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Review on selected essential oils from America as applied resources to control *Bemisia tabaci*, an important agronomical pest

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America-available EOs in the control of *Bemisia tabaci*.

ABSTRACT

Bemisia tabaci, also known as whitefly, is a significant agricultural pest that feeds on a wide range of crops and causes extensive damage, leading to significant yield losses and reduced crop quality, causing losses of billions of dollars on the American continent. Several pesticides are used to control *B. tabaci*, but they can have adverse effects on human health and the environment. As an alternative, essential oils (EOs) are gaining increasing attention due to concerns over the safety and environmental impact of synthetic pesticides. In this context, it is necessary to optimize scientific information on the insecticidal action of natural products found in American countries against *B. tabaci*, so this review discusses the insecticidal activity of EOs from various plant species. Among the studied EOs, those of the Rutaceae family are highly efficient, with *Citrus aurantiifolium* and *Citrus limon* having the highest insecticidal and deterrent activities due to their high concentration of α-terpineol. Other EOs from disseminated American plants, such as *Pelargonium graveolens*, *Piper callosum*, and *Laurel nobilis*, also showed significant insecticidal and deterrent activities. Hence, the review highlights that the America-available EOs can be used as a sustainable alternative to the control of *B. tabaci*.

1. INTRODUCTION

Food loss due to pest attacks is a significant problem that affects the global food supply chain. Pests, including insects, rodents, and fungi, can damage crops during growth, harvesting, transportation, and storage. This loss not only impacts the availability and affordability of food, but also has significant economic, social, and environmental consequences [1]. The World Health Organization estimates that about one-third of all food produced globally is lost or wasted, with pests contributing significantly to this figure [2]. Agricultural losses caused by pests in America can vary according to many factors, such as crop type, region, and year. However, it is estimated that losses caused by pests can reach billions of dollars each year in the region. For example, in Brazil, the largest agricultural producer in Latin America, it is estimated that losses caused by pests and diseases in crops can reach around US$17.7 billion per year. In the United States, losses caused by pests and diseases in agricultural crops can reach US$120 billion per year [3,4]. In addition to the economic costs associated with food loss, such as decreased income for farmers and increased prices for consumers, there are also environmental costs, including increased greenhouse gas emissions due to food waste decomposition [5]. Therefore, addressing food loss due to pests is critical to ensuring global food security and sustainability [6].

In this context, *Bemisia tabaci*, commonly known as the silverleaf whitefly, is a significant worldwide agricultural pest that feeds on a wide range of crops, including fruits, vegetables, and ornamental plants [7]. This tiny insect is considered a serious threat to global food security due to the extensive damage it causes to crops, leading to significant yield losses and reduced crop quality [8]. *B. tabaci* has a piercing-sucking mouthpart that allows it to extract sap from plants, leading to the development of leaf yellowing, deformation, and even death. In addition, this pest is known to transmit more than 100 plant viruses, causing further damage to crops [9,10]. The economic impact of *B. tabaci* on agriculture is substantial, with billions of dollars lost every year due to crop damage and the cost of pest management. Therefore, effective control measures are critical to reduce the impact of this pest on food production and ensure global food security [11].

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There are several pesticides used to control *B. tabaci*, including neonicotinoids, organophosphates, pyrethroids, and insect growth regulators. However, these pesticides can have adverse effects on human health and the environment [12]. Neonicotinoids are also known to harm non-target organisms such as bees and other beneficial insects, leading to concerns about their impact on the environment and biodiversity [13]. On the other hand, organophosphates and pyrethroids are also commonly used to control *B. tabaci*. Nonetheless, these pesticides are highly toxic to humans and can cause a range of health problems, including headaches, nausea, dizziness, and respiratory problems. Long-term exposure to these pesticides has been linked to more serious health issues such as cancer, neurological disorders, and developmental problems [14]. Moreover, insect growth regulators, such as methoprene, are a safer alternative to traditional pesticides as they specifically target insect development and do not harm beneficial insects or humans. However, they can still have negative impacts on the environment if not used properly, such as unintended effects on non-target organisms [15]. Due to these several limitations, the use of alternative pest control methods, such as biological control and biopesticides, is currently targeted, aiming at sustainability and the promotion of consumer health [16].

