**Review**

**Insecticidal and Nematicidal Contributions of Mexican Flora in the Search for Safer Biopesticides**

Beatriz Hernández-Carlos ¹ and Marcela Gamboa-Angulo ²,*

¹ Instituto de Agroindustrias, Universidad Tecnológica de la Mixteca, Huajuapan de León, Oaxaca 69000, Mexico; bhcarlos@mixteco.utm.mx
² Unidad de Biotecnología, Centro de Investigación Científica de Yucatán, Calle 43 No. 130, Col. Chuburná, Mérida 97200, Mexico
* Correspondence: mmarcela@cicy.mx; Tel.: +52-999-942-8330

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**Abstract:** Plant metabolites have been used for many years to control pests in animals and to protect crops. Here, we reviewed the available literature, looking for the species of Mexican flora for which extracts and metabolites have shown activity against pest insects and parasitic nematodes of agricultural importance, as well as against nematodes that parasitize domestic cattle. From 1996 to 2018, the search for novel and eco-friendly biopesticides has resulted in the identification of 114 species belonging to 36 botanical families of Mexican plants with reported biological effects on 20 insect species and seven nematode species. Most plant species with detected pesticide properties belong to the families Asteraceae, Fabaceae, and Lamiaceae. Eighty-six metabolites have been identified as pesticidal active principles, and most have been terpenoids. Therefore, the continuation and intensification of this area of research is very important to contribute to the generation of new products that will provide alternatives to conventional pesticide agents. In addition, future studies will contribute to the recognition and dissemination of the importance of propagating plant species for their conservation and sustainable use.

**Keywords:** asteraceae; *Haemonchus*; insecticides; *Meloidogyne*; mexican plants; nematicides; pesticides; plant extracts; *Spodoptera*

1. Introduction

Pest control in the agricultural sector requires a greater number of alternative products that meet food safety, sustainability, and environmental care requirements. One of the strategies used to obtain new natural agents for protecting crops and domestic animals is the exploration of a diversity of plants and their metabolites [1,2]. Natural products with pesticidal properties have been demonstrated to be an important source of compounds which are used as raw materials in the development of new protective agents, both in their natural form or as semisynthetic derivatives exhibiting better effects. In addition, the chemical structures of the active components of natural products have guided the synthesis of other active compounds [3]. The exploration and use of natural products are currently increasing, with a greater focus on identifying metabolites for use in the treatment of human diseases, including parasitism and plant diseases, as well as products for use in pest control in the agricultural sector [4–9].

The biotic wealth of Mexico, which includes large tropical zones, is widely recognized as being among the greatest in the world, with Mexico harbouring an estimated 23,314 species of native vascular plants, approximately 49.8% of which are endemic [10]. Nevertheless, the amount of biodiversity prospecting for natural products in Mexico is low, and as in other countries, it has primarily focused on the search for products to control diseases or plagues that affect humans [11–13]. With respect to agricultural applications, most studies have focused on identifying antimicrobial agents rather
than insecticides, nematicides, and herbicides [5,13–15]. Regarding plants with insecticidal properties, the results of previous studies have identified 24 Mexican plant species with pesticidal potentials that are used in different regions of the country, many of which have been identified as medicinal plants by ethnobotanical antecedents [16]. In contrast, few botanical prospecting studies have been performed to identify plants with activities against phyto and zoonematode pests. Worldwide, few plant extracts have been shown to have an acaricidal activity, three of which are from Mexican flora and were tested on *Rhipicephalus microplus*, and only seven pure natural compounds have been identified as active principles [17]. Undoubtedly, *Tagetes erecta* (Asteraceae), a native plant of Mesoamerica, is currently recognized as one of the most promising plant species given its diverse biological activities against human and plant pathogens as well as against multiple pests [9,18].

Therefore, this work reviews the Mexican flora with extracts or secondary metabolites that have shown biological activity against pest insects or parasitic nematodes. Some plant species that were introduced to Mexico, such as *Allium sativum*, *Azadirachta indica*, and *Ricinus communis*, among others, are also discussed. The information was compiled from all of the electronic databases available at the institution, which included Google Scholar, SciFinder, PubMed, Redylac, Scopus, and Science Direct, among others.

2. Insecticidal Compounds and Plant Extracts

Research on natural products for controlling pest insects that affect plants has led to the identification of 85 plant species with extracts and metabolites that are effective against at least one of the evaluated targets. These plants belong to 26 botanical families, predominantly Asteraceae (31%), Lamiaceae (14%), Meliaceae (7%), Annonaceae (6%), Chenopodiaceae (6%), Fabaceae (5%), and Rutaceae (5%), with the rest belonging to the families Acanthaceae, Bignoniaceae, Brassicaceae, Burseraceae, Cactaceae, Caricaceae, Convolvulaceae, Euphorbiaceae, Lauraceae, Magnoliaceae, Papaveraceae, Petiveraceae, Piperaceae, Phytolaccaceae, Poaceae, Solanaceae, and Verbenaceae (<5% each).

Twenty pest insects were evaluated in the reviewed studies. The maize pest *Spodoptera frugiperda* J.E. Smith (Lepidoptera: Noctuidae) is the most frequently tested target together with *Spodoptera littoralis* Boisduval (Lepidoptera: Noctuidae) and *Spodoptera exigua* Hübner (Lepidoptera: Noctuidae), collectively representing 30% of the target pests assayed in the reviewed studies, and these species were followed by *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae, 14%), the sucker *Bemisia tabaci* Gennadius (Homoptera: Aleyrodidae, 11%), and *Trialeurodes vaporariorum* West. (Homoptera: Aleyrodidae, 11%). The remaining targets included *Anastrepha ludens* Loew (Diptera: Tephritidae), *Bactericera cockerelli* (Hemiptera: Psylloidea), *Copitarsia decolora* Guenée (Lepidoptera: Noctuidae), *Dactylopius opuntiae* Cockerell (Hemiptera: Coccoidea), *Leptinotarsa decemlineata* Say (Coleoptera: Chrysomelidae), *Prostephanus truncatus* Horn (Coleoptera: Bostrichidae), *Scyphophorus acupunctatus* Gyllenhaal (Coleoptera: Curculionidae), *Stomoxys calcitrans* Linneo (Diptera: Muscidae), *Tenebrio molitor* Linnaeus (Coleoptera: Tenebrionidae), *Trichoplusia ni* Hübner (Lepidoptera: Noctuidae), and *Zabrotes subfasciatus* Boheman (Coleoptera: Bruchidae). Other targets assayed included *Aedes aegypti* Linnaeus, *Anopheles albimanus* C.R.G. Wiedemann, and *Culex quinquefasciatus* Say (Diptera: Culicidae), which have been included in this review because they are all very important pest insects of humans and are also virus vectors.

In this review, first, the insecticidal compounds isolated and identified in enriched fractions (as alkaloids and terpenes) and essential oils (EOs) from Mexican plants are described by the targeted pests. The second part includes plant extracts which the active principles of are not yet known.

2.1. *Spodoptera* sp.

During investigations carried out on the control of *Spodoptera* sp. (*S. frugiperda* and *S. littoralis*), 43 effective natural compounds have been identified including terpenes (1–30), flavonoids (31–35), stilbenes (36–38), a coumarin (39), a ketone (40), and fatty acids (41–44). In addition, enriched fractions with metabolites that were identified as alkaloids (45–50) have been described. All of these compounds were
isolated from 21 plant species and exhibited different degrees of effectiveness against the assayed pest insects, with the most active metabolites obtained from plants of the Asteraceae family (Cedrela dugessi, Cedrela salvadorensis, Gutierrezia microcephala, Parthenium argentatum, and Roldana barba-johannis), the Fabaceae family (Lupinus aschenbornii, Lupinus montanus, and Lupinus stipulata), and the Asparagaceae family (Yucca periculosa), which induced the strongest median lethal concentration (LC$_{50}$ ≤ 65 ppm) against $S$. frugiperda. Other plant species with minor activities against $S$. frugiperda included Carica papaya, Crescentia alata, Lippia graveolens, Myrtillocactus geometrizans, Ricinus communis, Ruta graveolens, Vitex Hemsley, and Vitex mollis. In addition, five species from the genus Salvia and a member of the family Asteraceae (Senecio toluccanus) were found to have active compounds against $S$. littoralis.

