Identification of Volatile Compounds and Insecticidal Activity of Essential Oils from *Origanum compactum* Benth. and *Rosmarinus officinalis* L. against *Callosobruchus maculatus* (Fab.)

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This work was undertaken to investigate the volatile compounds and insecticidal activity of essential oils (EOs) from *Origanum compactum* Benth. and *Rosmarinus officinalis* L. against the crop pest *Callosobruchus maculatus* (Fab.). Essential oils of *Origanum compactum* (EOC) and *Rosmarinus officinalis* L. (EOR) were extracted by use of hydrodistillation, and their volatile compounds were profiled by gas chromatography-mass spectrometry (GC-MS). The insecticidal activity of extracted EOC and EOR was evaluated against *C. maculatus*. GC-MS analysis revealed that carvacrol (70.88%) and 1,8-cineole (62.35%) were the major constituents of EOC and EOR, respectively. EOC exhibited a potent insecticidal activity with calculated LC50 values of 6.77 and 3.57 μL/L air, 24 and 48 h posttreatment, respectively. Comparable LC50 values were obtained for EOR recording 6.25 and 3.82 μL/L, 48 h posttreatment. The effects of fumigation by the tested EOs on fertility (egg hatching) and the emergence of adult *C. maculatus* were also investigated. Notably, EOC completely abolished egg fertility judged by the abrogation of emergence of adults, regardless of the tested dose. By contrast, EOR completely inhibited the fertility and the emergence of *C. maculatus* adults at the dose of 16 μL/10 g. The outcome of the present study highlights the utility of the EOs from *O. compactum* Benth. and *R. officinalis* L. as natural sources of effective and ecofriendly pest-control agents.

1. Introduction

Nowadays, many environmental challenges influence agriculture worldwide. In addition to poor soil quality and cultivation techniques, there are problems related to insect pests. Pests attacking stored food legumes result in significant damage and loss of both quality and quantity. While losses attributed to pests are estimated to be around 40% in Africa, they do not exceed 3% in developed countries [1].
Despite the magnitude of losses caused by insect pests, a limited number of studies have shed light on pests in Africa. In Morocco, *C. maculatus* causes serious damage to stored legume foods, where *C. maculatus* larvae develop and feed on the cotyledons of legumes, particularly when no measures are taken. Pests are capable of destroying a crop within 4-5 months according to the Food and Agriculture Organization (FAO). Losses due to insect pests reached 35% of global agricultural production [2].

*C. maculatus* can be considered as one of the most growing challenges throughout the tropical and subtropical regions. It is a worry pest of several pulses including *Vigna unguiculata*, *Cicer arietinum*, *Glycine max*, and *Phaseolus vulgaris*. These pulses are an important food source for millions of people based in tropical and subtropical areas. Cowpea seeds are most attacked pulses by *C. maculatus* and cause maximum damage, which could reach 2–5 kg seeds within 45–90 days when stored under optimal temperature (30 ± 10°C) and moisture conditions (75 ± 3%) [3].

Insecticides represent one of the most used control methods to manage insect pests. However, the resistance of insects to modern insecticides is still a great challenge facing chemical insecticides. In addition, these chemicals can possess risks to consumers and cause even harmful effects in the long term [4]. The plant kingdom represents a potentially effective alternative as a source of natural pest-control agents. Aromatic plants contain essential oils (EOs) that possess natural insecticidal activities. Hence, the insect-controlling potential of plant-derived EOs has been widely tested against pests attacking stored grains through their insecticidal potencies [5–8]. In this context, several researchers have reported lethal effects of EOs against plant and human pests [9, 10].

This work aimed to investigate the profile of volatile compounds and fumigant activity of EOs from *Origanum compactum* Benth. and *Rosmarinus officinalis* L. against *Callosobruchus maculatus* (Fab).

### 2. Materials and Methods

#### 2.1. Insect Breeding

*C. maculatus* was obtained from a local warehouse and subsequently bred in glass jars with 500 g of *Vigna unguiculata* seeds. Jars were maintained at a temperature of 27 ± 1°C, relative humidity of 70 ± 5%, and a photoperiod of 14 h (light)/10 h (dark).

#### 2.2. Plant Material

*O. compactum* was harvested from the region of Taounate from Morocco, whereas *R. officinalis* was harvested from the region of Taza, Morocco. Thereafter, the studied plants were identified by a botanist before being deposited at the Herbarium of Sidi Mohamed Ben Abdellah University. Next, the leaves were cleaned and dried in the shade at room temperature for 15 days.

