The Journal of Agricultural Sciences - Sri Lanka
Vol. 19, No 3, September 2024. Pp 548-565
http://doi.org/10.4038/jas.v19i3.10325

Comprehensive Review: Essential Oils Found in Africa and Asia as Green Controllers of *Bemisia tabaci*, a Worldwide Agronomical Pest

E.A. Venegas-Casanova[1], R.D.D.G. de Albuquerque[2*1], F.T. Cerna-Reyes[3], G.K. Céspedes-Cáceres[4], F.R. Rubio-López[1] and S.L. Rodríguez Chamorro[5]

Received: 13th June 2023 / Accepted: 06th August 2024

ABSTRACT

Purpose: *Agricultural losses caused by pests have a profound impact on African and Asian countries. In this context, the whitefly Bemisia tabaci is an important global pest and attacks many vegetables. However, conventional pesticides cause unwanted effects on the environment and consumers, in addition to the development of resistance. Therefore, sustainable resources have been used and researched, including those of natural origin.*

Research Method: *The objective of this review was to compile and discuss studies of essential oils found in Asian and African countries with action against B. tabaci. For this, scientific studies on active essential oils were searched in databases such as Scopus, Web of Science, Google Scholar, and Science Direct.*

Findings: *The work explored essential oils from 48 different species belonging to 19 families. Notably, the families Asteraceae, Lamiaceae, Lauraceae, Myrtaceae, and Poaceae presented the highest number of studies. Among the evaluated oils, Allium sativum oil demonstrated potent fumigant insecticidal action. Similarly, essential oils from Cinnamomum camphora, Thymbra spicata, Rosmarinus officinalis, and Laurus nobilis exhibited high activity against pests. Promising essential oils with high potency against pests also include Mentha pulegium, Mentha viridis, and Syzygium aromaticum.*

Research Limitations: *Despite the diversity of active essential oils against B. tabaci, further studies on the development and stability of formulations must be carried out.* ***Originality/value:*** *This review highlighted the abundance of active essential oils in Africa and Asia as natural resources for sustainable pest management in the B. tabaci control.*

Keywords: *Biological control, Essential oils, Insecticidal activity, Phytochemicals.*

INTRODUCTION

The global food supply chain faces a significant challenge: the loss of food caused by pest infestation. Insects, rodents, and fungi are responsible for damaging crops at various stages, from growth and harvesting to transportation and storage. This not only affects the availability and affordability of food but also has far-reaching economic, social, and environmental consequences (Kiaya, 2014). The World Health Organization estimates that pests contribute significantly to the staggering statistic that approximately one-third of all food produced worldwide is lost or wasted (FAO, 2022).

[1]Facultad de Farmácia, Departamento de Farmacotecnia, Universidad Nacional de Trujillo, Avenida Juan Pablo II, P.O.Box 13011, Centro, Trujillo, La Libertad, Peru
[2]Laboratório de Tecnologia de Produtos Naturais, Universidade Federal Fluminense, Street Mario Vianna, 523, P.O.Box 24241-000, Santa Rosa, Niterói, RJ, Brasil
[3]Universidad Católica de Trujillo Benedicto XVI, Av. Panamericana Nte. 555, P.O.Box 13006, Moche, Trujillo, La Libertad, Peru
[4]Universidad Peruana Unión, Street Los Mártires, P.O. Box 22201, Tarapoto, San Martín, Peru
[5]Universidad César Vallejo, Av. Larco, P.O. Box 20008, Centro, Piúra, Peru
*richardcabofrio@gmail.com
https://orcid.org/0000-0002-8442-3849

Specifically in many African and Asia countries, agricultural loss is a critical concern as these continents house a significant proportion of the global population. According to recent data, Africa is home to over 1.3 billion people, and Asia boasts a population exceeding 4.6 billion (United Nations, 2021. Furthermore, both continents are characterized by a considerable number of individuals living below the poverty line. In Africa, it is estimated that over 40% of the population lives in extreme poverty, struggling to meet basic needs (World Bank, 2022). Similarly, in Asia, nearly 25% of the population faces the challenges of poverty (Asian Development Bank, 2021).

The impact of agricultural loss in these regions is staggering. Crop damage caused by pests, diseases, inadequate storage facilities, and adverse weather conditions leads to substantial food loss. According to the Food and Agriculture Organization of the United Nations (FAO), in Africa alone, an estimated 20–30% of agricultural produce is lost annually, significantly impacting food availability and exacerbating food insecurity (FAO, 2022). In Asia, where 75% of farmers are dependent on agriculture, the situation is equally alarming. This fact can be exemplified in China, one of the main agricultural centers globally, where agricultural loss due to pest attacks has quadrupled in 50 years (Hess, 2022).

These agricultural losses have severe consequences for the already vulnerable populations in Africa and Asia. Insufficient food availability and increased prices affect the ability of individuals and families living in poverty to access an adequate and nutritious diet. Moreover, the loss of income for small-scale farmers further perpetuates the cycle of poverty, making it challenging for them to escape the grip of destitution. The adverse effects extend beyond immediate food security concerns, encompassing broader economic, social, and environmental dimensions (FAO, 2021).

Within this context, the silverleaf whitefly, scientifically known as *Bemisia tabaci*, emerges as a significant agricultural pest worldwide, posing a threat to crops such as fruits, vegetables, and ornamental plants (Rathee and Dalai, 2018) (Fig. 1). This tiny insect wreaks havoc on global food security by causing extensive damage to crops, resulting in substantial losses in yield and diminished crop quality (Sani *et al*., 2020). With its piercing-sucking mouthparts, *B. tabaci* extracts sap from plants, causing leaf yellowing, deformation, and even plant death. Furthermore, this pest is a known carrier of over 100 plant viruses, compounding the damage inflicted upon crops (Chandel *et al*., 2010; Ellango *et al*., 2015). The economic impact of *B. tabaci* on agriculture is significant, leading to billions of dollars in losses annually, considering both crop damage and pest management expenses. Therefore, implementing effective control measures is crucial to mitigate the impact of this pest on food production and ensure global food security (Horowitz *et al*., 2020).

Various pesticides, including neonicotinoids, organophosphates, pyrethroids, and insect growth regulators, are employed to control *B. tabaci*. However, these pesticides carry adverse effects on human health and the environment (Vassiliou *et al*., 2011). Neonicotinoids, for example, are known to harm non-target organisms such as bees and other beneficial insects, raising concerns about their environmental impact and effects on biodiversity (Bass and Fields, 2018). Organophosphates and pyrethroids, commonly used pesticides to control *B. tabaci*, are highly toxic to humans, causing health issues like headaches, nausea, dizziness, and respiratory problems. Long-term exposure to these pesticides has been linked to more severe conditions, including cancer, neurological disorders, and developmental problems (Ongono *et al*., 2020).