### 2.1.1. Terpenes

The tocotrienols and hydroquinones isolated from the methanol extract (MEx) of the aerial parts of $R$. barba-johannis (Asteraceae) included sargachromenol (1), methyl and acetyl sargachromenol derivatives (2, 3), sargahydroquinic acid (4), methyl and acetyl sargahydroquinic acid derivatives (5, 6), and sargquinic acid (7). Metabolites 1, 3, and 6 showed potent insecticidal activity against the fifth-stage larvae of $S$. frugiperda, with median lethal dose (LD$_{50}$) values of 2.94, 3.89, and 4.83 ppm, respectively. Metabolite 4 was most effective against first-instar $S$. frugiperda larvae, with a LC$_{50}$ of 5.77 ppm. Furthermore, acetylated metabolite 3 was the most potent compound against the emergence of $S$. frugiperda adults from pupae, while the efficacy was further increased using a mixture of acetylated compounds 1, 3, and 7 (LD$_{50}$ = 3.26 ppm) [19]. Furthermore, Cespedes [20] identified two cyloarten-type triterpenes, argentatin A (8) and argentatin B (9), from a methanol extract (MEx) of the aerial parts of $P$. argentatum. Although both metabolites showed good insecticidal and growth inhibition activities, the MEx was consistently more potent than either triterpene alone. Methanol extract, 8, and 9 showed a potent toxicity towards $S$. frugiperda adults, with LD$_{50}$ values of 3.1, 12.4, and 19.8 ppm, respectively. In addition, the insecticidal activities of MEx and compound 8 against the fifth-instar larvae of $S$. frugiperda were tested, with LC$_{50}$ values of 6.4 and 17.8 ppm and median mortality concentration (MC$_{50}$) values of 6.9 and 21.3 ppm, respectively. In agreement with these results, the observed growth and relative growth indices seven days after treatment with both metabolites and MEx revealed a delay in the time of $S$. frugiperda pupation and adult emergence and an increase in deformities. Acetylcholinesterase inhibition (83.5% and 100%) was observed using MEx at 5 and 25 ppm, respectively, but not for the pure compounds (90–100% at 50 ppm).

The *G. microcephala* clerodane diterpene bacchabolvic acid (10) and its synthetic methyl ester (10a) were shown to cause significant mortality (MC$_{50}$ = 10.7 and 3.46 ppm, respectively) towards $S$. frugiperda neonatal larvae, good toxicity against adults (LD$_{50}$ = 6.59 and 15.05 ppm, respectively), and moderate acetylcholinesterase inhibitory activity [21]. The leaves of two Meliaceae species, *C. salvadorensis* and *C. dugessi*, were shown to produce a mixture of photogedunin α and β (11, 12) and gedunin (13). The mixture of compounds 11 and 12, as well as 13 and its acetate derivative (13a), caused good $S$. frugiperda larval mortality (LC$_{50}$ = 10, 8, and 39 ppm, respectively) [22]. A labdane-type anticalopic acid (14) from *Vitex hemsleyi* showed an effective antifeedant dose of 90.6 ppm against sixth-instar $S$. frugiperda larvae [23]. Sterols isolated from the aerial parts of *M. geometrizans* (Cactaceae), including macdougallin (15), penicocer (16), and a mixture of the two metabolites 15:16 (4:6), displayed a high toxicity towards $S$. frugiperda (LD$_{95}$ = 285, 125, and 135 ppm, respectively). In addition, at 20 ppm, the mixture of 15 and 16 drastically resulted in the total inhibition of $S$. frugiperda pupation and the emergence of adults [24].

Terpenes with noticeable activity against $S$. frugiperda (100 ppm: 65–80% larval mortality) have been identified in enriched fractions from *Crescentia alata*, including ningpogenin (17), β-sitosterol (18), stigmasterol (19), and 6β,7β,8α,10-tetra-p-hydroxybenzoyl-cis-2-oxabicycle-4(3.0)nonan-3-one (20) [25,26]. Guevara [27] reported that monoterpenes thymol (21) and carvacrol (22) were the major components in a hexanic extract of *L. graveolens* leaves. This extract caused deformations in $S$. frugiperda adults at different concentrations (10–100 ppm).
The pest *S. littoralis* was also shown to be sensitive to seven antifeedant clerodane-type diterpenoids obtained from several *Salvia* species (AI<sub>50</sub> < 90 ppm). These diterpenoids included kerlinolide (23); 1(10)-dehydrosalviarin (24) from *Salvia lineata*; from *Salvia keerlii*, 13,14-dihydro-3,4 epoxy-melissodoric acid methyl ester acetate (25), 2β-acetoxy-7α-hydroxy-neo-clerodan-3,13-dien-18,19:16,15-diolide (26) from *Salvia melissodora*; salviarin (27) from *Salvia rhychophila*; and 6β-hydroxysalviarin (28) and semiatrin (29) from *Salvia semiatrata*. The most effective of these was 25, with an AI<sub>50</sub> value of 1 ppm [28]. The metabolite toluccanolide A (30), isolated from *S. toluccanus*, and its acetate derivative (30a) showed a significant antifeedant effect against *S. littoralis* (57% and 69.6%, respectively) after an application of this compound (50 µg/cm<sup>2</sup>) to leaves (Table 1, Figure 1) [29].

**Table 1.** Insecticidal terpenes from Mexican flora effective on *Spodoptera* sp.

| Insect | Species/Family | Plant Part | Compound/Extract (Toxicity) | Ref. |
|--------|----------------|------------|-----------------------------|------|
| *S. frugiperda* | *Roldana barba-johannis* | AP | Sargachromenol (1) (LD<sub>50</sub> = 2.94 ppm on fifth instar, 24 h; LC<sub>50</sub> = 19.12 ppm on first instar, 7 days) Methyl sargachromenol (2) (LD<sub>50</sub> = 15.52 ppm on fifth instar, 24 h; LC<sub>50</sub> = 20.76 on first instar, 7 days) Acetyl sargachromenol (3) (LD<sub>50</sub> = 3.89 ppm on fifth instar, 24 h; LC<sub>50</sub> = 33.31 ppm on first instar, 7 days) Sargahydroquinic acid (4) (LD<sub>50</sub> = 10.17 ppm on fifth instar, 24 h; LC<sub>50</sub> = 5.77 on first instar, 7 days) Methyl sargahydroquinic acid (5) (LD<sub>50</sub> = 14.89 ppm on fifth instar, 24 h; LC<sub>50</sub> = 62.02 on first instar, 7 days) Acetylated Mixture (LD<sub>50</sub> = 3.26 ppm on fifth instar, 24 h; LC<sub>50</sub> = 5.77 on first instar, 7 days) | [19] |
| *Parthenium argentatum* | *Asteraceae* | AP | Argentatin A (8) (LD<sub>50</sub> = 12.4 ppm on fifth instar, 24 h; LC<sub>50</sub> = 17.8 ppm, 7 days; MC<sub>50</sub> = 21.3 ppm, 7 days) Argentatin B (9) (LD<sub>50</sub> = 19.8 ppm, on fifth instar, 24 h; LC<sub>50</sub> = 36.1 ppm, 7 days; MC<sub>50</sub> = 37 ppm, 7 days) Methanol (LD<sub>50</sub> = 3.1 ppm, on fifth instar, 24 h; LC<sub>50</sub> = 6.4 ppm, 7 days; MC<sub>50</sub> = 6.9 ppm, 7 days) | [20] |
| *Gutierreza microcephala* | *Asteraceae* | AP | Bacchabolivic acid (10) (MC<sub>50</sub> = 10.7 ppm, 7 days; LD<sub>50</sub> = 6.59 ppm, 24 h; 50 ppm: 90.2% IAche) Methyl ester of 10 (10a) (MC<sub>50</sub> = 3.46 ppm, 7 days; LD<sub>50</sub> = 15.05 ppm, 24 h; 50 ppm: 60% IAche) | [21] |
| *Cedrela dugessi* | *Meliaceae* | Leaves | α and β-Photogedunin (11 and 12) mixture (LC<sub>50</sub> = 10 ppm, 7 days; 19.2 ppm: 88% larval growth inhibition; 5 ppm: 23 and 85% pupation and emergence reduction) α and β-Photogedunin acetates (11a and 12a) mixture (LC<sub>50</sub> = 8 ppm, 7 days) Gedunin (13) (LC<sub>50</sub> = 39 ppm, 7 days; 5 ppm: 91% larval growth inhibition; 5 ppm: 6.2 and 78.5% pupation and emergence reduction) | [22] |
| *Cedrela salvadorensis* | *Meliaceae* | Leaves | α- and β-Photogedunin (11 and 12), α- and β-photogedunin acetates (11a and 12a) mixture gedunin (13) | [22] |
| *Vitex hemsleyi* | *Lamiaceae* | Leaves | Anticopalic acid (14) (EC<sub>50</sub> = 90.6 ppm, L6 larvae) | [23] |
Table 1. Cont.