#### 2.3. Extraction of Essential Oils

One hundred grams of *O. compactum* and *R. officinalis* leaves were soaked in 750 mL of distilled water before being extracted at 100°C by use of a Clevenger apparatus for 4 h. The obtained EOs were dehydrated with anhydrous sodium sulfate before being stored in a refrigerator at 4°C until further use [11].

#### 2.4. Gas Chromatography-Mass Spectrometry Analysis

The volatile compounds of the studied plants were determined by using GC-MS. Briefly, 0.1 μL of the sample was injected for analysis using a gas chromatograph coupled to a mass spectrophotometer (Agilent Technologies 5973 with an Agilent 19091S-433 HP-5MS column, 30 m long, 0.25 mm inner diameter, and 0.25 μm film thickness of the stationary phase) in positive mode. Helium was used as the carrier gas, with a typical pressure range (psi) of 0.9 mL/sec. The oven temperature program was set between 60 and 300°C for 10 min and then held at 300°C for 20 min. The detector temperature was set at 250°C, whilst the injector temperature was set at 260°C. Identification of compounds was performed by comparing retention times with standards of the database [12].

#### 2.5. Insecticidal Activity Test

The insecticidal activity test was carried out to evaluate the activity of the essential oils in a vapor phase as reported in earlier work [11]. To achieve this goal, Whatman paper discs (3 × 3 cm) impregnated with different concentrations of the tested EOs (4, 8, 12, 16, and 20 μL/L of air) were attached to the inner surface of the stoppers of each jar to avoid their direct contact with the insects. Next, 10 g of cowpea seed and five pairs of *C. maculatus* aged from 0 to 48 h were separately introduced into each jar. Total mortality of insect individuals by each dose was recorded daily for 5 days. Egg-laying capacity of the females of *C. maculatus* was calculated by use of a magnifying binocular. Jars were subsequently maintained at a temperature of 27 ± 1°C, relative humidity of 70 ± 5%, and a photoperiod of 14 h (light)/10 h (dark) until the emergence phase of adults.

#### 2.6. Statistical Analysis

The results were expressed as means (±SD). A two-way analysis of variance (ANOVA) was used to analyze the effect of varying doses and exposure periods on mortality and fecundity of females and the emergence of adult *C. maculatus*. Significant differences between treatments were calculated by using Tukey’s multiple range tests (*p* < 0.05). The lethal concentration LC50, LC90, chi-square, and 95% confidence intervals for each regression coefficient were calculated by use of probit analysis [13]. A significant difference was considered when *p* < 0.05.

### 3. Results and Discussion

#### 3.1. Analysis of Essential Oil Components

The results of the volatile compounds profile of EOC are given in Figure 1 and Table 1. In this sense, the analysis showed the presence of 12 major compounds representing 99.89% of the total oil composition. EOC was majorly composed of carvacrol (70.88%) followed by caryophyllene oxide (7.97%), α-cymene (5.68%), and thymol (5.16%). Concerning the
volatile compounds profile of EOR, GC-MS analysis revealed the presence of nine major compounds representing 99.89% of the total oil composition. EOR was mainly composed of 1,8-cineole (62.35%), camphor (23.14%), borneol (5.51%), and camphene (4.10%) (Figure 2 and Table 2).

### Table 1: Volatile compounds of EOC identified by GC-MS.

| Peak | RT    | Compound       | Chemical formula | Chemical class | RI    | Cal | Lit | Area (%) |
|------|-------|----------------|------------------|----------------|-------|-----|-----|----------|
| 1    | 4.94  | o-Cymene       | C10H14            | MO.H           | 1024  | 1024 | 5.68 |
| 2    | 5.67  | Terpinolene    | C10H16            | MO.H           | 1280  | 1282 | 0.93 |
| 3    | 6.44  | β-Terpineol    | C10H18O           | MO.O           | 1143  | 1144 | 0.53 |
| 4    | 6.55  | α-Terpineol    | C10H20O           | MO.O           | 1163  | 1164 | 4.58 |
| 5    | 7.00  | Piperitenone    | C10H14O           | MO.O           | 1341  | 1343 | 1.34 |
| 6    | 7.31  | Carvacrol      | C10H14O           | MO.O           | 1297  | 1299 | 70.88 |
| 7    | 7.40  | Thymol         | C10H14O           | MO.O           | 1290  | 1290 | 5.16 |
| 8    | 8.37  | Trans-Caryophyllene | C15H24        | ST.H           | 1594  | 1598 | 0.60 |
| 9    | 9.47  | Caryophyllene oxide | C15H24O        | ST.O           | 1986  | 1986 | 7.97 |
| 10   | 9.79  | Adamantanone   | C10H14O           | MO.O           | 1309  | 1311 | 0.86 |
| 11   | 9.90  | Naphthalene    | C11H10O           | O              | 1445  | 1447 | 0.65 |
| 12   | 9.98  | Camphene       | C10H16            | MO.H           | 1065  | 1028 | 0.81 |