While insect growth regulators like methoprene offer a safer alternative to traditional pesticides by specifically targeting insect development without harming beneficial insects or humans, improper use can still have unintended effects on non-target organisms, posing risks to the environment (Tunaz and Uygun, 2004). Given these limitations, alternative pest control methods, such as biological control and biopesticides, are currently being explored, prioritizing sustainability and consumer health (Smith and Perfetti, 2020).

Plant extracts and essential oils have been utilized for centuries as natural pest control methods due to their broad-spectrum activity and lower toxicity compared to synthetic pesticides. These substances, derived from various plant parts like leaves, flowers, roots, and seeds, contain a range of compounds with insecticidal and repellent properties (Dubey *et al*., 2011). Particularly, essential oils have gained increasing attention for their potential in pest management, driven by concerns surrounding the safety and environmental impact of synthetic pesticides. Several studies have demonstrated the efficacy of essential oils in controlling various agricultural pests, including aphids, whiteflies, mosquitoes, and bedbugs.

Furthermore, essential oils offer versatility in application methods such as spraying, fumigation, and baiting, expanding their potential across different

Figure 1: Adult *B. tabaci* settled on the leaf.
Source: Commonwealth Scientific and Industrial Research Organisation (CSIRO)

crops (Bakkali *et al*., 2008; Isman *et al*., 2006; Pavela *et al*., 2018). Apart from their effectiveness in pest control, essential oils possess the advantages of being biodegradable, sustainable, cost-effective, and minimizing the emergence of pest resistance due to their natural complexity and diverse composition (Iqbal *et al*., 2021; Ogungbe and Setzer, 2013). Therefore, it is essential to consolidate scientific knowledge on the insecticidal properties of natural products found in African and Asian countries against *B. tabaci*. Thus, this review aims to encompass and discuss studies focusing on essential oils that exhibit relevant action against this significant agricultural pest.

MATERIALS AND METHODS

The research was carried out using the combination of "essential oil," "activity," and "*Bemisia tabaci*". The following research databases were used for the review: Science Direct (116 documents), Web of Science (45 documents), Scopus (1601 documents), and Google Scholar (3670 documents). According to the relevance order, repeated articles or those that only cited studies on the subject in question were excluded, so that 118 articles had their content analyzed. Only studies with essential oils from plants collected in Asian or African countries or purchased by laboratories located in these countries were taken into account. After careful selection, 19 articles about the proposed central theme were included and discussed in the two next sections of the review, which excludes the articles described in the introduction and discussion sections.

LITERATURE REVIEW

Acoraceae

Wagan and researchers (2023) also evaluated the effect of *Acorus tatarinowii* rhizomes EO, showing 95.62% mortality in the laboratory in 24 h and 58.25% in the greenhouse by direct contact, an insecticide activity rate by fumigation of 98.75% in the laboratory in 8 h, and deterrent oviposition activity (7.0% in the laboratory and 10.38% in the greenhouse, in 24 h), using a concentration of 10 mg/mL (Wagan *et al*., 2016).

Amaranthaceae

The study by Liu *et al*. (2014) demonstrated that the *Chenopodium ambrosioides* EO showed an LC_{50} equal to 8.80 ppm after 24 h by fumigation (Liu *et al*., 2014).

Amaryllidaceae

The *Allium sativum* EO, at the concentration of 2.0%, presented repellent (93%) and deterrent (95.55%, after 10 days) activities, besides showing an insecticide effect by fumigation assay (LC_{50} = 141.13 ppm), within

48 hours. The study also informed that, when combined with cetan (a synthetic insecticide), thyme, or cumin oils, the mortality index increased. The concentration of 1000 ppm reduced egg hatching by 50%, while the larval mortality reached 66.43% after 48 h (Hussein, 2017). In another study with *A. sativum* EO, the 0.5% and 0.1% spray formulations caused 100% mortality against the Q and B *B. tabaci* biotypes during 24 h exposure, being more efficient than all positive controls tested, including those with natural or synthetic actives (Kim *et al*., 2012).

On the other side, in the study of Liu *et al*. (2014), the EO from *A. sativum* showed an LC_{50} equal to 0.11 ppm after 24 h by fumigation. Diallyl trisulfide (61.87%), diallyl disulfide (19.47%), and diallyl sulfide (4.41%) were the main compounds of the oil, showing LC_{50} values of 0.08, 0.12, and 1.68 ppm, respectively (Liu *et al*., 2014). The work of Wagan *et al*. (2022) showed the activity of *A. ascalonicum* plant EO, which presented a repellence rate of 70.70%, approximately 17% mortality by direct contact, and a deterrent oviposition percentage of 44.75% in 24 h, using a concentration of 10 mg/mL. Its main constituent was sulfinylbis methane (6.56%) (Wagan *et al*., 2022).

Anacardiaceae

The EO from *Schinus terebenthifolia* fruits, an American sandbank species, showed an LC_{50} equal to 102 ppm in 48 h. The test was performed by spraying tomato plants infested with the adult *B. tabaci*. α-pinene (36.9%), α-phellandrene (32.8%), limonene (11.9%), and α-terpineol (6.0%) were the main constituents of the oil (Hussein *et al*., 2017).

Apiaceae

The *Cuminum cyminum* EO, at the concentration of 2.0%, presented repellent (87%), deterrent (87%, after 10 days), and insecticide (LC_{50} = 141.13 ppm, after 48 h) activities. The study also informed that, when combined with cetan, thyme, or cumin oils, the mortality index increased. The concentration of 1000 ppm reduced egg hatching by 30%, while the larval mortality reached 54% (Hussein, 2017). *Foeniculum vulgaris* seeds EO was also effective against adult *B. tabaci*, showing an LC_{50} equal to 7.06 μg/mL air after 24 hours. Trans-anethole was the EO's major compound (82.80%), with 4-allyl anisole (6.56%) and limonene (5.79%) (Sertkaya *et al*., 2010). Wagan and researchers (2016) also evaluated the effect of *Heracleum hemsleyanum* roots EO, showing 69.38% mortality in the laboratory in 24 h and 83.75% in the greenhouse by direct contact, an insecticide activity rate by fumigation of 60.50% in the laboratory in 8 h, and deterrent oviposition activity (7.25% in the laboratory and 17.12% in the greenhouse, in 24 h) (Wagan *et al*., 2016).

Asteraceae

Artemisia absinthium EO (1 μL) repelled 78.9% of adult *B. tabaci* in a Y-tube olfactometer test. Its 0.5% concentration caused 80% mortality by contact toxicity. Additionally, the major compounds β-pinene (27.78%) and linalool (23.41%) repelled 61.11% and 62.22% of the adults, respectively (Li *et al*., 2022). The 0.5% and 0.1% spray formulations from *Artemisia pallens* demonstrated better selectivity against B biotype *B. tabaci* (93% and 31% mortality) when compared to Q biotype (93% and 13% mortality). The 0.5% formulation was more efficient than all positive controls tested, including those with natural or synthetic actives (Kim *et al*., 2012).