| Insect                   | Species/Family             | Plant Part | Compound/Extract (Toxicity) | Ref. |
|--------------------------|----------------------------|------------|----------------------------|------|
| *Myrtillocactus geometrizans* | Cactaceae                  | Whole      | Macdougallin (15) (LD$_{95}$ = 285 ppm; 50 ppm: 97.2% M; 0% pupation; 0% emergence) | [24] |
|                          |                            |            | Peniocerol (16) (LD$_{95}$ = 125 ppm; 50 ppm: 97.2% M; 0% pupation; 0% emergence) mixture (4:6) 15 + 16 (LD$_{95}$ = 135 ppm; 20 ppm: 97.2% M; 0% pupation; 0% emergence) | |
| *Crescentia alata*       | Bignoniaceae               | Fruits     | Fraction enriched with ningpogenin (17) (100 ppm: 80% larval mortality); fraction enriched with: β-sitosterol (18), stigmasterol (19) and 6β,7β,8α,10-tetra-p-hydroxybenzoyl-cis-2-oxabicycle[4.3.0]nonan-3-one (20) (100 ppm: 65% larval mortality) | [25], [26] |
| *Lippia graveolens*      | Verbenaceae                | Leaves     | Hexane (10–100 ppm: deformed adults), thymol (21, 70.6%), carvacrol (22, 22.8%) | [27] |
| *S. littoralis*           | *Salvia keerlii*           | AP         | Kerolinolide (23) (AI$_{50}$ = 67 ppm) | [28] |
| *Salvia lineata*          | *Lamiaceae*                | AP         | 1(10)-Dehydrosalviarin (24, AI$_{50}$ = 32 ppm) | [28] |
| *Salvia melissodora*      | *Lamiaceae*                | AP         | 13,14-Dihydro-3,4 epoxy-melissodoric acid methyl ester acetate (25) (AI$_{50}$ = 1 ppm) 2-β-acetoxy-7α-hydroxy-neo-clerodan-3,13-dien-18:19:16,15-diolide (26) (AI$_{50}$ = 84 ppm) | [28] |
| *Salvia rhyacophila*      | *Lamiaceae*                | AP         | Salviarin (27) (AI$_{50}$ = 81 ppm) 6β-Hydroxysalviarin (28) (AI$_{50}$ = 24 ppm) | [28] |
| *Salvia semiatrata*       | *Lamiaceae*                | AP         | Semiatrin (29) (AI$_{50}$ = 87 ppm) | [28] |
| *Senecio toluccanus*      | *Asteraceae*               | Roots      | Tolucanolidol A (30) and tolucanolidol A acetate (30a) (50 µg/cm$^2$: 57 and 69.6% antifeedant effect, respectively) | [29] |

* Endemic; AP: Aerial parts; AI$_{50}$ = Median antifeedant index; EC$_{50}$ = Effective antifeedant concentration; GD$_{50}$ = Median Growth Dose; ID$_{50}$ = Median Inhibitory Dose; LC$_{50}$ = Median Lethal Concentration; LD$_{50}$ = Median Lethal Dose; LV$_{50}$ = Median Larval Viability; IAche: Inhibition of acetylcholinesterase; MC$_{50}$ = Median Mortality Concentration.
2.1.2. Flavonoids

Flavonoids isolated from the aerial parts of *G. microcephala* exhibited moderate effects against *S. frugiperda*, with these compounds including 5,7,2′-trihydroxy-3,6,8,4′,5′-pentamethoxyflavone (31), 5,7,4′-trihydroxy-3,6,8-trimethoxyflavone (32), 5,7,2′,4′-tetrahydroxy-3,6,4′,5′-tetramethoxyflavone (33), and 5,2′-dihydroxy-3,6,7,8,4′,5′-hexamethoxyflavone (34). Flavone 31 displayed the lowest LC₅₀...
value (3.9 ppm) against neonatal S. frugiperda larvae [21]. In addition, flavones 31–34 exhibited 93.7–100% acetylcholinesterase inhibitory activity at 50 ppm (Table 2, Figure 2).

| Species/Family | Plant Part | Compound (Toxicity) | Ref. |
|----------------|------------|---------------------|------|
| Gutierrezia microcephala * Asteraceae | AP | 5,7,2′-Trihydroxy-3,6,8,4′,5′-pentamethoxyflavone (31) (MC₅₀ = 3.9 ppm, 7 days; LD₅₀ = 36.65 ppm, 24 h; 50 ppm: 35.9% IAche) | [21] |
| | | 5,7,4′-Trihydroxy-3,6,8,5′-trimethoxyflavone (32) (50 ppm: 27.5% IAche) | |
| | | 5,7,2′,4′-Tetrahydroxy-3,6,8,5′-tetramethoxyflavone (33) (MC₅₀ = 27.8 ppm, 7 days; 50 ppm: 27.5% IAche) | |
| | | 5,2-dihydroxy-3,6,7,8,4′,5′-hexamethoxyflavone (34) (80 ppm: 17.8% IAche) | |

* Endemic; IAche: Inhibition of acetylcholinesterase; LD₅₀ = Median Lethal Dose; MC₅₀ = Median Mortality Concentration.

Figure 2. Insecticidal flavonoids (31–35) and stilbenes (36–38) effective on Spodoptera frugiperda.

Rutin (35) is a flavonol glycoside-reported R. graveolens constituent (Figure 2), which was also tested and showed no effect towards S. frugiperda [30].

2.1.3. Stilbenes

Stilbenes identified from the bark of Y. periculosa (Asparagaceae) included resveratrol (36), 4,4′-dihydroxystilbene (37), and 3,3′,5,5′-tetrahydroxy-4-methoxystilbene (38), with 38 being the most potent and exhibiting an LC₅₀ value of 5.4 ppm towards neonatal larvae at seven days and a median growth inhibition (GI₅₀) value of 3.45 ppm at 21 days (Table 3, Figure 2) [31].

| Species/Family | Plant Part | Compound (Toxicity) | Ref. |
|----------------|------------|---------------------|------|
| Yucca periculosa * Asparagaceae | Bark | Resveratrol (36) (LD₅₀ = 24.1 ppm, 24 h; GI₅₀ = 5.94 ppm, 21 days; LC₅₀ = 6.4 ppm, 7 days) | [31] |
| | | 4,4′-Dihydroxystilbene (37) (LD₅₀ = 38 ppm, 24 h; GI₅₀ = 9.24 ppm, 21 days; LC₅₀ = 27.6 ppm, 7 days) | |
| | | 3,3′,5,5′-Tetrahydroxy-4-methoxystilbene (38) (LD₅₀ = 10.1 ppm, 24 h; GI₅₀ = 3.45 ppm, 21 days; LC₅₀ = 5.4 ppm, 7 days) | |

* Endemic; GI₅₀ = Median Growth inhibition; LD₅₀ = Median Lethal Dose; LC₅₀ = Median Lethal Concentration.

2.1.4. Coumarin and Ketone

The leaves of R. graveolens were shown to produce psoralen (39) and a median chain ketone 2-undecanone (40), both of which were effective against neonatal S. frugiperda larvae. However, metabolite 39 was more potent than 40, with larval mortalities of 100% and 50% respectively observed at a concentration of 1 mg/mL (Table 4) [30].
Table 4. A coumarin and a ketone active on Spodoptera frugiperda.

| Species/Family   | Plant Part | Compound (Toxicity)                                      | Ref. |
|------------------|------------|----------------------------------------------------------|------|
| Ruta graveolens  | Leaves     | Psoralen (39) (1 mg/mL: 100% larval mortality)           | [30] |
|                  |            | 2-Undecanone (40) (1 mg/mL: 50% larval mortality)       |      |

2.1.5. Fatty Acids

Additional compounds with reported activity against *S. frugiperda* include palmitic (41), oleic (42), linoleic (43), and linolenic (44) acids (Table 5), which exhibited LV$_{50}$ values of $\leq 1354$ ppm, with the most active compounds being unsaturated fatty acids. These active fatty acids were detected in *C. papaya* seeds and *R. communis* leaves grown in Mexico [32,33]. Both of these plant species are widely distributed, and *R. communis* is recognized for its pesticidal effects and high fatty acid content [34]. Furthermore, the powdered seed of *C. papaya* has been shown to cause larval mortality and weight reduction in *S. frugiperda* [35,36].