Monoterpene hydrate (MO.H) 7.42
Monoterpene oxygenated (MO.O) 83.25
Sesquiterpenes hydrate (ST.H) 0.60
Sesquiterpenes oxygenated (ST.O) 7.97
Others (O) 0.65
Total identified (%) 99.89

RI, retention indices; Lit, literature; Cal, calculate; RT, retention time in minutes.

### 3.2. Insecticidal Activity Test

#### 3.2.1. Effect on Adult Mortality

Insecticidal activity of EOC and EOR against the adults of *C. maculatus* is given in Table 3. Statistical analysis revealed that the observed insecticidal effect is both time and dose-dependent. EOC exhibited significantly...
high mortality rate as a function of increasing concentrations 
\( (F = 156.60; \text{df} = 5, 48; \ p < 0.0001) \) and exposure time 
\( (F = 102.25; \text{df} = 2, 48; \ p < 0.0001) \), whereas EOR showed 
significant variation in \( C. \) maculatus mortalities at different 
concentrations \( (F = 348.49; \text{df} = 5, 36; \ p < 0.0001) \) and was 
highly significant with increasing exposure time \( (F = 229.8; \text{df} = 2, 36; \ p < 0.0001) \). The \( LC_{50} \) value for EOC was 6.77 and 
3.57 \( \mu \text{L/L} \) air 24 h and 48 h postexposure, respectively; whereas, 
the \( LC_{90} \) ranged from 35.90 to 15.17 \( \mu \text{L/L} \), respectively. The \( LC_{50} \) 
value for EOR ranged from 6.25 to 3.82 \( \mu \text{L/L} \) 48-hour post-
exposure, whereas the \( LC_{90} \) ranged from 20.70 to 12.40 \( \mu \text{L/L} \) 
(Table 3).

![Figure 2: Chromatographic profile of EOR volatile compounds identified by GC-MS.](image)

**Table 2: Volatile compounds of EOR identified by GC-MS.**

| Peak | RT  | Compound       | Chemical formula | Chemical class | RI  | Area (%) |
|------|-----|----------------|------------------|----------------|-----|----------|
| 1    | 4.16| Camphene       | C10H16           | MO.H           | 1085| 1068     | 4.10    |
| 2    | 4.47| Cis-Ocimene    | C10H16           | MO.H           | 1037| 1037     | 1.30    |
| 3    | 4.94| o-Cymene       | C10H14           | MO.H           | 1024| 1024     | 1.07    |
| 4    | 4.99| Limonene       | C10H16           | MO.H           | 1028| 1029     | 0.91    |
| 5    | 5.03| 1,8-Cineol     | C10H18O          | MO.O           | 1186| 1186     | 62.35   |
| 6    | 6.17| Camphor        | C10H16O          | MO.O           | 1146| 1146     | 23.14   |
| 7    | 6.38| Borneol        | C10H18O          | MO.O           | 1169| 1169     | 5.51    |
| 8    | 14.56| Santolinyl acetate | C12H2O2       | O              | 1172| 1174     | 0.80    |
| 9    | 16.46| Butanoic acid  | C11H22O2         | O              | 1196| 1197     | 0.72    |

RI, retention indices; RT, retention time in minutes.

Monoterpene hydrate (MO.H) 7.38
Monoterpene oxygenated (MO.O) 91
Sesquiterpenes hydrate (ST.H) 0
Sesquiterpenes oxygenated (ST.O) 0
Others (O) 1.52
Total identified (%) 99.90
As given in Table 4, both EOC and EOR showed dose and exposure time-dependent insecticidal activities, leading to 100% of adult mortality 72 h postexposure. At the highest dose, EOC induced 90.0% of adult mortality (20 μL/L air/10 g) 24 and 48-hour posttreatment, whereas at the highest dose, EOR exhibited 100% of adult mortality 24-hour posttreatment. No mortalities were recorded in control groups.