On the other hand, the study of Zandi-Sohani *et al*. (2018) described the insecticidal activity of the 0.3% *Artemisia siberia* EO against adult *B. tabaci*, reaching circa 90% mortality in 24 hours (Zandi-Sohani *et al*., 2018). The insecticidal study of *Erigeron floribundus* EO was conducted by Tia *et al*. (2013). Using a concentration equal to 0.4 μL/L air, the EO presented a mortality rate of 88.8% in 24 hours. The main constituents of the active oil were limonene (21.9%), (Z)-β-farnesene (16.3%), (E)-methyl-lachnophyllate (9.6%), and (E)-β-caryophyllene (9.5%). Despite this, the composition demonstrated to be different when the EO was collected by headspace technique, in which, the limonene presented a percentage equal to 24.7% and the (Z)-β-farnesene composition decreased to only 5.4%, whereas the (E)-methyl-lachnophyllate was not identified, and the (E)-β-caryophyllene showed a concentration equal to 4.2%. Also, myrcene, β-pinene, and germacrene D enhanced their concentration from 1.0%, 5.0%, and 3.9% to 14.0%, 12.3%, and 11.8%, respectively (Tia *et al*., 2013).

Ferulaceae

The study of Zandi-Sohani *et al*. (2018) described the insecticidal activity of the 0.3% *Ferula gummosa* EO against adult *B. tabaci*, reaching circa 90% mortality in 24 hours (Zandi-Sohani *et al*., 2018).

Geraniaceae

The study of Zandi-Sohani *et al*. (2018) described the insecticidal activity of the 0.3% *Pelargonium roseum*

EO against adult *B. tabaci*, causing 100% mortality in 24 hours (Zandi-Sohani *et al.*, 2018).

Lamiaceae

A study with *Ocimum gratissimum* leaves EO was conducted using a Fisher Block System, showing that the 5% dilution was toxic to adult *B. tabaci*, decreasing 31.5% when compared to the negative control. The treatment was performed for 115 days, with an interval of 14 days starting on the 45th day after the plantation of cotton plants. Moreover, the *O. gratissimum* EO presented anti-cholinesterase activity on acetyl (1.60 mg Galantamine equivalent - GALAE) and butyrylcholinesterase (4.62 mg GALAE) inhibitors. *p*-cymene (37.0%) and thymol (18.7%) were the main compounds of the oil (Kobenan *et al.*, 2022). *Thymus vulgaris* EO, at the concentration of 2.0%, presented repellent (98.36%), deterrent (100%, after 10 days), and insecticide (LC_{50} = 71.75 ppm, after 48 h) activities.

The study also informed that, when combined with cetan, garlic, or cumin oils, the mortality index increased. Still, the concentration of 1000 ppm reduced egg hatching by 60%, while the larval mortality reached 76.42% (Hussein, 2017). In another study with *T. vulgaris* EO (red thymus), its 0.5% and 0.1% spray formulations demonstrated better selectivity against Q biotype *B. tabaci* (87% and 16% mortality, respectively), when compared to B biotype (75% and 8% mortality). For the *Origanum vulgare* EO, the effect on Q biotype *B. tabaci* reached 98% and 21% mortality, while the results against the B biotype were 94% and 19%, respectively.

Similar results were observed for the *Nepeta cataria* EO, showing that the mortality rate was higher against the Q biotype (98% and 90% for 0.5% and 0.1%, respectively), while 43% and 17% mortality were reached when tested against the B biotype. The 0.5% formulations were more efficient than all positive controls tested, including those with natural or synthetic actives (Kim *et al.*, 2012). In turn, *T. pulegioides* EO (1 μL) repelled 83.3% of adult *B. tabaci* in a Y-tube olfactometer test, while its 0.5% concentration caused 84% mortality by contact toxicity. Additionally, the major compounds thymol (36.18%), carvacrol (13.43%), *p*-cymene (10.85%), and thymol methyl ether (7.45%) repelled 73.33%, 44.44%, 64.44%, and 70% of the adults, respectively (Li *et al.*, 2022).

The work of Wagan *et al.* (2022) showed the activity of *Mentha haplocalyx* leaves EO, which presented a repellence rate of 77.67%, approximately 54% mortality by direct contact, and a deterrent oviposition percentage of 58.25% in 24 h, using a concentration of 10 mg/mL. Its main constituents were L-(-) menthol (8.26%), 9,12,15-octadecatrienoic acid, (Z,Z,Z) (4.48%), and hexadecanoic acid (4.40%) (Wagan *et al.*, 2022). *Thymbra spicata* subsp. *spicata* and *Rosmarinus officinalis* leaves EO were also effective against adult *B. tabaci*, showing an LC_{50} equal to 0.44 and 2.86 μg/mL air, respectively, after 24 hours. Carvacrol was the *T. spicata* EO major compound (70.93%), with *p*-cymene (13.77%) and λ-terpinene (6.98%), while borneol (20.4%), camphor (19.5%), and 1,8-cineole (17.4%) were the main constituents of *R. officinalis* EO (Sertkaya *et al.*, 2010). Another EO from the *Mentha* genus, *M. spicatus*, was also effective against *B. tabaci* adults, with 99.1% mortality when used at a concentration of 10 μg/954 mL in 24 hours. Carvone (40.9%), limonene (16.1 %), and γ-terpinene (13.8 %) were the EO major compounds. Carvone also presented high insecticidal activity, although to a lower extent when compared to the EO (100 % mortality using the concentration of 10 μg/954 mL) (Choi and Kim, 2004). The study of Zandi-Sohani (2011) described the insecticidal activity of five EOs from Lamiaceae species.

The most active oils were extracted from *Mentha pulegium* and *Mentha viridis*, presenting 100 % mortality, in 6 h, using a concentration of 2 μL/L air. In their turn, EOs from *Zataria multiflora*, *R. officinalis*, and *Satureja hortensis* presented the same mortality rate in 12 h (Zandi-Sohani, 2011). In the study of Aslan *et al.* (2004), the *S. hortensis* EO, at 3.125 μL/L concentration, caused 44 % mortality, in 24 hours. For *T. vulgaris* and *O. basilicum* EOs, the values were equal to 27 % (Aslan *et al.*, 2004). Moreover, the study by Liu *et al.*. (2014) informed that the EO from *Agastache rugosa* showed an LC_{50} equal to 7.08 ppm against *B. tabaci*, after 24 hs, by fumigation (Liu *et al.*, 2014).

Lauraceae

In a fumigant test against adult insects, the EO from *Cinnamomum bejolghota* fresh leaves presented an LC_{50} equal to 1.52 μL/L air. Moreover, the EO showed no significant physiological changes in eggplant (*Solanum melogena*) (Pumnuan *et al.*, 2017). The 0.5% spray formulation from *C. zeylanicum* bark EO caused 100% mortality against the Q and B *B. tabaci* biotypes during 24 h exposure, being more efficient than all positive controls tested, including those with natural or synthetic actives. On the other side, the 0.1% formulation demonstrated better selectivity against the Q biotype (75%) when compared to the B biotype (45%) (Kim *et al.*, 2012).