Table 5. Fatty acids with biological activity on Spodoptera frugiperda.

| Species/Family   | Plant Part | Compound (Toxicity)                                      | Ref. |
|------------------|------------|----------------------------------------------------------|------|
| Carica papaya    | Seeds      | Palmitic acid (41) (LV$_{50}$ = 989 ppm)                 | [32] |
|                  |            | Oleic acid (42) (LV$_{50}$ = 1353.4 ppm)                 |      |
|                  |            | Powder in artificial diet (15%: 90% mortality, 72 h, all varieties) | |
| Ricinus communis | Leaves     | Linoleic acid (43) (LV$_{50}$ = 857 ppm, 1st instar larvae) | [33] |
|                  |            | Linolenic acid (44) (LV$_{50}$ = 849 ppm, 1st instar larvae) |      |

LV$_{50}$ = Median Lethal Volume.

2.1.6. Alkaloidal Fractions

Alkaloid-enriched fractions from leaves of three species of *Lupinus* (Fabaceae) showed remarkable toxic effects against *S. frugiperda* (LD$_{50}$ = 16–70 ppm). These fractions primarily contained lupanine (45), multiflorine (46), sparteine (47), aphylline (48), α-sparteine (49), and epi-aphylline (50) (Table 6, Figure 3), with a commercial standard of 47 used during the evaluations. Interestingly, *L. montanus* and *L. aschenbornii* had high amounts of 47 (640 and 780 µg/g, respectively), whereas it was absent from *L. stipulatus*, which instead contained 48 and 50 as major alkaloids (280 and 307 µg/g, respectively). The alkaloidal fraction of *L. stipulatus* was the most toxic and fast-acting against *S. frugiperda*, with an LD$_{50}$ value of 20 µg/mL at seven days, similar to that observed for 47 (LD$_{50}$ = 11 µg/mL) [37].

Table 6. Alkaloids effective on Spodoptera frugiperda.

| Plant Species/Family | Plant Part | Compound (Toxicity)                                      | Ref. |
|----------------------|------------|----------------------------------------------------------|------|
| *Lupinus aschenbornii* | Leaves     | Alkaloids extract (LD$_{50}$ = 24 µg/mL, 7 days)         | [37] |
|                      |            | Lupanine (45, 86 µg/g), multiflorine (46, 31 µg/g),      |      |
|                      |            | sparteine (47, 780 µg/g), 47 commercial standard (LD$_{50}$ = 11 µg/mL, 7 days) | |
| *Lupinus montanus*   | Leaves     | Alkaloids extract (LD$_{50}$ = 65 µg/mL, 7 days)         | [37] |
|                      |            | Aphylline (48, 17.6 µg/g), 45 (9.2 µg/g), α-sparteine    |      |
|                      |            | (49, 5 µg/g), 47 (640 µg/g)                              |      |
| *Lupinus stipulatus* | Seeds      | Alkaloids extract (LD$_{50}$ = 20 µg/mL, 7 days)         | [37] |
|                      |            | 48 (280 µg/g), epi-aphylline-like (50, 307 µg/g), 45 (11.7 µg/g) | |

* Endemic; LD$_{50}$ = Median Lethal Dose.
These plants included *Bursera copallifera* with one showing activity against *S. frugiperda*, 2.1.7. Plant Extracts with Activity against *Spodoptera*

The crude organic extracts of 10 plant species exhibited effective insecticidal activities against *S. frugiperda*, with one showing activity against *S. exigua*, the results of which are shown in Table 7. These plants included *Bursera copallifera*, *Bursera grandiflora*, *Bursera lancifolia*, *Ipomoea murucoides*, *Ipomoea pauciflora*, *Salvia connivens*, *Salvia microphylla*, *Tagetes erecta*, *Trichilia havanensis*, and *Vitex mollis*.

Table 7. Plant extracts from Mexican flora with activity on *Spodoptera* sp.

| Insect   | Plant Species/Family | Plant Part | Extract (Toxicity) | Ref. |
|----------|----------------------|------------|--------------------|------|
| *S. exigua* | *Trichilia havanensis* *Meliaceae* | Seeds   | Oil (7000 mg/L: 56% LM, 12 days; 100 mg/L: 71.3% LWR) | [38] |
|          |                      |          | Solid fraction (7000 mg/L: 56% LM, 12 days; 100 mg/L: 98.5% LWR) | |
| *S. frugiperda* | *Bursera copallifera* *Burseraceae* | Leaves   | Ethyl acetate (1000 ppm: 73% LWR, 7 days; IC₅₀ = 553 µg/mL IAche) | [42] |
|          |                      |          | Methanol (1000 ppm: 55% LWR, 7 days; IC₅₀ = 367 µg/mL IAche) | |
|          |                      | Leaves stem | Acetonic leaves extract (500 ppm: 47% LM; 50% LWR, 14 days); hexanic leaves extract (500 ppm: 44% deformed pupae, 14 days); | [41] |
| *Bursera grandifolia* *Burseraceae* | Seeds | | Methanol leaves extract (500 ppm: 45% LM; 35% deformed pupae, 14 days) | [41] |
| *Bursera lancifolia* *Burseraceae* | Seeds | | Ethyl acetate (1000 ppm: 39% LWR, 7 days; IC₅₀ = 397 µg/mL IAche) | [42] |
|          |                      |          | Methanol (1000 ppm: 32% LWR, 7 days; IC₅₀ = 707 µg/mL IAche) | |
| *Ipomoea murucoides* *Convolvulaceae* | Roots | | Methanol (LC₅₀ = 2.69 mg/mL) | [45] |
| *Ipomoea pauciflora* *Convolvulaceae* | Seeds | | Hexane (LC₅₀ = 1.68 mg/mL) | [43] |
|          |                      |          | Chloroform (LC₅₀ = 0.55 mg/mL) | |
| *Salvia connivens* *Lamiaceae* | AP | | Chloroform (LV₅₀ = 936 ppm, 1st instar larvae) | [44] |
| *Salvia microphylla* *Lamiaceae* | AP | | Chloroform (LV₅₀ = 916 ppm, 1st instar larvae) | [44] |
| *Tagetes erecta* *Asteraceae* | Leaves | | Hexane, acetone, and ethanol (LC₅₀ = 312.2, 264.9, and 152.2 ppm respectively on L1 larvae) | [40] |
| *Vitex mollis* *Lamiaceae* | Leaves | | Dichloromethane (LC₅₀ = 46.35 ppm) | [39] |
|          |                      |          | Chloroform-methanol 1:1 (LC₅₀ = 13.63 ppm) | |
|          |                      |          | methanol (LC₅₀ = 61.05 ppm) | |

*Endemic; IC₅₀ = Median Inhibitory Concentration; IAche: Inhibition of acetylcholinesterase; LC₅₀ = Median Lethal Concentration; LV₅₀ = Median Larval Viability; LM: larval mortality; LWR: larval weight reduction.*
Against *S. exigua*, only the activity of an extract from *T. havanensis* seeds was reported, with an acetic acid extract and its supernatant oil causing significant larval mortality and weight reduction. Furthermore, the acetone extract caused a noticeable delay in the development of *S. exigua* larvae when used at 500 mg/L [38].

The insecticidal activity of *V. mollis* extracts (dichloromethane, chloroform-methanol, and methanol) towards *S. frugiperda* was very interesting. A chloroform-methanol (1:1) extract from *V. mollis* leaves caused noteworthy mortality against *S. frugiperda* larvae, with an LC$_{50}$ value of 13.63 ppm observed, greater than that of previously reported terpenes (vide infra). In addition, *P. americana* were moderately sensitive to EOs from the leaves of *V. mollis* (Table 8, Figure 4) [49,50].

At 500 ppm, the acetonic extract from leaves was the most effective, with a 50% reduction in larval weight observed after seven days. However, the hexane, acetone, and ethanol leaf extracts all exhibited lethal activities against *S. frugiperda* larvae, with observed LC$_{50}$ values of 312.2, 246.9, and 152.2 ppm, respectively [40].

Other organic plant extracts with activity against *S. frugiperda* include acetonic extracts of *B. copallifera*, ethyl acetate extracts of *B. lancifolia*, and a methanol extract of *B. grandifolia*, which caused deformations in pupae or adults at different concentrations; acetylcholinesterase is also inhibited by these extracts [41,42]. In addition, *I. murioides*, *I. pauciflora*, *S. connivens*, and *S. microphylla* extracts displayed slight effects against first-stage larvae of *S. frugiperda* at high concentrations (Table 7) [42–45].