Plant extracts and essential oils (EOs) have been used for centuries as natural pest control methods due to their broad-spectrum activity and lower toxicity compared to synthetic pesticides. These substances are derived from various parts of plants, including leaves, flowers, roots, and seeds, and contain a variety of compounds that have insecticidal and repellent properties [17]. Particularly, the use of EOs in pest management is gaining increasing attention due to concerns over the safety and environmental impact of synthetic pesticides. Several studies have demonstrated the effectiveness of EOs in controlling various agricultural pests, such as aphids, whiteflies, mosquitoes, and bedbugs. In addition, EOs can be used in different ways, such as spraying, fumigation, and application in baits, which increases their versatility and possibility of application in different cultures [18-20]. In addition to their effectiveness in controlling pests, they have the added advantage of being biodegradable, sustainable, and cost-effective, besides minimizing the emergence of pest resistance, due to the variety and natural complexity of their substances [21,22].

In this context, it is necessary to optimize scientific information on the insecticidal action of natural products found in American countries against *B. tabaci*, so this review will cover and discuss the studies involved with EOs that have relevant action against this important agronomic pest.

2. METHODOLOGY

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 and only studies with EOs from plants collected in American countries or purchased by laboratories located in America were taken into account. Then, after careful selection, 11 articles about the proposed central theme were included and discussed in the two next sections of the review, which exclude the articles described in the introduction and discussion sections. Tables 1 and 2 summarize the selected articles and their main information.

3. RESULTS

3.1. EOs Found in America with Insecticidal Activity Against *Bemicia Tabaci*

3.1.1. Annonaceae

Free and nanoencapsulated EOs from *Xylopia aromatica* leaves and fruits decreased the oviposition of *B. tabaci* in common bean leaves. At a concentration of 2%, the free EO from leaves and fruits caused up to 98 and 96% deterrent activity, respectively, whereas the encapsulated EOs reached 91 and 88% activity, respectively. These results were considered very high since the positive control (pyriproxifen 1%) caused less than 10% deterrent activity. For the leaves EO, the major compounds were bicyclogermacrene (44.80%), α-pinene (8.23%), and β-pinene (7.75%), while in fruits they were α-pinene (35.40%), β-phellandrene (31.05%), and β-pinene (22.51%) [23].

3.1.2. Bignoniaceae

Mansoa alliaceae EO caused nymph mortality (LC_{50} = 10.99 µL/mL and LC_{90} = 22.25 µL/mL, after 5 days of exposure), which was also observed in the semifield condition (90.54% efficacy). Still, the EO demonstrated a reduction in cotton pest colonization as well as ovicidal, repellent, and deterrent activities. The major constituents of the oil were diallyl trisulfide (52.8%) and diallyl disulfide (33.9%) [24]. The EO from *Adenocalymma alliaceum* was also effective against the *B. tabaci* type B tomato settlement (50% reduction), besides producing an oviposition deterrent effect (71.1% reduction). Moreover, the EO showed insecticide activity against nymphs and adults, with a LC_{50} equal to 0.4 and 0.8 µL/L air in 72 and 3 h, respectively. Its main compounds were diallyl trisulfide (66.9%) and diallyl sulfide (23.3%) [25].

3.1.3. Geraniaceae

The EO from *Pelargonium graveolens* was effective against the *B. tabaci* type B tomato settlement (73.6% reduction), besides producing an oviposition deterrent effect (90.9% reduction). Moreover, the EO showed insecticide activity against adult insects, with a LC_{50} equal to 0.6 µL/L air in 24 h. Its main compounds were the alcohol monoterpenes geraniol (42.3%) and linalool (16.4%) [25].

3.1.4. Lamiaceae

The EO from *Plectranthus neochilus* was effective against the *B. tabaci* type B tomato settlement (34.5% reduction), besides producing an oviposition deterrent effect (61.5% reduction). Its main compounds were trans-caryophyllene (30.7%), as well as the bicyclic monoterpenes α-thujene (11.7%), α-pinene (15.0%), and β-pinene (8.3%). In the same study, it was described the adult insecticidal activity of *Vitex agnus castus*, presenting an LC_{50} equal to 1.2 µL/L air in 24 hours, whereas its major constituents were the monoterpenes 1.8-cineole (33.2%) and sabinene (22.7%) [25].