The work of Wagan *et al.* (2022) informed the activity of *C. camphora* small leaves EO, which presented a repellence rate equal to 84.83%, 64.25% mortality by direct contact, and a deterrent oviposition percentage of 63.44% in a period of 24 h, using a concentration of 10 mg/mL. Its main constituents were 1,5-heptadien-4-one, 3,3,6-trimethyl acetic acid (59.94%), and nerolidol (12.18%) (Wagan *et al.*, 2022). Wagan and collaborators (2017) also evaluated the effect of *Litsea cubeba* fruit EO, which presented 69.14% (fumigation) and 54.77% (greenhouse) repellency and a deterrent oviposition percentage of 48.62% (fumigation) and 36.16% (greenhouse) in a period of 24 h, using a concentration of 10 mg/mL (Wagan *et al.*, 2018a). *Laurus nobilis* leaves EO was also effective against adult *B. tabaci*, showing an LC_{50} equal to 1.82 μg/mL air after 24 hours. 1,8-cineole was the EO major compound (35.50%), with sabinene (15.0%) and α-terpineol acetate (14.20%) (Sertkaya *et al.*, 2010).

Myristicaceae

The fruit EO from *Myristica fragrans* at 10 mg/mL showed maximum fumigation toxicity (79.17 ± 3.00%), contact toxicity (72.50 ± 4.23%), and repellency (76.67 ± 7.15%) in the laboratory experiments after 8, 48, and 24 hours, respectively, whereas in the greenhouse experiments the observed effects were repellency (maximum value: 58.33 ± 3.50%) and anti-oviposition (46.11 ± 5.38%) activity after 24 h of exposure (Wagan *et al.*, 2017).

Myrtaceae

In a fumigant test against an adult insect, the EO from *Syzigium aromaticum* dried bud presented an LC_{50} equal to 1.36 μL/L air in 24 h. Moreover, the EO showed no significant physiological changes in eggplant (*Solanum melogena*) (Pumnuan *et al.*, 2017). In a similar study, Liu *et al.* (2014) demonstrated that the *S. aromaticum* EO showed an LC_{50} equal to 13.54 ppm against adult *B. tabaci* after 24 h by fumigation (Liu *et al.*, 2014). In another study, different results were observed for the *S. aromaticum* leaf and bud EOs. The 0.5% formulation from leaf EO presented a higher mortality rate against the Q biotype (96% against 93%), whereas the 0.1% formulation from leaf EO and both bud EO formulations were more active against the B biotype (24% against 14% for the 0.1% leaf EO, 99% against 90% for the 0.5% bud EO, 18% against 8% for the 0.1% bud EO) (Kim *et al.*, 2012).

The EO from *Corymbia citriodora* leaves showed an LC_{50} equal to 249 ppm in 48 h. The test was performed by spraying tomato plants infested with adult *B. tabaci*. α-citronellal (53.1%), α-citronellol (13.7%), and citronellol acetate (12.2%) were the main constituents of the oil (Hussein *et al.*, 2017). The insecticidal study of *Melaleuca leucadendron* EO was conducted by Tia *et al.* (2013). The EO provides a $TL_{50} < 1$ hour, using a concentration equal to 0.4 μL/L air, presenting a mortality rate of 87.5% in 24 hours. The main constituents of the active oil were 1,8-cineole (50.4%), viridiflorol (16.4%), α-pinene (12.4%), and α-terpineol (8.1%). Nevertheless, the composition demonstrated to be different when the EO was collected by headspace technique, in which the 1,8-cineole presented a percentage equal to 48.5% and the viridiflorol and α-pinene compositions decreased to 0.7% and 6.8%, respectively, whereas the α-terpineol enhanced its concentration to 14.5% (Tia *et al.*, 2013).

Piperaceae

Wagan and collaborators (2017) also evaluated the effect of *Piper nigrum* fruit EO, which presented 63.67% (fumigation) and 44.17% (greenhouse) repellency and a deterrent oviposition percentage of 51.02% (fumigation) and 43.35% (greenhouse) in a period of 24 h, using a concentration of 10 mg/mL (Wagan *et al.*, 2018a).

Poaceae

The insecticidal effect on *B. tabaci* was observed for the *Cymbopogon flexuosus* EO and its major compounds, geranial (47.3%) and neral (34.7%), that make up a mixture denominated citral. The concentration of 0.9% of the EO and citral caused 88.79% and 90.12% adult mortality by direct contact, respectively, in 24 hours of treatment, which demonstrated the importance of the citral contribution to insecticidal activity. Moreover, the ovipositional deterrent activity was also evaluated for both samples, so that the EO and citral had values of -66% and -44%, respectively (Chandra *et al.*, 2021). The insecticidal activity was also performed on a species from the same genus named *C. nardus*.

The mortality rate observed at the highest concentration (6.66 μL/L air) was 94.3%, and the LC_{50} was 1.028 μL/L air. Furthermore, the essential oil was highly repellent against *B. tabaci* in a dual-choice bioassay (Repellence index = 0.59 in 12 h), besides presenting significant deterrence of females from laying eggs (Oviposition deterrent index = 67.63) on essential oil-treated chili (*Capsicum annuum* L.) leaves. Geraniol (19.34%), methyl eugenol (8.80%), and methyl isoeugenol (8.19%) were the main constituents of the oil, whereas the oxygenated and hydrocarbon monoterpenoids were the major groups, with a total of 56.28% and 31.27%, respectively (Saad *et al.*, 2017). In a fumigant test against adult insects, the EO from *C. citratus* leaves had an LC_{50} equal to 1.46 μL/L air. A similar result was found in the *C. nardus* EO, with an LC_{50} of 1.60 μL/L air. Moreover, the EOs showed no significant physiological changes in eggplant (*Solanum melogena*) (Pumnuan *et al.*, 2017). Another study with *C. citratus* leaves EO was conducted using a Fisher Block System, where the 1% dilution was particularly toxic to the whitefly, decreasing 23.5% when compared to the negative control.

At the same time, it favored the installation of beneficial insects in cotton plots. The treatment was performed for 115 days, with an interval of 14 days starting at the 45th day. Moreover, the *C. citratus* EO presented anti-cholinesterase activity on acetyl (2.26 mg Galantamine equivalent - GALAE) and butyrylcholinesterase (2.78 mg GALAE) inhibitors. Geranial (33.5%), neral (25.9%), and myrcene (23.4%) were the main compounds of the oil (Kobenan *et al.*, 2022). The 0.5% spray formulation from *Vetiveria zizanioides* caused 100% mortality against the Q and B *B. tabaci* biotypes during 24 h exposure, being more efficient than all positive controls tested, including those with natural or synthetic actives. The 0.1% formulation demonstrated better selectivity against the Q biotype (49%) when compared to the B biotype (46%) (Kim *et al.*, 2012).