3.2.2. Effect on Fecundity. The fecundity of *C. maculatus* females was strongly affected by the insecticidal effects of EOs tested. The obtained results showed a significant decrease in the number of eggs laid by females after being exposed to the vapor of EOC and EOR relative to the control (Figure 3 and Table 5). At the highest dose used for testing (20 μL/L seeds), the two EOs completely inhibited the fecundity of females relative to the control value of 196.66 ± 11.54. ANOVA analysis indicated that the EOs-mediated toxicity against *C. maculatus* fecundity was highly significant as a function of increasing concentrations (*F* = 1123.48; *df* = 5, 24; *p* < 0.0001). Moreover, there is no significant difference between EOC and EOR towards the fecundity of females (*F* = 6.31; *df* = 1, 24; *P* = 0.0191). This can be explained by the fact that *C. maculatus* has sensitivity towards EOs of the tested aromatic plants.

### Table 3: Lethal concentrations (μL/L) and chi-square (χ²) values for EOC and EOR against adult *C. maculatus*.

| Essential oils | Days | LC₅₀ (μL/L) | 95% CI | LC₉₀ (μL/L) | 95% CI | df | χ² |
|---------------|------|-------------|--------|-------------|--------|----|----|
| EOC           | 1    | 6.77        | 0.58–10.99 | 35.90       | 17.98–50242.031 | 3   | 1.23 |
|               | 2    | 3.57        | 0.039–6.20  | 15.17       | 9.39–302.76     | 3   | 1.32 |
| EOR           | 1    | 6.25        | 2.39–8.99   | 20.70       | 13.41–103.89    | 3   | 2.28 |
|               | 2    | 3.82        | 0.42–6.05   | 12.40       | 8.23–51.18      | 3   | 2.66 |

3.2.3. Effect on Fertility. The obtained results showed that both EOC and EOR significantly reduced the egg hatchability when compared to the control in a dose and time-dependent manner (Figure 4 and Table 5). For all tested EOC doses, egg hatching was not recorded compared to the control fecundity rate of 94.02 ± 4.08. Similarly, EOR exhibited a potent egg hatching inhibitory effect, wherein the dose of 16 μL/L, resulted in complete abrogation of egg hatchability (Figure 4; Table 5). EOC possessed a toxic effect on the fertility of *C. maculatus* eggs irrespective of the tested dose, whereas EOR inhibited the fertility at the highest tested dose. Therefore, EOC exhibited a far more potent inhibitory effect on egg hatchability than EOR.

### Table 4: Effect of essential oils on mortality of *C. maculatus* as a function of concentrations and exposure times.

| Essential oils | Doses (μL/L of air/10 g) | Exposure time (h) |
|---------------|--------------------------|-------------------|
| EOC          | 24h                     | 48h               | 72h               | 96h               |
| 4            | 36.66±5.77              | 66.66±5.27        | 90±1.0            | 100±0             |
| 8            | 53.33±5.77              | 73.33±6.54        | 96.66±5.70        | 100±0             |
| 12           | 63.33±5.77              | 86.66±6.54        | 100±0             | 100±0             |
| 16           | 73.33±5.27              | 96.66±5.70        | 100±0             | 100±0             |
| 20           | 93.33±3.74              | 100±0             | 100±0             | 100±0             |
| Control      | 0±0                     | 0±0               | 0±0               | 0±0               |
| EOR          | 4                        | 36.66±3.35        | 63.33±3.11        | 100±0             | 100±0             |
| 8            | 46.66±5.77              | 70±0.0            | 100±0             | 100±0             |
| 12           | 63.33±3.07              | 86.66±6.54        | 100±0             | 100±0             |
| 16           | 76.66±2.01              | 100±0             | 100±0             | 100±0             |
| 20           | 100±0                   | 100±0             | 100±0             | 100±0             |
| Control      | 0±0                     | 0±0               | 0±0               | 0±0               |
3.2.4. Effect on Adult Emergence. The obtained results showed no *C. maculatus* adults’ emergence in *Vigna unguiculata*. Seeds provisory treated with EOC regardless of the used dose; meanwhile, the total inhibition of *C. maculatus* adults’ emergence by EOR was recorded for the highest dose used for testing 16 μL/10 g (Figure 5 and Table 5). Therefore, EOC exhibited higher inhibitory activity on the emergence rate of *C. maculatus* adults as compared to that of EOR.