3.1.5. Lauraceae

The study of Ringuelet *et al*. (2012) demonstrated the effect of *Laurel nobilis* EO 5% on *B. tabaci*, leading to its repellence (73.1%) and mortality (53%) after 24 h, with five daily applications. The effect was improved when the laurel EO was mixed with *C. citratus* EO at a 1:1 proportion. With this condition, the repellence index enhances to 84.34%, and the mortality rate reaches 55.5% [26].

3.1.6. Piperaceae

Piper marginatum EO caused nymph mortality (LC_{50} = 9.39 µL/mL and LC_{90} = 20.79 µL/mL, after 5 days of exposure), which was also observed in the semifield condition (91.51% efficacy). Still, the EO demonstrated a reduction in cotton pest colonization as well as

Table 1: Essential oils obtained in American countries with insecticidal/repellent/deterrent activity against *Bemisia tabaci*.

Plant species	Family	EO origin	Main constituents (%)	References
Xylopia aromatica	Annonaceae	Leaves	Bicyclogermacrene (44.80), α-pinene (8.23) and β-pinene (7.75)	Peres *et al*., 2020
		Fruits	α-pinene (35.40), β-phellandrene (31.05) and β-pinene (22.51)	
Mansoa alliaceae	Bignoniaceae	ND	Diallyl trisulfide (52.8) and diallyl disulfide (33.9)	Santana *et al*., 2022
Adenocalymma alliaceum			Diallyl trisulfide (66.9) and diallyl sulfide (23.3)	Fanella *et al*., 2015
Pelargonium graveolens	Geraniaceae		Geraniol (42.3) and linalool (16.4)	
Plectranthus neochilus	Lamiaceae		Trans-caryophyllene (30.7), α-thujene (11.7), α-pinene (15.0) and β-pinene (8.3)	
Vitex agnus-castus			1.8-cineole (33.2) and sabinene (22.7)	
Laurus nobilis	Lauraceae	Leaves	ND	Ringuelet *et al*., 2012
Piper marginatum	Piperaceae	ND	(*E*)-methyl eugenol (34.7) and (*Z*)-methyl eugenol (27.5)	Santana *et al*., 2022
Piper callosum			safrole (29.3), α-pinene (19.2), and β-pinene (14.3)	Fanella *et al*., 2015
Cymbopogon citratus	Poaceae	Leaves	ND	Ringuelet *et al*., 2012
Zanthoxylum riedelianum	Rutaceae	Fruits	Limonene (29.22), β-myrcene (22.79), bicyclogermacene (18.13) and germacrene D (14.40)	Pereira *et al*., 2018
			γ-elemene (21.2), germacrene D (14.2), sabinene (11.9) and limonene (11.3)	Costa *et al*., 2017
		Leaves	γ-elemene (24.81), phytol (18.16), bicyclogermacrene (16.18), *cis*-nerolidol (8.26), and D-germacrene (6.52)	Christofoli *et al*., 2022
Zanthoxylum rhoifolium		Fruits	β-phellandrene (76.8)	Pereira *et al*., 2022
			Sabinene (55.9), germacrene D (17.1) and β-myrcene (8.03)	Costa *et al*., 2017
		Leaves	Whereas β-elemene (31.26), D-germacrene (18.16), β-caryophyllene (12.09), δ-elemene (7.63), β-cedrene (6.69), bicyclogermacrene (4.57) and E-caryophyllene (3.63)	Christofoli *et al*., 2015
Citrus aurantifolia		Peels	Limonene (37.73), β-pinene (9.89), α-terpineol (5.04)	Ribeiro *et al*., 2020
Citrus limon			Limonene (40.70), β-pinene (18.14), α-terpineol (2.78)	
Citrus reticulata			Limonene (70.96), myrcene (4.61)	
Citrus sinensis×reticulata			Limonene (77.79), p-Mentha-2,4 (8)-diene (9.80), myrcene (6.50)	
Clonorchis sinensis var. pear			ND	Ribeiro *et al*., 2010
Citrus aurantium				

EO: Essential oil.

ovicidal, repellent, and deterrent activities. The major constituents of the oil were (*E*)-methyl eugenol (34.7%) and (*Z*)-methyl eugenol (27.5%) [24]. The EO from *Piper callosum* was also effective against the *B. tabaci* type B tomato settlement (70.8 % reduction), besides promoting an oviposition deterrent effect (91.5 % reduction). Its main compounds were safrole (29.3%), α-pinene (19.2%), and β-pinene (14.3%) [25].

