted the potential of EO containing this constituent for further development as possible natural insecticides or fumigants in insect infestation control strategies.

On top of that, the test conducted by González-Morales *et al*. (2021) revealed that a novel EO formulation containing the terpenoid of citronellic acid as one of the main compositions displayed insect repellent activity by eliciting avoidance response against bed bugs of *Cimex lectularius*. Citronellic acid was reported to exhibit neuroinhibitory effects based on a neurophysiology study carried out against *C. lectularius* at concentration ranged between 0.5–5 mM (Gaire *et al*., 2019; González-Morales *et al*., 2021). In the present study, a slightly higher percentage of citronellic acid was observed in the leaf oil of *E. elatior* than in the flower oil, contributing to complete repellency (100%) of rice weevils at 4 µL/30 cm^2 after 2 hours of treatment, corroborating the findings from Gaire *et al.* (2019), claiming that citronellic acid was a dose-dependent substance. This component was reported to increase the nervous activity of the insect at high concentrations and more importantly, has low evaporation rates during a 24-h period (Gaire *et al*., 2019).

In addition, the leaf oil of *E. elatior* possesses a sweet, spicy aroma due to its major constituent of *α*-cadinene (Paranagama and Gunasekera, 2011). The presence of tasmanone in the leaf oil of *E. elatior* might add to the rapid and strong repellent activity against *S. oryzae*. This component also appeared in the leaf EO of *Eucalyptus subarea* and *E. lateritic,* demonstrating insecticidal activity by targeting the insects' octopamine receptor (Matos *et al*., 2015; Senadeera, 2017). Identification of further known insecticidal component, γ-terpinene, in the leaf oil of *E. elatior* lent support to its insect repellency potential. γ-terpinene was reported to demonstrate a significant insecticidal activity towards the cotton leafworm, *Spodoptera littoralis* (LC_{50}=23.94 g/L) and the bean aphid, *Aphis fabae* (18.03 g/L) (Abbassy *et al*., 2009). Those insects are considered as destructive insect pests for a variety of crops. In addition to a pronounced insecticidal activity, this component was reported to be able to enhance the insecticidal activity of synthetic insecticides of profenofos and methomyl by having a synergistic effect of two to three-fold against both insects (Abbassy *et al*., 2009).

Thus, the presence of those components possessing insect-repelling effect based on encouraging reports from existing studies adds more support for the rapid repellent activity against *S. oryzae* presented in this study. Terpenoids are known to possess antifeedant properties, deterring insects from feeding on treated grains and thus mitigating damage caused by *S. oryzae* larvae within stored crops (Huang *et al*., 2022). Moreover, terpenoids are considered safer alternatives to existing insecticides due to their natural origins and lower toxicity to non-target organisms and humans. Mechanistically, they interfere with insects' neurotransmitters, enzymes, and other physiological processes, influencing their behaviour and survival. However, their effectiveness as insect repellents can vary based on factors such as concentration,

Table 3: Chemical composition of essential oil from several parts of *E. elatior.*

Chemical compounds	Retention time (min)	Kovats Indices		Percentage (%)	
		Exp. KI	Ref. KI	Leaves	Flower
α-Phellandrene	9.434	1004.2	1004.1	1.13	-
γ-Terpinene	11.037	1058.6	1059.7	4.46	-
Dihydromyrcenol	11.361	1069.5	1069.0	1.47	-
Methyl octanoate	12.929	1122.6	1123.0	2.47	-
Prenyl hexanoate	17.799	1291.6	1292.0	5.12	-
Citronellic acid	18.367	1312.3	1312.0	1.46	0.13
β-Cedrene	21.200	1419.9	1419.0	6.63	0.10
Nootkatene	23.692	1516.9	1517.0	1.51	-
α-Cadinene	24.176	1537.2	1537.0	9.63	-
α-Copaen-11-ol	24.213	1538.7	1539.0	-	5.72
6-Methylcoumarin	24.552	1552.9	1553.0	3.68	-
n-Hexyl benzoate	25.188	1579.5	1579.0	14.82	-
Salvial-4(14)-en-1-one	25.524	1593.6	1593.4	8.90	-
Tetradecanal	25.925	1610.8	1611.0	-	9.27
1,10-Diepicubenol	25.964	1612.5	1612.3	4.41	-
10-*epi*-*γ*-Eudesmol	26.105	1618.7	1618.7	-	1.24
(*Z*)-8-hydroxylinalool	26.115	1619.1	1619.0	1.43	-
1-*epi*-Cubenol	26.303	1627.1	1627.0	0.74	1.13
Cubenol	26.699	1644.7	1645.0	2.57	-
2-Pentadecanone	27.948	1699.4	1699.1	2.21	-
Tasmanone	28.526	1726.0	1726.0	0.23	-
Chamazulene	28.599	1729.8	1730.0	0.44	-
(*Z*)-Ligustilide	28.712	1734.6	1734.0	-	13.25
(2*E*,6*E*)-Farnesol	28.904	1743.4	1743.5	1.46	-
γ-Costol	28.945	1745.3	1745.0	0.58	-
8*α*-11-Elemodiol	28.962	1746.1	1746.0	-	3.24
α-Amylcinnamyl acetate	29.178	1756.0	1756.0	-	1.55
β-Bisabolenal	29.438	1768.0	1768.0	1.24	1.46
Hexadecanal	30.479	1816.6	1816.5	0.17	1.29
Isopropyl tetradecanoate	30.729	1828.9	1828.0	-	3.78
(2*E*,6*E*)-Farnesyl acetate	31.065	1845.2	1845.0	-	1.18
1,10 *β*-epoxy-6-oxofuranoeremophilane	31.135	1848.6	1848.0	1.07	-
Cyclohexadecanolide	32.842	1932.8	1933.0	-	4.59
Methyl octadecanoate	36.432	2123.1	2124.0	-	0.33
Oroselone	36.980	2152.1	2152.0	-	10.01
3*α*-14,15-dihydromanool oxide	40.138	2339.0	2337.0	-	7.71