Rutaceae

Wagan and collaborators (2017) also evaluated the effect of *Zanthoxylum bungeanum* fruit EO, which presented 36.96% (greenhouse) repellency and a deterrent oviposition percentage of 22.87% (greenhouse) in a period of 24 h, using a concentration of 10 mg/mL (Wagan *et al.*, 2018a).

Schisandraceae

The study by Liu *et al.* (2014) demonstrated that the *Illicium verum* EO showed an LC_{50} equal to 8.61 ppm after 24 hours, by fumigation (Liu *et al.*, 2014).

Stemonaceae

Wagan and researchers (2016) also evaluated the effect of *Stemona japonica* roots EO, which presented 51.88% (laboratory, in 24 h) and 86.67% (greenhouse) mortality by direct contact, insecticide activity rate by fumigation equal to 44.00% (laboratory, in 8 h), besides deterrent oviposition activity (12.62% laboratory and 12.87% greenhouse, in 24 h) (Wagan *et al.*, 2016).

Verbenaceae

The effect of the nanoemulsion containing *Lippia multiflora* leaves EO was observed against *B. tabaci*, so that the 1% concentration showed maximum fumigant effects against whitefly adults (81.48%) and contact toxicity against whitefly nymphs (46.44%), adult mites (49.81%), and mite nymphs (66.46%) within 24 h. In the greenhouse experiments, one of the main constituents, squalene (0.37%), showed maximum repellency against whitefly adults (89.59%), whitefly nymphal toxicity (80.08%) and mite toxicity (78.74%) within 24 h. The EO demonstrated maximum antioviposition activity against whiteflies (63.58%) and toxicity to mite nymphs (82.45%) within 24 h. 9–12-Octadecadienoic acid (1.81%) and ethyl linoleate (1.30%) were the two EO main constituents (Wagan *et al.*, 2018b). Another insecticidal study made with *L. multiflora* EO was conducted by Tia *et al.* (2013). The EO from a plant collected in Yamoussoukro, Ivory Coast, provided a $TL_{50} < 1$ hour, using a concentration equal to 0.4 μL/L air, presenting a mortality rate of 97.4% in 24 hours. The main constituents of the active oil were linalool (22.3%), 1,8-cineole (11.4%), geranial (10.6%), and neral (7.8%). However, the composition demonstrated to be different when the EO was collected by headspace technique, in which the linalool presented a percentage equal to 33.6%, the 1,8-cineole composition decreased to 4.5%, and the concentrations of geranial and neral increased to 15.7% and 12.7%, respectively (Tia *et al.*, 2013).

Zingiberaceae

Wagan and collaborators (2018a) also evaluated the effect of *Curcuma longa* EO, which presented 56.72% (fumigation) and 18.93% (greenhouse) repellency and a deterrent oviposition percentage of 68.46% (fumigation) in a period of 24 h, using a concentration of 10 mg/mL (Wagan *et al.*, 2018a). Tia *et al.* (2013) also evaluated the insecticidal activity of *Aframomum latifolia* leaves EO, which presented a TL_{50} equal to 7.18 h, using a concentration equal to 0.4 μL/L air, and a mortality rate of 90.8% in 24 hours. The main constituents of the EO were β-pinene (51.6%), (E)-β-caryophyllene (12.3%), sabinene (7.6%), and α-humulene (5.1%) (Tia *et al.*, 2013).

The following Table 1 and Table 2 summarize the selected articles of this section and their main information.

Table 1: Essential Oils found in Africa and Asia with insecticidal/larvicidal activity against *Bemisia tabaci*

Plant Species	Family	EO Origin	Biological Activity	References
Acorus tatarinowii	Acoraceae	Rhizomes	Mortality by direct contact: 95.62% (laboratory in 24 h) and 58.25% (greenhouse); insecticide activity rate by fumigation equal to 98.75% (laboratory in 8 h); deterrent oviposition activity (7.0% laboratory and 10.38% greenhouse in 24 h) 10 mg/mL	Wagan *et al.* 2016
Chenopodium ambrosioides	Amaranthaceae	NI	Mortality by fumigation: LC50 equal to 8.80 ppm after 24 hours	Liu *et al.* 2014
Allium sativum	Amaryllidaceae	Bulbs	Repellent (93%) and deterrent (95.55% after 10 days) activities; insecticide effect by fumigation assay (LC50 = 141.13 ppm) within 48 hours at 2% conc.	Hussein 2017
Allium ascalonicum	Amaryllidaceae	Entire plant	Repellence (70.70%); mortality by direct contact: approximately 17%; deterrent oviposition percentage of 44.75% in a period of 24 h at 10 mg/mL.	Wagan *et al.* 2022
Schinus terebenthifolia	Anacardiaceae	Fruits	Mortality by fumigation: an LC50 equal to 102 ppm in 48 h	Hussein *et al.* 2017
Cuminum cyminum	Apiaceae	NI	Repellent (87%) and deterrent (87% after 10 days) activities; insecticide effect by fumigation (LC50 = 141.13 ppm after 48 h) at 2% conc.	Hussein 2017
Foeniculum vulgaris	Apiaceae	Seeds	Mortality by fumigation: LC50 equal to 7.06 μg/mL air after 24 hours	Sertkaya *et al.* 2010
Heracleum hemsleyanum	Apiaceae	Roots	Mortality by direct contact: 69.38 % (laboratory, in 24 h) and 83.75 % (greenhouse); insecticide activity rate by fumigation equal to 60.50 % (laboratory, in 8 h); deterrent oviposition activity (7.25 % laboratory and 17.12 % greenhouse, in 24 h), 10 mg/mL	Wagan *et al.*, 2016.
Artemisia absinthium	Asteraceae	NI	1 µL repelled 78.9 % of adult B. tabaci, in a Y-tube olfatometer test; 0.5 % concentration caused 80 % mortality by contact toxicity.	Li *et al.*, 2022
Artemisia pallens	Asteraceae	NI	0.5 and 0.1 % spray formulations caused 93 and 31 % mortality against the B biotype and, 93 and 13 % against the Q biotype, respectively	Kim *et al.*, 2012
Artemisia Siberia	Asteraceae	NI	Mortality by fumigation: 0.3 % conc. reached circa 90 % in 24 hours	Zandi-Sohani *et al.*, 2018
Erigeron floribundus	Asteraceae	NI	Mortality by fumigation: 88.8 % in 24 hours, at 0.4 μL/L air	Tia *et al.*, 2013
Ferula gummosis	Ferulaceae	NI	Mortality by fumigation: 0.3 % conc. reached circa 90 % in 24 hours	Zandi-Sohani *et al.*, 2018
Pelargonium roseum	Geraniaceae	NI	Mortality by fumigation: 0.3 % conc. reached 100 % in 24 hours	Zandi-Sohani *et al.*, 2018