3.1.7. Poaceae

The study of Ringuelet *et al*. (2012) demonstrated the effect of *Cymbopogon citratus* EO 5% on *B. tabaci*, leading to its repellence (77.32%) and mortality (31.2%) after 24 h with five daily applications. The effect was improved when the laurel EO was mixed with *L. nobilis* EO at a 1:1 proportion. With this condition, the repellence index enhances to 84.34%, and the mortality rate reaches 55.5% [26].

3.1.8. Rutaceae

Pereira *et al*. (2018) showed the insecticidal activity of the *Zanthoxylum riedelanum* fruit EO as well as that of its nanosphere-encapsulated form against *B. tabaci*. In a free-choice test, the encapsulated and free EO, in a concentration equal to 1.5%, reduced the number of whitefly eggs by approximately 70%. However, in the larvicidal assay, both formulations killed 82.87% and 91.23% of 2nd-instar whitefly nymphs, respectively. Although the encapsulated EO displayed lower insecticidal activity, it offers a greater advantage over the free EO due to the photodegradation protection conferred by the nanosphere polymer. Limonene (29.22%), β-myrcene (22.79%), bicyclogermacene (18.13%), and germacrene D (14.40%) were the major constituents of the EO [27]. More recently, the same research group evaluated the insecticidal activity of the *Zanthoxylum rhoifolium* fruit EO in its free and encapsulated form in nanospheres. The concentrations in a range between 0.25 and 1.25% reduce adult whitefly oviposition by up to 71%. Also, the formulation containing 1.5% EO caused up to 91% mortality of second-instar nymphs. But when the test was conducted under high temperature and light radiation conditions, the insecticidal effect of the treatments with 1.5% encapsulated EO improved the mortality (84.3%) when compared to the free form (64.8%). The sesquiterpene β-phellandrene (76.8%) was the major compound of the oil [28]. In a previous study, both aforementioned *Zanthoxylum* EOs were evaluated for their deterrent oviposition activities against *B. tabaci* biotype B. The best results obtained in the bioassays were achieved at concentrations ranging from 1.0 to 2.0% for both EOs, with a reduced efficiency of egg laying of 85 and 98%, respectively. For these assays, the chemical composition of the oils was γ-elemene (21.2%), germacrene D (14.2%), sabinene (11.9%), and limonene (11.3%) for *Z. riedelanium,* and sabinene (55.9%), germacrene D (17.1%), and β-myrcene (8.03%) for *Z. rhoifolium* [29]. Also, the insecticidal and deterrent effects of *Z. riedelianum* and *Z. rhoifolium* leaf EOs were evaluated. Bioassays with free and nanoencapsulated

Table 2: Biological activity of America-available essential oils on *Bemisia tabaci.*