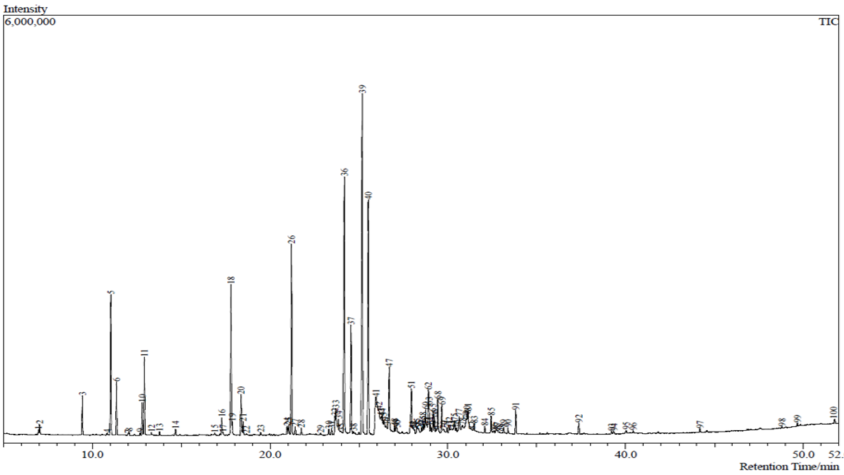

Figure 4: GCMS chromatogram of *E. elatior* leaf EO.

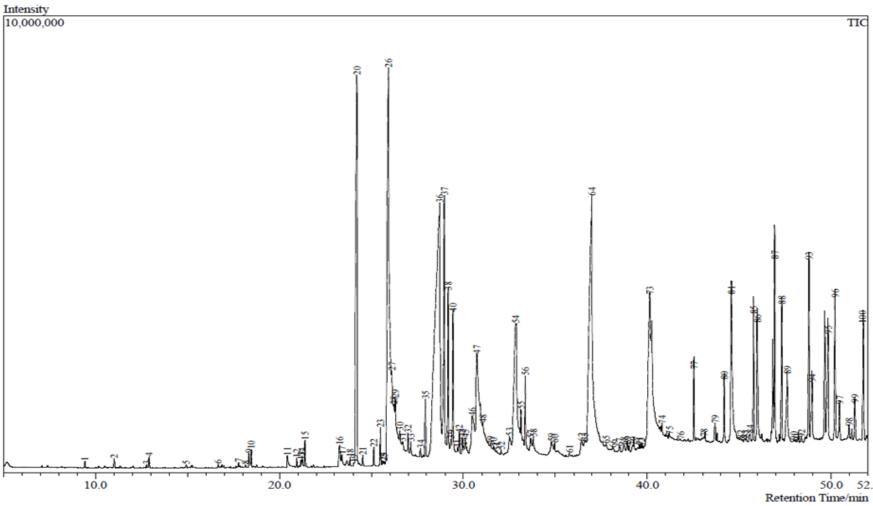

Figure 5: GCMS Chromatogram of *E. elatior* flower EO.

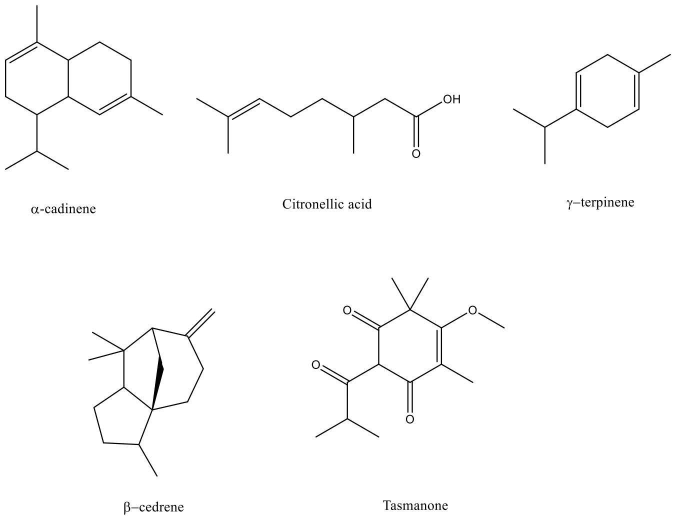

Figure 6: Chemical structures of compounds from *E. elatior* EO possessed insect-repelling effects.

formulation, application method, and environmental conditions (Stejskal *et al*., 2021).

CONCLUSION

Our present findings add to existing knowledge on the potential of plant-based EO, particularly the leaf and flower EO of *E. elatior* as alternative substitutes to conventional insect-repelling agents. With the strong repellency activity exhibited by both leaf and flower EOs against *S. oryzae*, it is hoped that this study would provide some insight into addressing the issue of insect resistance in stored product protection. In addition, the rapid repelling effect of both EOs after 2 hours of exposure provides a practical option in reducing the spread of insect pests from stored products, particularly for instant management and control of *S. oryzae*. In the future, it is recommended to perform more studies related to the microencapsulated technique to prolong the EO repellency effect, thus extending their applicability in insect pest control that is not just limited to small-scale farmers.

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