Ocimum gratissimum	Lamiaceae	Leaves	Populational control: 31.5 % decreasing, using 5% concentration during 115 days with an interval of 14 days starting at the 45th day after the plantation of cotton plants	Kobenan *et al.*, 2022
Thymus vulgaris	Lamiaceae	NI	Repellent (98.36 %), deterrent (100 %, after 10 days), and insecticide (LC50 = 71.75 ppm, after 48 h) activities, at 2% conc.	Hussein, 2017
Thymus vulgaris	Lamiaceae	NI	0.5 and 0.1 % spray formulations caused 75 and 8 % mortality against the B biotype and, 87 and 16 % against the Q biotype, respectively	Kim *et al.*, 2011
Thymus vulgaris	Lamiaceae	NI	Mortality by fumigation: 27 % at 3.125 μL/L air, after 24 hours	Aslan *et al.*, 2004
Origanum vulgare	Lamiaceae	NI	Mortality by fumigation: 27 % at 3.125 μL/L air, after 24 hours	Aslan *et al.*, 2004
Origanum vulgare	Lamiaceae	NI	0.5 and 0.1 % spray formulations caused 94 and 19 % mortality against the B biotype and, 98 and 21 % against the Q biotype, respectively	Kim *et al.*, 2012
Nepeta cataria	Lamiaceae	NI	0.5 and 0.1 % spray formulations caused 43 and 17% mortality against the B biotype and, 98 and 90 % against the Q biotype, respectively	Kim *et al.*, 2012
Thymus pulegioides	Lamiaceae	NI	1 μL repelled 83.3 % of adult B. tabaci, in a Y-tube olfatometer test; 0.5 % concentration caused 84 % mortality by contact toxicity.	Li *et al.*, 2022
Mentha haplocalyx	Lamiaceae	Leaves	Repellence (77.67 %); mortality by direct contact: approximately 54 %; deterrent oviposition percentage of 58.25%, in a period of 24 h, at 10 mg/mL.	Wagan *et al.*, 2022
Mentha spicatus	Lamiaceae	Leaves	Mortality by fumigation: 10 μg/954 mL conc. reached 99.1 % in 24 hours	Choi and Kim, 2004
Mentha pulegium	Lamiaceae	Leaves	Mortality by fumigation: 100 % at 2 μL/L air, after 6 hours	Zandi-Sohani *et al.*, 2011
Mentha Viridis	Lamiaceae	Leaves	Mortality by fumigation: 100 % at 2 μL/L air, after 6 hours	Zandi-Sohani *et al.*, 2011
Satureja hortensis	Lamiaceae	Leaves	Mortality by fumigation: 100 % at 2 μL/L air, after 12 hours	Zandi-Sohani *et al.*, 2011
Satureja hortensis	Lamiaceae	Leaves	Mortality by fumigation: 44 % at 3.125 μL/L air, after 24 hours	Aslan *et al.*, 2004
Zataria multiflora	Lamiaceae	Leaves	Mortality by fumigation: 100 % at 2 μL/L air, after 12 hours	Zandi-Sohani *et al.*, 2011
Thymbra spicata	Lamiaceae	Leaves	Mortality by fumigation: LC_{50} equal to 0.44 μg/mL air, after 24 hours	Sertkaya *et al.*, 2010
Agastache rugosa	Lamiaceae	NI	Mortality by fumigation: LC_{50} equal to 7.08 ppm, after 24 hours	Liu *et al.*, 2014
Cinnamomum bejolghota	Lauraceae	Fresh leaves	Mortality by fumigation: LC_{50} equal to 1.52 μL/L, after 24 hours	Pumnuan *et al.*, 2017

Cinnamomum zeylanicum	Lauraceae	NI	0.5 and 0.1 % spray formulations caused 100 and 45 % mortality against the B biotype and, 100 and 75 % against the Q biotype, respectively	Kim *et al.*, 2012
Cinnamomum camphora	Lauraceae	Small leaves	Repellence (84.83 %); mortality by direct contact: 64.25 %; deterrent oviposition percentage of 63.44 %, in a period of 24 h, at 10 mg/mL.	Wagan *et al.*, 2022
Litsea cubeba	Lauraceae	Fruits	Repellence: 69.14 % (fumigation) and 54.77 % (greenhouse); deterrent oviposition: 48.62 % (fumigation) and 36.16 % (greenhouse), both in a period of 24 h, at 10 mg/mL.	Wagan *et al.*, 2018a
Laurus nobilis	Lauraceae	Leaves	Mortality by fumigation: LC_{50} equal to 1.82 μg/mL air, after 24 hours	Sertkaya *et al.*, 2010
Myristica fragrans	Myristicaceae	Fruits	Fumigation toxicity (79.17 ± 3.00%), contact toxicity (72.50 ±4.23%), and repellency (76.67 ± 7.15%) in the laboratory experiments after 8, 48 and 24 hours, respectively; greenhouse experiments: repellency (maximum value: 58.33 ±3.50%) and anti-oviposition (46.11 ± 5.38%) activity, after 24 h of exposure	Wagan *et al.*, 2017
Syzigium aromaticum	Myrtaceae	Dried buds	Mortality by fumigation: LC_{50} equal to 1.36 µL/L, after 24 hours	Pumnuan *et al.*, 2017
Syzigium aromaticum	Myrtaceae	Dried buds	Mortality by fumigation: LC_{50} equal to 13.54 ppm, after 24 hours	Liu *et al.*, 2014
Syzigium aromaticum	Myrtaceae	Leaves and Buds	0.5 and 0.1 % spray formulations from leaves EO caused 93 and 14 % mortality against the B biotype and, 96 and 24 % against the Q biotype, respectively; 0.5 and 0.1 % spray formulations from buds EO caused 99 and 18 % mortality against the B biotype and, 93 and 8 % against Q biotype, respectively	Kim *et al.*, 2012
Corymbia citriodora	Myrtaceae	Leaves	Mortality by fumigation: an LC_{50} equal to 249 ppm in 48 h	Hussein *et al.*, 2017
Melaleuca leucadendron	Myrtaceae	NI	Mortality by fumigation: 87.5 % in 24 hours, at 0.4 μL/L air; TL50 < 1 hour	Tia *et al.*, 2013
Piper nigrum	Piperaceae	Fruits	Repellence: 63.67 % (fumigation) and 44.17 % (greenhouse); deterrent oviposition: 51.02 % (fumigation) and 43.35 % (greenhouse), both in a period of 24 h, at 10 mg/mL.	Wagan *et al.*, 2018a
Cymbopogon flexuosus	Poaceae	Leaves	Mortality by direct contact: 88.79% at 0.9 %; Deterrent oviposition: 66 % at 0.9 %	Chandra *et al.*, 2021
Cymbopogon nardus	Poaceae	Leaves	Mortality by fumigation: LC_{50} equal to 1.028 μL/L air, after 24 hours; Repelence index = 0.59 in 12 h;Oviposition deterrent index = 67.63	Saad *et al.*, 2017
Cymbopogon nardus	Poaceae	Leaves	Mortality by fumigation: LC_{50} equal to 1.60 μL/L, after 24 hours	Pumnuan *et al.*, 2017