Plant species	EO origin	Biological activity	References
Xylopia aromatica	Leaves	Deterrent activity at 2%: 98% reduction	Peres *et al*., 2020
	Fruits	Deterrent activity at 2%: 96% reduction	
Mansoa alliaceae	ND	Nymph mortality: LC_{50}=10.99 µL/mL and LC90=22.25 µL/mL, after 5 days of exposure), also observed in semifield condition (90.54% efficacy). Also presents ovicidal, repellent and deterrent activities	Santana *et al*., 2022
Adenocalymma alliaceum		Nymph insecticidal activity: LC_{50}=0.4 and 0.8 µL/L air in 72 and 3 h, respectively. Deterrent activity: 71.1% reduction. Anti-settlement activity on tomato: 50% reduction	Fanella *et al*., 2015
Pelargonium graveolens		Adult insecticidal activity: LC_{50}=0.6 µL/L air in 24 h. Deterrent activity: 90.9% reduction. Anti-settlement activity on tomato: 73.6% reduction	
Plectranthus neochilus		Deterrent activity: 61.5% reduction. Anti-settlement activity on tomato: 34.5% reduction	
Vitex agnus-castus		Adult insecticidal activity: LC_{50}=1.2 µL/L air in 24 h. Deterrent activity: 90.9% reduction. Anti-settlement activity on tomato: 73.6% reduction	
Laurus nobilis	Leaves	Repellence (73.1%) and mortality (53%) activities, after 24 h (5% concentration). With *C. citratus* EO 1:1 proportion: Repellence (84.3%) and mortality (55.5%)	Ringuelet *et al*., 2012
Piper marginatum	ND	Nymph mortality (LC_{50}=9.39 µL/mL and LC90=20.79 µL/mL, after 5 days of exposure), also observed in semifield condition (91.51% efficacy). Also presents ovicidal, repellent and deterrent activities	Santana *et al*., 2022
Piper callosum		Deterrent activity: 91.5% reduction. Anti-settlement activity on tomato: 70.8% reduction	Fanella *et al*., 2015
Cymbopogon citratus	Leaves	Repellence (77.3%) and mortality (31.2%) activities, after 24 h (5% concentration). With *Laurus nobilis* EO 1: 1 proportion: Repellence (84.3%) and mortality (55.5%)	Ringuelet *et al*., 2012
Zanthoxylum riedelianum	Fruits	Insecticidal activity (1.5%): 70% reduction; Larvicidal activity: 91.23% against 2nd instar nymphae	Pereira *et al*., 2018
		Deterrent activity at 1 and 2%: 95 and 98% reduction, respectively	Costa *et al*., 2017
	Leaves	Nymph insecticidal activity at 5%; 100%, after 16 days of treatment. Deterrent activity: 97% reduction, after 6 days of treatment	Christofoli *et al*., 2022
Zanthoxylum rhoifolium	Fruits	Larvicidal activity (1.5%): 91% against 2nd instar nymphae. Deterrent activity: 71% reduction	Pereira *et al*., 2022
		Deterrent activity at 1 and 2%: 95 and 98% reduction, respectively	Costa *et al*., 2017
	Leaves	Nymph insecticidal activity at 5%; 100%, after 16 days of treatment. Deterrent activity: 98% reduction, after 6 days of treatment	Christofoli *et al*., 2015
Citrus aurantifolia	Peels	Fumigant activity (LC_{50}=0.70 µL/L air). Deterrent activity: 85.51%, 0.125 µL/L air	Ribeiro *et al*., 2020
Citrus limon		Fumigant activity (LC_{50}=1.77 µL/L air). Deterrent activity: 86.34%, 0.8 µL/L air	
Citrus reticulata		Fumigant activity (LC_{50}=3.04 µL/L air). Deterrent activity: 82.71%, 1 µL/L air	
Citrus sinensis×reticulata		Fumigant activity (LC_{50}=5.39 µL/L air). Deterrent activity: 94.93%, 3 µL/L air	
Clonorchis sinensis var. pear		Fumigant activity (LC_{50}=3.80 µL/L air). Deterrent activity (IC50=4 µL/L air)	Ribeiro *et al*., 2010
Citrus aurantium		Fumigant activity (LC_{50}=5.80 µL/L air). Deterrent activity (IC50=5 µL/L air)	

EO: Essential oil

EOs of *Z. rhoifolium* significantly reduced the number of nymphs and eggs of *B. tabaci*, so that the best results were observed with the free EO at a concentration of 5% in a free-choice test, which causes 100% mortality (nymphs) after 16 days of treatment and 98% (oviposition) reduction after 6 days of treatment. Under the same conditions, the EO from *Z. ridelianum* 5% presented the best result, causing 100% mortality of nymphs and 97% ovipositon reduction. γ-elemene (24.81%), phytol (18.16%), bicyclogermacrene (16.18%), *cis*-nerolidol (8.26%), and D-germacrene (6.52%) were the major compounds of *Z. riedlianum* EO, whereas β-elemene (31.26%), D-germacrene (18.16%), β-caryophyllene (12.09%), δ-elemene (7.63%), β-cedrene (6.69%), bicyclogermacrene (4.57%), and E-caryophyllene (3.63%) were the main substances in *Z. rhoifolium* EO [30,31].