### 2.2. Aedes aegypti, Anopheles albimanus, and Culex quinquefasciatus

The extracts and metabolites of 11 plant species displayed activity against the Culicides *A. aegypti*, *A. albimanus*, and *C. quinquefasciatus*, vectors of the human diseases, dengue fever, malaria, and lymphatic filariasis, respectively. These plant species included *A. indica*, *Argemone mexicana*, *Erythrina Americana*, *Heliopsis longipes*, *Persea americana*, *Pseudocalymma alliaceum*, *Pseudomodningium perniciosum*, *Ruta chalepensis*, *Salmea scandens*, *Thymus vulgaris*, and *Zanthoxylum fagara* (Tables 8–10 and Figure 4).

#### 2.2.1. Alkaloids

An alkamide named affinin (51), isolated from *H. longipes* roots, and its reduced product *N*-isobutyl-2E-decanamide (52) were moderately active against *A. aegypti* (LC$_{50}$ = 7.38 and 36.97 mg/L, respectively). Moreover, the Coleoptera *A. albimanus* was more sensitive to these compounds, with LC$_{50}$ values of 4.24 and 7.47 mg/L, respectively. However, a crude ethanol extract displayed lower lethal activity against the larval stage of *A. albimanus* and *A. aegypti*, with LC$_{50}$ values of 2.48 and 4.07 mg/L, respectively (Table 8) [46]. The alkaloidal fraction from *E. americana* seeds induced high *C. quinquefasciatus* larval mortality, with an LC$_{50}$ value of 87.5 mg/L. After chromatographic purification, *β*-eritroidina (53) and erisovina (54) were obtained and tested; however, these pure compounds exhibited lower *C. quinquefasciatus* larvicidal activities in comparison with the alkaloidal fraction (LC$_{50}$ = 225 and 399 mg/L, respectively) [47]. In contrast, EOs from *S. scandens*’ stem bark caused a potent lethal effect on *A. albimanus* larvae (2.5 µg/mL), with the isomers *N*-isobutyl-(2E,4E,8Z,10Z)-dodecatetraenamide and *N*-isobutyl-(2E,4E,8Z,10E)-dodecatetraenamide (55, 56; 39.7%) constituting the majority of the compounds in this EO [48].

#### 2.2.2. EOs

Among the assayed EOs, the EO obtained from leaves of *S. scandens* was the most active and had the lowest LC$_{50}$ of 0.3 µg/mL on the larvae of *A. aegypti* [48]. *Culex quinquefasciatus* larvae were moderately sensitive to EOs from the leaves of *P. americana* (800 mg/L: 57.5% mortality) and *P. alliaceum* (LC$_{50}$ = 385.29 ppm). The EO from *P. americana* was observed to contain estragole (57, 61.86%), sabinene (58, 15.16%), and α-pinene (59, 14.26%), while that of *P. alliaceum* consists primarily of diallyl disulphide (60, 50.05%), diallyl sulphide (61, 11.77%) and trisulphide di-2-propenyl (62, 10.37%) (Table 8, Figure 4) [49,50].
2.2.3. Plant Extracts

The screening of extracts from six plants for activity against the fourth-instar *A. aegypti* larvae identified those of *A. mexicana* and *P. perniciosum* as the most effective (Table 9). Hexane and acetone extracts from *A. mexicana* seeds and hexane extracts from the bark of *P. perniciosum* showed the lowest larvicidal activities, with LC_{50} values of 80, 50, and 20 µg/mL, respectively [51]. Other organic extracts observed to have larvicidal activity against *A. aegypti* include those of *R. chalepensis*, *T. vulgaris*, and *Z. fagara*, exhibiting notable LC_{50} values of 1.8, 4.4 and 75.1 µg/mL, respectively [52]. In contrast, the aqueous extract of *A. indica* showed slight effects towards four different instars of *C. quinquefasciatus* (LD_{50} = 410–550 ppm) [53].
Table 9. Plant extracts from Mexican flora with activity on *Aedes aegypti* and *Culex quinquefasciatus*.

| Insect                  | Species/Family          | Plant Part | Extract (Toxicity)                          | Ref.  |
|-------------------------|-------------------------|------------|---------------------------------------------|-------|
| *Aedes aegypti*         | *Argemone mexicana*     | Seeds      | Hexane (LC\(_{50}\) = 80 µg/mL, 48 h) acetone (LC\(_{50}\) = 50 µg/mL, 48 h) | [51]  |
| *Pseudosmodingium*      | *pernicosum* *^*         | Bark       | Hexane (LC\(_{50}\) = 20 µg/mL, 48 h)      | [51]  |
| *Ruta chalepensis*      | *Rutaceae*              | Aerial part| Ether and methanol (LC\(_{50}\) = 1.8 and 6.4 µg/mL, respectively, 24 h) | [52]  |
| *Thymus vulgaris*       | *Lamiaceae*             | Leaves     | Ether (LC\(_{50}\) = 4.4 ppm, 24 h, 4th instar larvae) | [52]  |
| *Zanthoxylum fagara*    | *Rutaceae*              | Fruits     | Ether (LC\(_{50}\) = 75.1 µg/mL, 24 h)     | [52]  |
| *Culex quinquefasciatus*| *Azadirachta indica*    | Seeds      | Aqueous (1st instar: LD\(_{50}\) = 460 ppm; 2nd instar LD\(_{50}\) = 440 ppm; 3rd instar LD\(_{50}\) = 410 ppm; 4th instar; LD\(_{50}\) = 550 ppm) | [53]  |

* Endemic; LC\(_{50}\) = Median Lethal Concentration; LD\(_{50}\) = Median Lethal Dose.

2.3. *Anastrepha ludens*

Foliarn and stem extracts from three species of the family Annonaceae, *Annona diversifolia*, *A. lutescens*, and *A. muricata*, as well as one species of the family Magnoliaceae, *Magnolia dealbata*, showed good activity against the Mexican fruit fly *A. ludens* (Coleoptera). Among the assayed extracts, the aqueous extracts from stems exhibited the best effect at 100 µg/mL, with the greatest effect (95.9%) caused by *A. lutescens* (Table 10) [54,55].

Table 10. Plant extracts from Mexican flora with activity on *Anastrepha ludens* and *Bactericera cockerelli*.

| Insect                  | Species/Family          | Plant Part | Extract (Toxicity)                          | Ref.  |
|-------------------------|-------------------------|------------|---------------------------------------------|-------|
| *Anastrepha ludens*     | *Annona diversifolia*   | Leaves     | Ethanol stems (1000 µg/mL: 89.3%, third instar LM, 72 h) | [54]  |
|                         |                         | Stems      | Aqueous leaves (100 µg/mL: 70.3% third instar LM, 72 h) |       |
|                         |                         |            | Aqueous stems (1000 µg/mL: 74.3% third instar LM, 72 h) |       |
| *Annona lutescens*      | *Annonaceae*            | Leaves     | Ethanol leaves (1000 µg/mL: 27.0%, third instar LM, 72 h) | [54]  |
|                         |                         | Stems      | Ethanol stems (1000 µg/mL: 70.3%, third instar LM, 72 h) |       |
|                         |                         |            | Aqueous leaves (100 µg/mL: 81.7% third instar LM, 72h)  |       |
|                         |                         |            | Aqueous stems (100 µg/mL: 95.9% third instar LM, 72 h)  |       |
| *Annona muricata*       | *Annonaceae*            | Leaves     | Ethanol leaves (1000 µg/mL: 63.3%, third instar LM, 72 h) | [54]  |
|                         |                         | Stems      | Ethanol stems (1000 µg/mL: 61.5%, third instar LM, 72 h) |       |
|                         |                         |            | Aqueous leaves (100 µg/mL: 78.3% third instar LM, 72 h) |       |
|                         |                         |            | Aqueous stems (100 µg/mL: 86.0 third instar LM, 72 h)   |       |
| *Magnolia dealbata*     | *Magnoliaceae*          | Dry sarcotesta | Ethanol (0.1 mg/mL: 12.8% survival after 3 days; Abbott index: 86.8%, adults) | [55]  |
| *Bactericera cockerelli*| *Annona muricata*       | Seeds      | Hexanol (LC\(_{50}\) = 193.5 ppm, 72 h) | [55]  |

LC\(_{50}\) = Median Lethal Concentration; LM: Larval Mortality.
2.4. Bactericera cockerelli

The potato psyllid (B. cockerelli) displayed sensitivity to hexanol extracts of A. muricata seeds, with a lethal effect observed using 193.5 ppm after 72 h (Table 10) [56].