### 4. Discussion

The obtained results showed that EOC was higher in carvacrol (70.88%), which is in agreement with previous reports [17], which revealed that EO of *O. compactum* possessed high insecticidal activity against Spodoptera littoralis larvae, with an LD50 of 0.05 mL/larva. Similarly, *O. compactum* possessed the insecticidal effect against adults of *Musca domestica* and *Mayetiola destructor* [17–19]. In this study, EOR was shown to be effective against *C. maculatus*, which is corroborated by findings reported by another previous work [20]. In that study, authors reported that EO of *R. officinalis* was bioactive against *C. maculatus*. Accordingly, Douiri and co-workers reported the insecticidal effect for EO of *Rosmarinus species* on *C. maculatus* males and females with LC50 varying from 5.51 to 2.43 μL/L air and 6.80 to 3.04 μL/L air, respectively [21].

In the present work, the insecticidal effect of the studied oils resulted in a significant reduction in the number of eggs laid per female. It is thus fitting to conclude that our results were comparable with those reported by Douiri and co-workers [22], who showed that EOs from *Asteraceae* species efficiently controlled *C. maculatus* potently impacting their fecundity, longevity, fertility (89.03–93.40%), and success rate (80–90%). In addition, LC50 was determined to be 2.5 and 23.3 μL/L of air for females and 2.56 and 46.07 μL/L for males. In this context, Bounechada et al. stated that the leaf powder of *Ocimum basilicum* completely abrogated the emergence of *Trogoderma granarium*, which
indicated that *Ocimum basilicum* might serve as an ecofriendly control agent specifically for this pest species [2].

Furthermore, it was reported that at a dose of 33.3 μL/L, the essential oils of *Melaleuca quinquenervia* and *Ocimum gratissimum* significantly reduced the oviposition of the *C. maculatus* females by 98.78% ± 0.87 and 99.94 ± 0.35%, respectively [23, 24]. In this study, the obtained results showed that EOs efficiently controlled the fertility of *C. maculatus* (hatching eggs). In this case, EOC completely inhibited the hatching of eggs laid by the female *C. maculatus*, regardless of the used dose. Meanwhile, the total inhibition of hatching eggs by EOR was obtained by the highest dose used. Specifically, at the dose of 400 μL, EOs extracted from *O. basilicum* and *O. gratissimum* inhibited the hatching of eggs of *C. maculatus* [25]. Similarly, Ketoh et al. stated that *C. schoenanthus* EO inhibited hatching egg and development of neonate *C. maculatus* larvae at the dose of 33.3 μL/mL [26]. In addition, EO of *Z. multiflora* has been previously reported to exhibit a strong insecticidal effect against eggs, larvae, and adults of *C. maculatus* [27].

Our results also showed that the tested EOs efficiently controlled the emergence of *C. maculatus* adults. EOC has completely prevented the total emergence of adults irrespective of the concentration used, whereas EOR prevented the emergence of *C. maculatus* when applied at the highest dose. Moussa Kéïta et al. [25] with a drop in the emergence of *C. maculatus* adults to 0 and 4% follow exposure to EOs of *Ocimum basilicum* and *Ocimum gratissimum*. It was also reported that the emergence of *C. maculatus* F1 adults was significantly inhibited by EO of *Alpinia calcarata* at concentrations of 0.80 g/L using fumigant toxicity [28]. Similarly, the emergence of *C. maculatus* has been previously reported to be also controlled by *Allium sativum* [21].

EOs from aromatic plants exhibit a potent insecticidal effect by fumigation, contact, and repulsion assays [5, 8, 29]. EOs are known for their ovicidal, repellent, and insecticidal activities against various insects attacking stored products [29]. The mechanism of action (MOA) of EOs against insects was investigated by Renoz and co-workers who reported that EOs resulted in *Sitophilus granarius* death by altering a variety of key biological processes and activities, namely, muscular and neurological systems, cellular respiration, protein synthesis, development, reproduction, and insects’ behavior [30]. Rajendran et al. reported that terpenoids have gained particular attention among other constituents of EOs because of their potent fumigant effect against stored grain insects [31]. In this context, it has been postulated that *C. maculatus* could absorb EOs along with their components, for example, terpenoids. Consequently, the toxicity of the tested EOs in the current study is hypothesized to be attributed to the presence of carvacrol [32, 33].