Cymbopogon citratus	Poaceae	Leaves	Mortality by fumigation: LC_{50} equal to 1.46 μL/L, after 24 hours	Pumnuan *et al.*, 2017
Cymbopogon citratus	Poaceae	Leaves	Populational control: 23.5 % decreasing, using 1% concentration during 115 days with an interval of 14 days starting at the 45th day after the plantation of cotton plants	Kobenan *et al.*, 2022
Vetiveria zizanioides	Poaceae	NI	0.5 and 0.1 % spray formulations caused 100 and 46 % mortality against the B biotype and, 100 and 49 % against the Q biotype, respectively	Kim *et al.*, 2012
Zanthoxylum bungeanum	Rutaceae	Fruits	Repellence: 36.96 % (greenhouse); deterrent oviposition: 22.87 % (greenhouse), both in a period of 24 h, at 10 mg/mL.	Wagan *et al.*, 2018a
Illicium verum	Schisandraceae	NI	Mortality by fumigation: LC_{50} equal to 8.67 ppm, after 24 hours	Liu *et al.*, 2014
Stemona japonica	Stemonaceae	Roots	Mortality by direct contact: 51.88 % (laboratory, in 24 h) and 86.67 % (greenhouse); insecticide activity rate by fumigation equal to 44 % (laboratory, in 8 h); deterrent oviposition activity (12.62 % laboratory and 12.87 % greenhouse, in 24 h), 10 mg/mL	Wagan *et al.*., 2016
Lippia multiflora	Verbenaceae	Leaves	1 % conc. showed maximum fumigant effects against whitefly adults (81.48%) and contact toxicity against whitefly nymphs (46.44%), adult mites (49.81%), and mite nymphs (66.46%), at 24 h; maximum anti-oviposition activity against whiteflies (63.58%) and toxicity to mite nymphs (82.45%), at 24 h	Wagan *et al.*, 2018b
Lippia multiflora	Verbenaceae	NI	Mortality by fumigation: 97.4 % in 24 hours, at 0.4 μL/L air; TL_{50} < 1 hour	Tia *et al.*, 2013
Curcuma longa	Zingiberaceae	Roots	Repellence: 56.72 % (fumigation) and 18.93 % (greenhouse); deterrent oviposition: 68.46 % (fumigation), both in a period of 24 h, at 10 mg/mL.	Wagan *et al.*, 2018a
Aframomum latifolia	Zingiberaceae	Leaves	Mortality by fumigation: 90.8 % in 24 hours, at 0.4 μL/L air; TL_{50} equal to 7.18 h	Tia *et al.*, 2013

NI = Not Informed.

Table 2: Chemical composition of active EOs described in the review.

Plant Species	EO chemical composition	References
Allium sativum	Diallyl trisulfide (61.87 %), diallyl disulfide (19.47 %) and diallyl sulfide (4.41 %)	Liu *et al.*, 2014
Allium ascalonicum	Sulfinylbis methane (6.56 %)	Wagan *et al.*, 2022
Schinus terebenthifolia	α-pinene (36.9 %), α-phellandrene (32.8 %), limonene (11.9 %) and α-terpineol (6.0 %)	Hussein *et al.*, 2017
Foeniculum vulgaris	Trans-anethole (82.80 %), 4-allyl anisole (6.56 %), and limonene (5.79 %)	Sertkaya *et al.*, 2010
Artemisia absinthium	β-pinene (27.78 %) and linalool (23.41 %)	Li *et al.*, 2022
Erigeron floribundus	limonene (21.9 %), (Z)-β-farnesene (16.3 %), (E)-methyl-lachnophyllate (9.6 %) and (E)-β-caryophyllene (9.5 %).	Tia *et al.*, 2013
Ocimum gratissimum	p-cymene (37.0 %) and thymol (18.7 %)	Kobenan *et al.*, 2022
Thymus pulegioides	Thymol (36,18 %), carvacrol (13.43 %), p-cymene (10.85 %) and thymol methyl ether (7.45 %)	Li *et al.*, 2022
Mentha haplocalyx	L-(-)menthol (8.26 %), 9,12,15-octadecatrienoic acid, (Z, Z,Z) (4.48 %) and hexadecanoic acid (4.40 %)	Wagan *et al.*, 2022
Mentha spicatus	Carvone (40.9 %), limonene (16.1 %) and γ-terpinene (13.8 %)	Choi and Kim, 2004
Thymbra spicata	Carvacrol (70.93 %), p-cymene (13.77 %) and λ-terpinene (6.98 %)	Sertkaya *et al.*, 2010
Rosmarinus officinalis	Borneol (20.4 %), camphor (19.5 %) and 1,8-cineole (17.4 %)	
Cinnamomum camphora	1,5-hepcidin-4-one,3,3,6- trimethyl acetic acid (59.94 %), and nerolidol (12.18 %)	Wagan *et al.*, 2022
Laurus nobilis	1,8-cineole (35.50 %), sabinene (15.0 %), and α-terpineol acetate (14.20 %)	Sertkaya *et al.*, 2010
Corymbia citriodora	α-citronellal (53.1 %), α-citronellol (13.7 %), citronellol acetate (12.2 %)	Hussein *et al.*, 2017
Melaleuca leucadendron	1,8-cineole (50.4 %), viridiflorol (16.4 %), α-pinene (12.4 %) and α-terpineol (8.1 %)	Tia *et al.*, 2013
Cymbopogon flexuosus	Geranial (47.3 %) and neral (34.7 %)	Chandra *et al.*, 2021
Cymbopogon nardus	Geraniol (19.34 %), methyl eugenol (8.80 %) and methyl isoeugenol (8.19 %)	Saad *et al.*, 2017
Cymbopogon citratus	geranial (33.5 %), neral (25.9 %) and myrcene (23. 4 %)	Kobenan *et al.*, 2022
Lippia multiflora	9–12-Octadecadienoic acid (1.81 %) and ethyl linoleate (1.30 %)	Wagan *et al.*, 2018b
	linalool (22.3 %), 1,8-cineole (11.4 %), geranial (10.6 %) and neral (7.8 %)	Tia *et al.*, 2013
Aframomum latifolia	β-pinene (51.6 %), (E)-β-caryophyllene (12.3 %), sabinene (7.6 %) and α-humulene (5.1 %)	

Figure 2: Example of plants with high activity EOs against *Bemisia tabaci*. From left to right: bulbs of Allium sativum, leaves and fruits from *Cinnamomum camphora*, and leaves and flowers from *Thymbra spicata*. Sources: Nino Barbieri *(A. sativum)*, Peter Woodard *(C. camphora)*, and Gideon Pisanty *(T. spicata)*.

The review article on essential oils from species found on the African and Asian continents described the insecticidal, repellent, or ovicidal activity on Bemisia tabaci of 48 different species, distributed in 19 different families, among which, Asteraceae, Lamiaceae, Lauraceae, Myrtaceae, and Poaceae were the most representative families, with the highest number of studies.