The insecticidal activity of the genus *Citrus* on *B. tabaci* type B was evaluated by Ribeiro *et al*. (2020). In this study, the fumigant and fecundity bioassays were performed in order to measure the efficiency of peel EOs from four *Citrus* species after 24 h. Among the evaluated EOs, *Citrus aurantiifolia* (LC_{50} = 0.70 µL/L air) and *Citrus limon* (LC_{50} = 1.77 µL/L air) presented the best results in the fumigant test. In turn, *C. reticulata* and *C. sinensis* × *C. reticulata* EOs showed LC_{50} values equal to 3.04 and 5.39 µL/L air, respectively. Regarding the fecundity bioassay, the EO from *C. sinensis* × *C. reticulata* inhibits 94.93% of deposited eggs with a concentration of 3 µL/L air. In sequence, the EOs with the best results were: *C. limon* (86.34%, 0.8 µL/L air), *C. aurantiifolia* (85.51%, 0.125 µL/L air), and *C. reticulata* (82.71%, 1 µL/L air). The chemical composition of the EOs demonstrated a higher percentage of limonene in all species (77.79% in *C. sinensis* × *reticulata*, 60.96% in *C. reticulata*, 40.70% in *C. limon,* and 37.73% in *C. aurantiifolia*), whereas β-pinene was representative in *C. aurantiifolia* (9.89%) and *C. limon* (18.14%),

Figure 1: Example of plants with high activity EOs against *Bemisia tabaci*. At the top: *Citrus aurantfolia* (left), *Citrus limon* (right). At the bottom: *Pelargonium graveolens* (left), *Piper callosum* (right).

Figure 2: Adults of *Bemisia tabaci* settled on leaves.

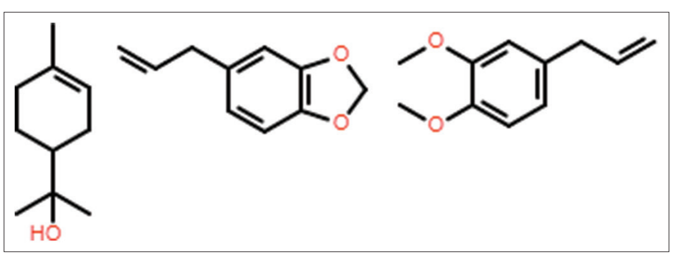

Figure 3: Important major compounds from EOs with high insecticidal activity against *B. tabaci.* From left to right: α-terpineol, safrole and methyl eugenol.

p-Mentha-2,4(8)-diene in *C. sinensis* × *C. reticulata* (9.80%), myrcene in *C. reticulata* (4.61%) and *C. sinensis* × *reticulata* (6.50%), and α-terpineol in *C. aurantiifolia* (5.04%) and *C. limon* (2.78%) [32]. Ten years before, similar results were obtained with peel EOs from *C. sinensis* var. pear and *C. aurantium*. In the fumigant assay, *C. sinensis* EO was the most active (LC_{50} = 3.80 μL/L air), followed by *C. aurantium* EO (LC_{50} = 5.80 μL/L air). In the oviposition deterrence assay, the *C. sinensis* EO was also more efficient than *C. aurantium*, presenting an IC_{50} = 4 μL/L air against a value equal to 5 μL/L air [33].

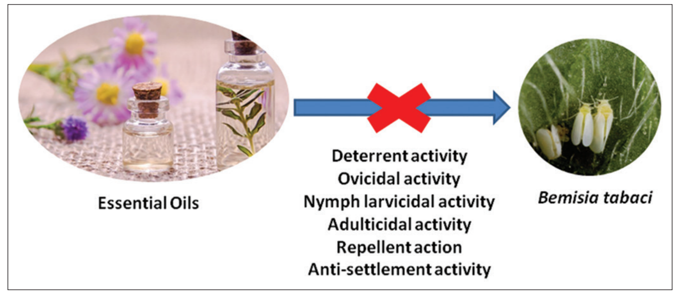

Figure 4: Use of essential oils as a sustainable insecticides.

4. DISCUSSION

In this review, at least eighteen plant species belonging to eight families were found to have EOs available in countries on the American continent with insecticide activity against *B. tabaci* [Figures 1 and 2]. The diversity of sources of natural resources is considered of great importance so that the emergence of resistance is minimized, in addition to the fact that the inherent chemical variety can also contribute to the synergistic action of the oils active compounds [Figure 3]. In addition, the diversity of active natural resources prevents only one or a few species from being exhausted to provide products in the fight against a particular pest.