In the present work, the insecticidal activity of both EOC and EOR could be due to bioactive compounds identified in the oils, particularly carvacrol, which is known for its bioactivity including the insecticidal effect [34]. In the current study, carvacrol was found to be the major component in EOC with 70.88%, whereas 1,8-cineole was reported to be the dominant constituent in EOR with 62.35%. Taken together, these monoterpenoid compounds could be responsible for the biological activity of these EOs. Additionally, 1,8-cineole, borneol, and thymol have been previously reported to exert adverse toxicities against *S. oryzae* adults at the lowest dose (0.1 μL/720 mL volume), 24 h posttreatment by fumigation [35]. Camphor and linalool caused 100% mortality for *R. dominica* adults, and this has been attributed to monoterpenoids contained in EOs accounting for the observed insecticidal activity [4]. It was also reported that carvacrol, linalool, thymol, terpineol, and eugenol inhibited the emergence of *A. obtectus* adults [36, 37]. Citral and 1,8-cineole contained in EO were found to be ovicides and strong inhibitors of the emergence of adult houseflies. Eugenol and (−)-menthol powerfully inhibited adult emergence *C. maculatus* adults [38]. The MOA by which terpenes can exert this insecticidal effect have been reported in an earlier work [28]. EO constituents can operate synergistically or individually depending on which insect pest is being targeted. For example, the two components D-limonene and α-terpineol showed a synergistic toxicity against *Trichoplusia ni*, whereas no correlation was found with toxicity against *Spodoptera frugiperda*. The MOA underlying the synergistic interaction of 1,8-cineole and camphor, the major constituent of the EO of *R. officinalis* against *Trichoplusia ni*, has already been reported by Tak et al. [39], who showed that 1,8-cineole enhances the penetration of camphor into the blood circulation through the insect’s body wall referred to as integument. The MOA of the reported insecticidal activity of EOs has been thoroughly investigated by Rattan and co-workers [40], who reported that EOs and their components, particularly thymol, result in insect death through the inhibition of acetylcholinesterase, thereby leading to its accumulation eventually causing hyperstimulation of nicotinic and muscarinic receptors and disrupted neurotransmission. Moreover, it might act by blocking the octopamine receptors through tyramine receptors cascade or by disruption of the octopaminergic system [40].

5. Conclusion

The obtained results revealed that the studied EOs efficiently controlled the insect life cycle, which could be attributed to its richness in specific bioactive monoterpenoid alcohols such as carvacrol. Taken together, the outcome of the present study highlights the benefits of the EOs extracted from *Origanum compactum* Benth. and *Rosmarinus officinalis* L. as effective ecofriendly pest-control agents. Further investigation is therefore warranted to evaluate the safety of these EOs and their nontarget toxicities against mammals and humans.

Data Availability

The data used to support the findings are included within the article.
Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] I. El-miziani, S. Lhaloui, M. El Bouhssini et al., “Étude des dégâts qualitatifs et quantitatifs dus aux Bruches sur les légumineuses au Maroc,” Rev. Marocaine Prot. Plantes. no vol. 9, 2016.

[2] M. Bounechada, M. Fenni, and F. Benia, “Survey of insects pest stored and biological control of Trogoderma granarium Everts in Setifian Region (north-east of Algeria),” Bull. UASVM Agric. vol. 68, no. 1, pp. 70–74, 2011.

[3] I. Mahfuz and M. Khalequzzaman, “Contact and fumigant toxicity of essential oils against Callosobruchus maculatus,” University Journal of Zoology, Rajshahi University, vol. 26, pp. 63–66, 2007.

[4] C. Regnault-Roger and A. Hamraoui, “Lutte contre les insectes phytophages par les plantes aromatiques et leurs molécules allélochimiques,” Acta Botanica Gallica, vol. 144, no. 4, pp. 401–412, 1997.

[5] J. M. Hill and A. V. Schoonhoven, “The use of vegetable oils in controlling insect infestations in stored grains and pulses,” Recent Adv. Food Sci. Technol., vol. 1, pp. 473–481, 2000.