2.5. Bemisia tabaci

To date, five studies have reported on the use of natural Mexican plant products in whitefly (B. tabaci) management. The results of these studies identified 11 Mexican plants with extracts that are effective against various B. tabaci life stages (eggs, nymphs, and adults). The plant species included Acalypha gaumeri, Agave tequilana, Annona squamosa, A. indica, Capsicum chinense, Carlowrightia myriantha, C. ambrosioides, Petiveria alliacea, Piper nigrum, Pluchea sericea, and Trichilia arborea.

Plant Extracts

Cruz-Estrada [57] investigated the effects of extracts from six plant species against B. tabaci eggs and reported that aqueous extracts from the leaves of A. gaumeri, A. squamosa, P. alliacea, and T. arborea exhibited activity (LC$_{50} = 0.36$–$0.42\% \text{w/v}$), as did the ethanol extracts of P. alliacea (LC$_{50} = 2.09$ mg/mL) and T. arborea (LC$_{50} = 2.14$ mg/mL). The latter two species showed the highest activity against B. tabaci nymphs (LC$_{50} = 1.27$ and 1.61 mg/mL, respectively). In parallel, leaf extracts from A. indica plants grown in Mexico were assayed. The toxic effects of the aqueous extracts of native plants were similar to those of A. indica aqueous extracts (LC$_{50} = 0.30\% \text{w/v}$) and were greater than those of the A. indica ethanol extract against eggs (LC$_{50} = 3.60$ mg/mL) and nymphs (LC$_{50} = 2.57$ mg/mL). A. tequilana juice (undiluted) and its hexanic extract (2%) promoted B. tabaci nymph mortality (100\% and 91\%, respectively), which is interesting given the significant quantities of juice obtained from the waste of this agave (Table 11) [58].

In another study (Table 11), the ethanol extracts of mature C. chinense fruits (creole orange variety) showed slight repellency and mortality effects against B. tabaci adults (LC$_{50} = 29.4\% \text{w/v}$, LT$_{50} = 7.31$ h). The concentration of capsaicinoids in the fruit of the habanero pepper was 1193.6 mg/kg. Capsaicinoids have been reported to have toxic and repellent effects against insects [59]. Ethanolic extracts from the leaves of C. ambrosioides and the fruits of P. nigrum showed good lethal activity against B. tabaci, with the lowest LC$_{50}$ of 1.6\% (w/v) observed for the P. nigrum extracts. Furthermore, P. nigrum produces high ethanolic extract yields (3.69\%), and this plant is inexpensive and accessible [60]. Finally, P. sericea is an interesting Asteraceae species which the extracts of have been shown to be effective against B. tabaci adults, with acetone, aqueous, and ethanolic extracts of the leaves shown to have moderate repellence activity (RI$_{50}$ of 0.52–0.78) [61].

| Species/Family     | Plant Part | Extract (Toxicity)                                                                 | Ref.  |
|--------------------|------------|-----------------------------------------------------------------------------------|-------|
| Acalypha gaumeri * | Leaves     | Aqueous (LC$_{50} = 0.39\% \text{w/v}$ on egg, 48 h) Ethanol (LC$_{50} = 3.54$ mg/mL on eggs; 3.15 mg/mL on nymphs, 48 h) | [57]  |
| Annona squamosa    | Leaves     | Aqueous (LC$_{50} = 0.36\% \text{w/v}$ on eggs, 48 h) Ethanol (LC$_{50} = 2.71$ mg/mL on eggs, 48 h; 2.66 mg/mL on nymphs, 48 h) | [57]  |
| Agave tequilana    | Leaves     | Juice (undiluted: 31\% mortality on adults) hexane (4\%: 100\% mortality on adults) | [58]  |
| Azadirachta indica | Leaves     | Aqueous (LC$_{50} = 0.30\% \text{w/v}$ eggs, 48 h) Ethanol (LC$_{50} = 4.14$ mg/mL eggs, 48 h; 10 ppm: 99.3\% mortality of nymphs) | [57]  |
| Capsicum chinense  | Fruits     | Ethanol (LC$_{50} = 29.4\% \text{w/v}$; LT$_{50} = 7.31$ h; RI = 0.11)             | [59]  |
| Carlowrightia myriantha * | Leaves | Aqueous (LC$_{50} = 1.1\% \text{w/v}$ on eggs) Ethanol (LC$_{50} = 2.69$ mg/mL on eggs; 3.10 mg/mL on nymphs) | [57]  |

Table 11. Plant extracts from Mexican flora with activity on Bemisia tabaci.
Table 11. Cont.

| Species/Family       | Plant Part | Extract (Toxicity)                                                                 | Ref.  |
|----------------------|------------|----------------------------------------------------------------------------------|-------|
| Chenopodium ambrosioides | Leaves    | Ethanol (LC$_{50}$: 3.26% w/v, resuspended in water)                            | [60]  |
| Chenopodiaceae       | Stems      |                                                                                  |       |
| Petiveria alliacea   | Aerial part| Aqueous (LC$_{50}$ = 0.42% w/v on eggs)                                        | [57]  |
| Petiveriaceae        |            | Alcohol (LC$_{50}$ = 2.09 mg/mL on eggs; 1.27 mg/mL on nymphs)                   |       |
| Piper nigrum         | Fruits     | Ethanol (LC$_{50}$: 1.6% w/v, resuspended in water)                             | [60]  |
| Piperaceae           |            |                                                                                  |       |
| Pluchea sericea      | Leaves     | Aqueous leaves (LC$_{50}$: 1190 ppm; RI = 0.52 on adults, 24 h)                  | [61]  |
| Asteraceae           | Stems      | Acetone leaves (LC$_{50}$: 700 ppm; RI = 0.78 on adults, 24 h)                  |       |
|                      |            | Ethanol leaves (LC$_{50}$: 1250 ppm RI = 0.66 on adults, 24 h)                   |       |
|                      |            | Aqueous stems (LC$_{50}$: 2620 ppm; RI = 0.54 on adults, 24 h)                  |       |
| Trichilia arboriæ    | Leaves     | Aqueous (LC$_{50}$ = 0.39% w/v on eggs, 48 h)                                   | [57]  |
| Meliaceae            |            | Ethanol (LC$_{50}$ = 2.14 mg/mL on eggs, 48 h; 1.61 mg/mL on nymphs)            |       |

* Endemic; LC$_{50}$: Median Lethal Concentration; RI: Repellency index.

2.6. Copitarsia Decolora and Dactylopius Opuntiae

The EOs of Beta vulgaris, C. graveolens, and Chenopodium berlandieri subsp. nuttalliae reduced the fecundity and fertility (75–99%) of C. decolora and increased (19–38%) the lengths of the larval and pupal periods (Table 12) [62].

Vazquez-García [63] reported that EOs obtained from Cymbopogon winterianus, L. graveolens, Mentha spicata, and Ocimum basilicum were active against the first-instar larvae of the prickly pear cochineal D. opuntiae, with LC$_{50}$ values ranging from 0.8–6.6 mL/100 mL. The most effective was the EO of M. spicata, the primary constituents of which were carvone (63, 61.03%) and limonene (64, 15.18%) (Table 12, Figure 5).

Table 12. Plant extracts from Mexican flora with activity against Copitarsia decolora and Dactylopius opuntiae.

| Insect                | Species/Family       | Plant Part | Extract (Toxicity)                                                                 | Ref.  |
|-----------------------|----------------------|------------|----------------------------------------------------------------------------------|-------|
| Copitarsia decolora   | Beta vulgaris        | Stems      | EOs (0.5%: 19% and 27% increased larval and pupal period length; 99% reduced fecundity and fertility) | [62]  |
| Chenopodium berlandieri subsp. nuttalliae | Whole plant | EOs (0.5%: 22% and 38% increased larval and pupal period length; 94% and 85% reduced fecundity and fertility) | [62]  |
| Chenopodium graveolens | Whole plant          | EOs (0.5%: 19% and 28% reduced larval and pupal period length; 75% and 96% reduced fecundity and fertility) | [62]  |
| Dactylopius opuntiae  | Cymbopogon winterianus | Leaves    | EOs (LC$_{50}$ = 6.6 mL/100 mL on 1st instar cochineal)                          | [63]  |
| Verbenaceae           | Leaves               | EOs (LC$_{50}$ = 5.2 mL/100 mL on cochineal mobile juveniles)                    | [63]  |
| Lippia graveolens     | Leaves               | EOs (LC$_{50}$ = 0.8 mL/100 mL solvent on cochineal mobile juveniles). Carvone (63, 61.03%) and limonene (64, 15.18%) | [63]  |
| Mentha spicata        | Leaves               | EOs (LC$_{50}$ = 2.4 mL/100 mL solvent on cochineal mobile juveniles)            | [63]  |
| Ocimum basilicum      | Leaves               | EOs (LC$_{50}$ = 2.4 mL/100 mL solvent on cochineal mobile juveniles)            | [63]  |

LC$_{50}$ = Median Lethal Concentration.
2.8. Prostephanus truncates

The larger grain borer (*P. truncates*) was shown to be susceptible to EO from the leaves of *Lippia palmeri*, with an LC_{50} value of 320.5 µL/L observed after 72 h. After the application of the EOs, a strong repellency against the insect at 200 µL/L was observed, and no insect emerged at 500 µL/L in 24 h. These EOs primarily contained 22 (58.9%) and p-cimene (66, 21.8%) as majority compounds (Table 14, Figure 7) [64].