Among the works carried out with multiple essential oils, the Liu *et al.*. study (2014) pointed to the use of Allium sativum essential oil as the most active EO (Fig. 2), with diallyl trisulfide as the main active responsible for the fumigant insecticidal action. Allyl disulfide and diallyl trisulfide (Fig. 3) are the main constituents responsible for the larvicidal activity of garlic, so their subsequent products are more toxic (Kimbaris *et al.*, 2009), due to the presence of the sulfur group in these molecules, which in turn interacts with proteins of high importance in insect metabolism, structure, and reproduction (Wu *et al.*, 2020).

The study of Wagan *et al.* (2022) highlighted the *Cinnamomum camphora* EO as the most active insecticide among the evaluated oils, presenting the 1,5-Heptadien-4-one, 3,3,6-trimethyl acetic acid as the major compound, which is a complex oxygenated monoterpenoid derivative. This class of substances is related to the specificity of the biological activity of essential oils, interacting specifically with enzymes, as described by Moghaddam and Mehdizadeh (2017). Moreover, this EO also has nerolidol, a potent sesquiterpenoid insecticide (Silva *et al.*, 2020), as the second most abundant substance.

In its turn, *Thymbra spicata* EO was the most active in the study of Sertkaya et al. (2010), presenting carvacrol as its main constituent. This substance is known to influence the metabolism of plant-predating insects, for example, inhibiting detoxifying and antioxidant enzymes and their genetic expressions in *Lymantria dispar*, in addition to causing genotoxic effects and mutations in *Drosophila* (Chen *et al.*, 2021; Nesterkina *et al.*, 2023). In the same study, the EOs from *Rosmarinus officinalis* and *Laurus nobilis* also demonstrated high activity against adults of *B. tabaci*, both of which showed the well-known insecticide 1,8-cineole as one of their major compounds, which inhibits the acetylcholinesterase activity from insects (Abdelgaleil *et al.*, 2009; Kahkeshani *et al.*, 2018).

Still regarding the activity of oils rich in oxygenated monoterpenes (OMs), the important insecticidal activity of *Cymbopogon nardus* can be highlighted, presenting more than 50% of its composition in OMs, including the three main substances, geraniol, methyl eugenol, and methyl isoeugenol. Additionally, the high effect of *Lippia multiflora* EO, in which linalool, 1,8-cineole, geranial, and neral were the major compounds, should be noted.

However, despite OMs being recognized as substances responsible for the greater biological activity of EOs, the importance of synergistic mechanisms cannot be ruled out. This is evident in the EO of *Mentha spicata*, which presented carvone as the main component but showed less efficiency compared to other EOs. The second major component of the *M. spicata* EO is limonene, a monoterpene hydrocarbon, which disrupts the plasmatic membrane as its principal mechanism of action, causing toxic and irritating effects to insects,

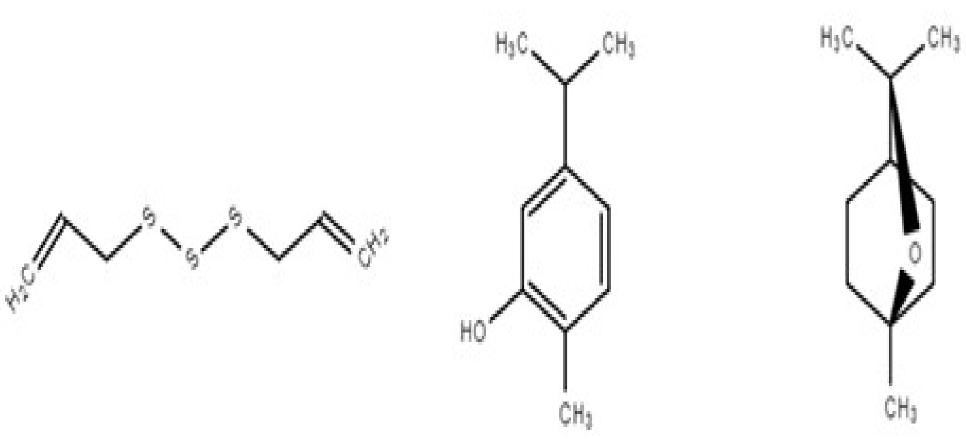

Figure 3: Important major compounds from EOs with high insecticidal activity against *B. tabaci.* From left to right: diallyl trisulfide, carvacrol, and 1,8-cineole. Source: Authors.).

mainly affecting the respiratory organs (Abdallah *et al.*, 2017).

Another factor to be considered is the resistance or susceptibility of *B. tabaci* biotypes to essential oils, as seen in the work by Kim et al. (2012), in which formulations showed different efficiency on the Q and B biotypes. In addition, using different concentrations of the actives, the specificity on the biotype was inverted.

Furthermore, it is already known that the composition of essential oils can vary according to environmental factors, including climate, degree of plant development, pollination, infestation, amount of sunlight, edaphic influence, and latitude, among others. Thus, a chemical study is necessary to standardize the use of these resources. Due to this, more detailed studies on the chemical variety of EOs must be conducted in some cases (Simões and Spitzer, 2007).

The method of extraction of essential oils can also be crucial to their quality. This was demonstrated in the study by Tia *et al.* (2013), where they compared the quantification of major compounds through conventional extraction and the headspace technique, the latter being more reliable to the actual composition of the oil in the vegetable (Wampler, 2020).

In addition, the high potency of oils such as those from *Foeniculum vulgare*, *Erigeron floribundus*, *Pelargonium roseum*, *Cinnamomum bejolghota*, *Melaleuca leucodendron*, *Mentha pulegium*, *M. viridis*, and *Syzygium aromaticum* could be highlighted. The latter has a large amount of eugenol, which has also been shown to be efficient against *B. tabaci* (Ribeiro *et al.*, 2020). In this way, the variety of essential oils found in African and Asian countries is abundant, indicating that further studies of formulations, field applications, and environmental toxicity are needed. These studies aim to promote the larger-scale use of these natural resources to reduce environmental interference and health risks to consumers, as well as to offer alternatives to the emergence of resistance to conventionally used pesticides.

CONCLUSION

In conclusion, the review article on essential oils from African and Asian species has provided valuable insights into their insecticidal, repellent, and ovicidal activities against *Bemisia tabaci*. Among the various essential oils studied, we exemplified those extracted from *Allium sativum*, *Cinnamomum camphora*, and *Thymbra spicata* as having high activity against *B. tabaci* with detailed chemical discussion. Furthermore, other essential oils with broad commercialization, for example, from *Foeniculum vulgare*, *Mentha pulegium*, *M. viridis*, and *Syzygium aromaticum*, also exhibited high potency against *B. tabaci*. Then, these findings highlight the abundant variety of essential oils available in African and Asian countries, so that further studies are necessary to explore the potential of these natural resources on a larger scale. Finally, their utilization can help reduce environmental interference, protect consumer health, and serve as alternatives to conventional pesticides, thus addressing the issue of pesticide resistance.

DECLARATION OF INTERESTS

The authors have no conflict of interest.

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