[6] G. H. Schmidt, E. M. Risha, and A. K. M. El-Nahal, “Reduction of progeny of some stored-product Coleoptera by vapours of Acorus calamus oil,” Journal of Stored Products Research, vol. 27, no. 2, pp. 121–127, 1991.

[7] S. M. Kéïta, C. Vincent, J.-P. Schmitt, J. T. Arnason, and A. Bélanger, “Efficacy of essential oil of Ocimum basilicum L. and O. gratissimum L. applied as an insecticidal fumigant and powder to control Callosobruchus maculatus (Fab.) [Coleoptera: bruchidae],” Journal of Stored Products Research, vol. 37, no. 4, pp. 339–349, 2001.

[8] E. Shaaya, M. Kostjkovski, J. Elberg, and C. Sukprakarn, “Plant oils as fumigants and contact insecticides for the control of stored-product insects,” Journal of Stored Products Research, vol. 33, no. 1, pp. 7–15, 1997.

[9] M. Isman, Pesticides Based on Plant Essential Oils, Pestic. Outlook U. K, 1999.

[10] L. A. Hummelbrunner and M. B. Isman, “Acute, sublethal, antifeedant, and synergistic effects of monoterpenoid essential oil compounds on the tobacco cutworm, Spodoptera littoralis (Lep., Noctuidae),” Journal of Stored Products Research, vol. 41, no. 1, pp. 363–371, 2005.

[11] F. Z. Jawhari, A. El Moussaoui, M. Bourbia et al., “Anacyclus pyrethrum (L.): chemical composition, analgesic, anti-inflammatory, and wound healing properties,” Molecules, vol. 25, no. 22, p. 5469, 2020.

[12] D. J. Finney, Probit analysis, Vol. 333, Cambridge University, London, UK, 3rd edition, 1971.

[13] H. Sbayou, N. Oubrim, B. Bouchrif, B. Ababou, K. Boukachabine, and S. Amghar, “Chemical composition and antibacterial activity of essential oil of Origanum compactum against foodborne bacteria,” International Journal of Engineering Research and Technology, vol. 3, no. 1, pp. 3562–3567, 2014.

[14] A. Belkamel, J. Baami, and A. Belkamel, “Origanum compactum (benh.),” Journal of Animal and Plant Sciences, vol. 19, no. 1, pp. 2880–2887, 2013.

[15] A. Ait-Ouazzou, S. Lóran, M. Bakkali et al., “Chemical composition and antimicrobial activity of essential oils of Thymus algeriensis, Eucalyptus globulus and Rosmarinus officinalis from Morocco,” Journal of the Science of Food and Agriculture, vol. 91, no. 14, pp. 2643–2651, 2011.

[16] R. Pabela, “Insecticidal activity of some essential oils against larvae of Spodoptera littoralis,” Fitoterapia, vol. 76, no. 7–8, pp. 691–696, 2005.

[17] R. Pabela, “Insecticidal properties of several essential oils on the house fly (Musca domestica L.),” Phytotherapy Research, vol. 22, no. 2, pp. 274–278, 2008.

[18] A. Lamiri, S. Lhaloui, B. Benjiali, and M. Berrada, “Insecticidal effects of essential oils against Hessian fly, Mayettella destructor (Say),” Field Crops Research, vol. 71, no. 1, pp. 9–15, 2001.

[19] M. Mahmoudvand, H. Abbasipour, M. H. Hoseinpour, F. Rastegar, and M. Basij, “Using some plant essential oils as natural fumigants against adults of Callosobruchus maculatus (F),” Coleoptera: bruchidae,” Minitis Entomology Zoology, vol. 6, no. 1, pp. 150–154, 2011.

[20] A. Ait-Ouazzou, S. Lorán, M. Bakkali et al., “Chemical composition and biological activity of Allium sativum essential oils against Callosobruchus maculatus,” IOSR Journal of Environmental Science, Toxicology and Food Technology, vol. 3, no. 1, pp. 30–36, 2013.

[21] L. F. Douiri, A. Boughdad, O. Assobhei, and M. Moummi, “Chemical composition and biological activity of Allium sativum essential oils against Callosobruchus maculatus,” I.C.A.R. Research, vol. 39, no. 1, pp. 77–85, 2003.