![Figure 5](image5.png)

**Figure 5.** The majority components in the EOs of *Mentha spicata* effective on *Dactylopius opuntiae*.

2.7. Leptinotarsa decemlineata

The metabolite 6-hydroxyeuryopsin (65) isolated from *S. toluccanus*, and its acetate derivative (65a) exhibited a higher antifeedant effect (85 and 93.3% at 50 µg/cm², respectively) against the Colorado potato beetle (*L. decemlineata*) than did *S. frugiperda* (*vide supra*) (Table 13, Figure 6) [29].

![Figure 6](image6.png)

**Figure 6.** Insecticidal metabolite 6-hydroxyeuryopsin from *Senecio toluccanus*.

| Insect             | Species/Family        | Plant Part | Extract/Compound (Toxicity)                                      | Ref. |
|--------------------|-----------------------|------------|------------------------------------------------------------------|------|
| *Leptinotarsa decemlineata* | *Senecio toluccanus* * Asteraceae | Roots      | 6-Hydroxyeuryopsin (65) and acetyloxyeuryopsin (65a) (50 µg/cm²: 85.5% antifeedant effect) | [29] |

* Endemic; LC_{50} = Median Lethal Concentration.

![Figure 7](image7.png)

**Figure 7.** Majority metabolite (p-Cimene) from extract of *Lippia palmeri*.
2.9. Sitophilus zeamais

The EOs of 14 plant species with activities against the stored grain pest *S. zeamais* were compiled. These EOs were primarily derived from members of the Asteraceae family (*Aster subulatus*, *Bahia absinthifolia*, *Chrysactinia mexicana*, *Erigeron longipes*, *Eupatorium glabratum*, *Heliopsis annua*, *Heterotheca inuloides*, *Hippocratea celastroides*, *Hippocratea excelsa*, *Senecio flaccidus*, *Stevia serrata*, and *Zaluzania peruviana*) as well as members of the Rutaceae and Verbenaceae families (*Stauranthus perforates* and *L. palmeri*, respectively).

2.9.1. Terpenes

The triterpenoid pristimerin (67) was isolated from the roots of *H. excelsa* and displayed a high antifeeding activity index (AAI) of 89% and slight mortality (M = 16%) when used in a 1% formulation against *S. zeamais* (Table 15, Figure 8) [65].

Table 15. Plant extracts and metabolites from Mexican flora with activity against *Sitophilus zeamais*.

| Species/Family          | Plant Part | Extract/Compound (Toxicity) | Ref. |
|------------------------|------------|-----------------------------|------|
| *Hippocratea excels* *Asteraceae* | Root cortex | 1% Pristimerin (67) (AAI = 89.2% and M = 16%, 5 days) | [65] |
| *Eupatorium glabratum* *Asteraceae* | Leaves | EOs (LC₅₀ = 16 (females) and 20 µL/mL (males) after 1 week); LT₅₀ = 53 (females) and 70 h (males); α-pinene (59, 29.5), α-phellandrene (68, 19.6%) | [66] |
| *Lippia palmeri* *Verbenaceae* | Leaves | EOs (LC₅₀ = 441.45 µL/L mortality, 48 h) p-cimene (66, 21.8%), 21 (58.9%) | [64] |
| *Aster subulatus* *Asteraceae* | Leaves | 1% Leaves powder (M = 80.5%, 15 days) | [67] |
| *Bahia absinthifolia* *Asteraceae* | Leaves | 1% powder (AE = 21.6%, 55 days) | [67] |
| *Chrysactinia mexicana* *Asteraceae* | Leaves | 1% Leaves powder (M = 80.5%, 15 days; AE = 0.0%, 55 days) | [67] |
| *Erigeron longipes* *Asteraceae* | Flower | 1% Flower powder (AE = 45.0%, 55 days) | [67] |
| *Heliopsis annua* *Asteraceae* | Flower | 1% powder (M = 88.3%, 15 days) | [67] |
| *Heterotheca inuloides var. rosei* *Asteraceae* | Leaves | 1% Leaf powder (M = 87.7%, 15 days; AE = 0.0%, 55 days) | [67] |
| *Hippocratea celastroides* *Asteraceae* | Roots | 1% Dichloromethane (AAI = 70.7%, 5 days) | [65] |
| *Senecio flaccidus* *Asteraceae* | Flower | 1% Powder (M = 80.7%, 55 days) | [67] |
| *Stevia serrata* *Asteraceae* | Leaves | 1% Leaf powder (M = 80.2%, 55 days) | [67] |
| *Zaluzania peruviana* *Asteraceae* | Leaves | 1% Leafs powder (M = 88.1%, 15 days; AE = 50.0%, 55 days) | [67] |
| *Stauranthus perforates* *Rutaceae* | Roots | Powder mixed with maize kernels (1–3%; 91, 95.5, and 100% mortality respectively, 15 days) | [67] |

*Endemic; AAI: Antifeedant Activity Index; AE: Adults emergence; M= Mortality; LC₅₀ = Median Lethal Concentration; LT₅₀ = Median Lethal Time.*
2.9.2. EOs

A bioactive EO from *E. glabratum* exhibited high activity against female and male *S. zeamais*, with LC50 values of 16 and 20 µL/mL, respectively, and median lethal times of 53 and 70 h, respectively. Chromatographic analyses of *E. glabratum* EO revealed the presence of α-pinene (59) and α-phellandrene (68, 19.6%) as the major compounds (29.5%) [66]. In contrast, the pest insect *S. zeamais* exhibited a slight sensitivity to EO from *L. palmeri* leaves, with LC50 value of 441.45 µL/L against adults after 48 h. In addition, this EO induced total repellency against maize weevil adults, with no emergence observed using a concentration of 1000 µL/L after 24 h, with major EO components having been previously described (21 and 66) (Table 15, Figure 8) [64].

2.9.3. Plant Extracts

Juárez-Flores [67] screened flower powder and leaf powders from 81 plant species belonging to the Asteraceae family. Among the 162 plant powders tested (1%, w/w), twelve powders showed remarkable lethal activities (>80%) against *S. zeamais*, but only two inhibited adult emergence (<22 insects), *B. absinthifolia* and *C. Mexicana* (Table 15). The most effective of these powders were those produced from the leaves of *C. mexicana*, which caused a mortality of 98% and no adult emergence. Similarly, the root powder of *S. perforates* mixed with maize kernel (3%) displayed total mortality against *S. zeamais* [68], while an acetone extract produced from the roots of *H. celastroides* and its precipitate resulted in slight antifeeding activity index values of 72.3 and 73.8 against the stored grain pest *S. zeamais*, respectively (Table 15) [65].

2.10. *Stomoxys calcitrans* and *Scyphophorus acupunctatus*

The flavanone pinocembrine (69) obtained from the aerial parts of *Teloxys graveolens* showed an LC50 value of 418.69 µg/mL against the third-stage larvae of the stable fly *S. calcitrans*, an ectoparasite of mammals (Table 16, Figure 9) [69].

Valdés-Estrada [70] reported that seed powders (15%) from *Trichilia havanensis*, *C. papaya*, and *Annona cherimola* had good effects (100, 90, and 63%, respectively) on the mortality of the larvae of *S. acupunctatus*. All powders inhibited the weight of the agave weevil. The most effective was *A. cherimola*. (Table 16).