Among the most studied species are those of the Rutaceae family. In the study by Ribeiro *et al*. (2020) [32], it was demonstrated that the EOs of *Citrus aurantiifolium* and *C. limon* were the most efficient in insecticide and deterrent activities. The same article informs that the two EOs were the richest in α-terpineol, which, in turn, was also tested for insecticidal activity, presenting an LC_{50} of 1.43 μL/L air, the most active among the majority tested, which suggests the specific participation of this substance in the mortality *of B. tabaci*, while the deterrent effect seems to have a multiple contribution of active substances. Furthermore, it is already well known that α-terpineol has repellent or insecticidal activity against different species, such as *Aedes aegypti*, *Sitophilus zeamais*, and *Stomoxys calcitrans*, and may interfere with olfactory responses in insect antennae, besides also presenting relevant anticholinesterasic activity [34,35]. As for the species of the genus *Zanthoxylum*, both were efficient in terms of mortality and oviposition deterrence of the intenses, even though their chemical components varied greatly in the aforementioned studies.

On the other hand, the study by Fanella *et al*. (2015) [25] demonstrated that the EOs of *P. graveolens* and *P. callosum* were more efficient in reducing the settlement of *B. tabaci* in tomato plants and oviposition. *P. graveolens* has a high concentration of oxygenated monoterpenes, while *P. callosum* has safrole as its main substance. Oxygenated monoterpenes (OM) are related to the specificity of the biological activity of EOs, as described by Moghaddam and Mehdizadeh (2017), as they can interact specifically with enzymes [36]. OMs with aromatic functions, such as safrole and methyl eugenol (the main compound in *P. marginatum*), are also powerful insecticides, which in turn are related to different mechanisms, including octopamine receptors blocking and potentiating ligand-gated chloride channels in the insect nervous system. Furthermore, the interaction with the cholinergic and detoxification systems of insects is also an important consideration [37].

The correlated diallyl trisulfide and diallyl disulfide are characteristic substances of Bigoniaceae species and possess several biological properties, including insecticide activity. However, it is believed that both compounds act antagonistically at the same action sites, connecting to them through bonds with the sulfur atom [38,39]. Then, according to these studies, they are probably the main ones responsible for the activity of the oils extracted from the species *M. alliaceae* and *A. alliaceum*.

Furthermore, the study by Ringuelet *et al*. (2012) [26] demonstrated that the EO from *L. nobilis* was more efficient than that from *Cymbopogon citratus* in causing mortality in *B. tabaci*, while the latter showed slightly more repellence efficacy. In addition, the study also reported that the equal mixture between the two oils increased both activities, contributing synergistically. Still, the EO from *X. aromatica* also presented interesting deterrent activity, in which the sesquiterpene bicyclogermacrene and the pinene isomers were the major compounds. Bicyclogermacrene has already demonstrated intense insecticidal activity and acts as a hormonal interferent [40]. In turn, pinenes can disrupt the cellular membrane due to their low polarity characteristic, disaggregating the lipid structure that makes up the inner layer of the membrane [41].

In addition, the use of EOs to control *B. tabaci* can also have a beneficial impact on the economic sector, in order to encourage the cultivation and commercialization of active species, the market for natural products, as well as, possibly in the long term, decrease the cost related to health treatments due to the adverse effects caused by synthetic pesticides.

Finally, the studies discussed here can serve as a basis for the implementation of new products for the control of *B. tabaci* in countries of the American continent in order to move towards a more sustainable insecticide control, replacing, in part, the conventional pesticides found at the moment [Figure 4].

5. CONCLUSION

This review article compiled and discussed the biological activities of American-available EOs against *B. tabaci*, one of the main agricultural pests worldwide. Among the most studied species were those of the Rutaceae family, including those of the genus *Citrus* and *Zanthoxylum*. In addition, species that produce particular groups of insecticidal compounds, as is the case with the Bigoniaceae, also demonstrated relevant activity against the pest. Furthermore, EOs from species that are widespread throughout America, such as *Cymbopogum citratus* and *L. nobilis*, and which can be considered abundant resources in the control of *B. tabaci*, have also been reported. In general, these studies can serve as a basis for the development of specific agricultural products that are more sustainable and safe for consumers.

6. AUTHORS' CONTRIBUTIONS

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agreed to be accountable for all aspects of the work. All the authors are eligible to be an author as per the International Committee of Medical Journal Editors (ICMJE) requirements/guidelines.

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9. ETHICAL APPROVALS

This study does not involve experiments on animals or human subjects.

10. DATA AVAILABILITY

All the data is available with the authors and shall be provided upon request.

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