[22] S. G. Chemgini, H. Abbasipour, J. Karimi, and A. Askarianzadeh, “Toxicity of Shirazi thyme, Zataria multiflora essential oil to the tomato leaf miner, Tuta absoluta (Lepidoptera: gelechiidae),” International Journal of Tropical Insect Science, vol. 38, no. 4, pp. 340–347, 2018.

[23] B. P. Seri-Kouassi, C. Kanko, L. R. N. Aboua et al., “Action des huiles essentielles de deux plantes aromatiques de Côte d’Ivoire sur Callosobruchus maculatus F,” du niébé.Comptes Rendus Chimie, vol. 7, no. 10–11, pp. 1043–1046, 2004.

[24] F. Rastegar, S. Moharramipour, M. Shojai, and H. Abbasipour, “Chemical composition and insecticidal activity of essential oil of Zataria multiflora Boiss.(Lamiaceae) against Callosobruchus maculatus (F),” (Coleoptera: bruchidae),” IJOBCwprs Bull, vol. 69, 2011.

[25] D. R. S. Barbosa, J. V. Oliveira, P. H. Silva et al., “Efficacy of bioactive compounds and their association with different cowpea cultivars against their major stored pest,” Pest Management Science, vol. 76, no. 11, pp. 3770–3779, 2020.
[29] J. M. Desmarchelier, *Grain Protectants: Trends and Developments*, pp. 722–728, Stored Prod. Prot. CAB Int, Wallingford UK, 1994.

[30] F. Renoz, S. Demeter, H. Degand et al., “The modes of action of Mentha arvensis essential oil on the granary weevil Sitophilus granarius revealed by a label-free quantitative proteomic analysis,” *Journal of Pest Science*, vol. 95, no. 1, pp. 1–15, 2021.

[31] S. Rajendran and V. Sriranjini, “Plant products as fumigants for stored-product insect control,” *Journal of Stored Products Research*, vol. 44, no. 2, pp. 126–135, 2008.

[32] O. Campolo, G. Giunti, A. Russo, V. Palmeri, and L. Zappalà, “Essential oils in stored product insect pest control,” *Journal of Food Quality*, vol. 2018, 2018.

[33] F. Burčul, M. Radan, O. Politeo, and I. Blažević, “Cholinesterase-inhibitory activity of essential oils,” *Advanced Chemical Research*, vol. 37, pp. 15–86, 2017.

[34] Y. Xie, K. Wang, Q. Huang, and C. Lei, “Evaluation toxicity of monoterpenes to subterranean termite, Reticulitermes chinensis Snyder,” *Industrial Crops and Products*, vol. 53, pp. 163–166, 2014.

[35] V. Rozman, I. Kalinovic, and Z. Korunic, “Toxicity of naturally occurring compounds of Lamiaceae and Lauraceae to three stored-product insects,” *Journal of Stored Products Research*, vol. 43, no. 4, pp. 349–355, 2007.

[36] P. J. Rice and J. R. Coats, “Insecticidal properties of several monoterpenoids to the house fly (Diptera: muscidae), red flour beetle (Coleoptera: tenebrionidae), and southern corn rootworm (Coleoptera: chrysomelidae),” *Journal of Economic Entomology*, vol. 87, no. 5, pp. 1172–1179, 1994.

[37] P. Kumar, S. Mishra, A. Malik, and S. Satya, “Housefly (Musca domestica L.) control potential of Cymbopogon citratus Stapf. (Poales: poaceae) essential oil and monoterpenes (citral and 1,8-cineole),” *Parasitology Research*, vol. 112, no. 1, pp. 69–76, 2013.

[38] O. E. Ajayi, A. G. Appel, and H. Y. Fadamiro, “Fumigation toxicity of essential oil monoterpenes to Callosobruchus maculatus (Coleoptera: chrysomelidae: Bruchinae),” *J. Insects* vol. 2014, 2014.

[39] J.-H. Tak, E. Jovel, and M. B. Isman, “Comparative and synergistic activity of Rosmarinus officinalis L. essential oil constituents against the larvae and an ovarian cell line of the cabbage looper, Trichoplusia ni (Lepidoptera: noctuidae),” *Pest Management Science*, vol. 72, no. 3, pp. 474–480, 2016.

[40] R. S. Rattan, “Mechanism of action of insecticidal secondary metabolites of plant origin,” *Crop Protection*, vol. 29, no. 9, pp. 913–920, 2010.