![Figure 8. Metabolites with activity against *Sitophilus zeamais*.](image1)

![Figure 9. Metabolite effective on *Stomoxys calcitrans*.](image2)
Table 16. Plant extracts and a metabolite from Mexican flora with activity on *Stomoxys calcitrans* and *Scyphophorus acupunctatus*.

| Insect                          | Species/Family         | Plant Part | Extract/Compound (Toxicity)                  | Ref. |
|---------------------------------|------------------------|------------|---------------------------------------------|------|
| *Stomoxys calcitrans*           | *Teloxys graveolens*   | Aerial part| Pinocembrine (69) (LC₅₀ = 418.69 µg/mL, 3rd stage larvae, 24 h) [69] |      |
| *Scyphophorus acupunctatus*     | *Annona cherimola*     | Seeds      | Powder (15% in artificial diet: 63% LM; larval, pupal, and adult weight reductions of 98.5, 40.6, and 45.0%, respectively, 24 days) [70] |      |
|                                 | *Carica papaya*        | seeds      | fresh seed (15% in artificial diet: 90% LM, 24 days) [70] |      |
|                                 | *Trichilia havanensis* | seeds      | Seed powder (15% in artificial diet: 100% LM, 24 days) [70] |      |

**LC₅₀**: Median Lethal Concentration; LM: Larval mortality.

2.11. *Tenebrio molitor* and *Trichoplusia ni*

Sterols 15 and 16 (Figure 1) from *M. geometrizans* (Cactaceae) and their combination (6:4) exhibited a high toxicity against the last-instar larvae of *T. molitor*, the yellow mealworm, causing acute toxicities with 5, 3, and 0% survival at 100 ppm, respectively. Interestingly, 15, 16, and their combination induced shortened *T. molitor* pupation and emergence, and many of the pupae died (Table 17) [24].

Only one report described assays against the cabbage looper *T. ni*, where volatile organic compounds from *A. indica* stems promoted significant neonatal and larval mortality (24 and 77%, respectively) at 1 g doses and an LD₅₀ of 5.6 g after 7 days (Table 17) [71].

Table 17. Plant extracts and metabolites from Mexican flora with activity on *Tenebrio molitor* and *Trichoplusia ni*.

| Insect               | Species/Family         | Plant Part | Extract/Compound (Toxicity)                  | Ref. |
|----------------------|------------------------|------------|---------------------------------------------|------|
| *Tenebrio molitor*   | *Myrtillocactus geometrizans* * | Whole plant| Macdougallin (15) (100 ppm: 5% survival) Peniocerol (16) (100 ppm: 3% survival) mixture (6:4) 15 + 16 (100 ppm: 0% survival) [24] |      |
| *Trichoplusia ni*    | *Azadirachta indica*  | Leaves     | Volatile compounds released (1 and 10 g: 24% and 63% neonate mortality; 77% and 79% larval mortality; LD₅₀ = 5.6 g, 7 days) [71] |      |

*Endemic; LD₅₀: Median Lethal Dose.*

2.12. *Trialeurodes vaporariorum*

In reviewing investigations on the effectiveness of Mexican plant products against the greenhouse whitefly, the species *Arundo donax*, *Petiveria alliacea*, *Phytolacca icosandra*, *Piper auritum*, *Raphanus raphanistrum*, and *Tagetes filifolia* were compiled.

2.12.1. EOs

Native populations of *T. filifolia* in Mexico contain high proportions of anethole, a phenylpropene present in the EOs from the plant. Therefore, the EOs from the flowers, leaves, and whole plants of *T. filifolia* were tested together with a commercial standard of trans-anethole (70) against *T. vaporariorum*. The lowest LC₅₀ value was observed using 70 (Figure 10), which produced an LC₅₀ value of 1.74 mg/mL and a median oviposition inhibition concentration (IOC₅₀) of 1.55 mg/mL, followed by the floral oil (LC₅₀ = 6.59 mg/mL), the foliar oil (LC₅₀ = 10.29 mg/mL), and the whole plant oil (LC₅₀ = 9.99 mg/mL). Another parameter measured was the median repellent concentration (RC₅₀),
with the floral oil being the most effective with an RC\(_{50}\) value of 0.13 mg/mL against \(T.\ vaporariorum\). The second instar of the nymphal stage of \(T.\ vaporariorum\) was noticeably sensitive to foliar oil (Table 18) [72].

![Chemical Structure](image)

**Figure 10.** Metabolites active against *Sitophilus zeamais*.

**Table 18.** Plant extracts from Mexican flora with activity on *Trialeurodes vaporariorum*.

| Species/Family | Plant Part | Extract (Toxicity) | Ref. |
|---------------|------------|--------------------|------|
| *Tagetes filifolia* Asteraceae | Flower | (RC\(_{50}\) = 2.0 mg/mL, 24 h; OIC\(_{50}\) = 7.9 mg/mL, adults) | [72] |
| | Leaves | (RC\(_{50}\) = 0.23 mg/mL; LC\(_{50}\) = 10.29 mg/mL, 24 h; OIC\(_{50}\) = 3.88 mg/mL, adults) | |
| | Whole plant | (RC\(_{50}\) = 0.24 mg/mL; LC\(_{50}\) = 9.9 mg/mL, 24 h; OIC\(_{50}\) = 3.56 mg/mL, adults) | |
| | Aerial part | trans-anethole (78) commercial standard (RC\(_{50}\) = 0.45 mg/mL; LC\(_{50}\) = 1.74 mg/mL, 24 h; OIC\(_{50}\) = 1.55 mg/mL, adults) | |
| *Piper auritum* Piperaceae | Leaves | Ethanol (LC\(_{50}\) = 116 mg/mL on adult, 24 h) | [73] |
| | | Acetone (OIC\(_{50}\) = 89.1 mg/mL on adult, 24 h) | |
| *Raphanus raphanistrum* Brassicaceae | Leaves | Water (IOC\(_{50}\) = 77.3 mg/mL, on adult, 24 h) | [73] |
| | | Ethanol (LC\(_{50}\) = 185.2 mg/mL, on adult, 24 h) | |
| *Petiveria alliacea* Petiveriaceae | Aerial part | Laboratory assays: Aqueous (LC\(_{50}\) = 4.6%), methanol (LC\(_{50}\) = 1.1%), dichloromethane (LC\(_{50}\) = 0.3%), in greenhouse (tomato); aqueous (LC\(_{50}\) = 16.6%), methanol (LC\(_{50}\) = 13.3%), dichloromethane (LC\(_{50}\) = 3.5%) | [74] |
| *Arundo donax* Poaceae | Roots | Aqueous (non-active) Methanol (LC\(_{50}\) = 0.57% and 34.79% w/v, *in vitro* and greenhouse RC\(_{50}\) =, respectively) | [75] |
| *Phytolacca icosandra* Phytolaccaceae | Leaves | Aqueous (non-active) Methanol (LC\(_{50}\) = 0.34% and 36.47% w/v, *in vitro* and greenhouse, respectively) | [75] |

IOC\(_{50}\): Median Inhibition of Oviposition Concentration; LC\(_{50}\) = Median Lethal Concentration; RC\(_{50}\) = Median Repellent Concentration.

2.12.2. Plant Extracts

Mendoza-García [73] reported that an ethanolic extract of *P. auritum* was the most toxic extract (LC\(_{50}\) = 116 mg/mL) tested against *T. vaporariorum* and that an aqueous extract of *R. raphanistrum* effectively inhibited oviposition (IOC\(_{50}\) = 77.3 mg/mL) against the greenhouse whitefly.

Evaluations of extracts applied to tomato crops under greenhouse conditions were reported to control *T. vaporariorum*. In one study, aqueous, methanol, and dichloromethane extracts from *P. alliacea* leaves showed remarkable LC\(_{50}\) values of 16.6, 13.3, and 3.5%, respectively [74]. In contrast, methanolic extracts from *A. donax* and *P. icosandra* exhibited slightly higher target LC\(_{50}\) values of 34.79 and 36.47%, respectively, under greenhouse conditions (Table 18) [75].
2.13. *Zabrotes subfasciatus*

The species *L. palmeri* and *Senecio salignus* exhibited effective activities against *Z. subfasciatus*, the main pest of common beans (*Phaseolus vulgaris*). A 0.07% solution of a root powder of the Asteraceae species *S. salignus* exerted lethal toxicity by contact against bean weevil adults after five days. When the concentration was increased, fewer days were required to control the pest, with a 0.07% solution producing LC$_{50}$ values of 0.03% and 0.08% after 3 days and median lethal times of 1.21 and 3.20 days observed for male and females, respectively. Therefore, males were more sensitive than females. In addition, the authors determined the optimal size of the root powder that should be used (<0.25 mm particles) [76].

**EOs**

EOs obtained from leaves of *L. palmeri* collected in the localities of Puerto de Oregano (PO) and Alamo (Al) exhibited lethal and ovicidal activities against *Z. subfasciatus* at 1.35 µL/g, with two months of persistence. EOs from leaves collected in PO was slightly more lethal than EOs obtained from leaves collected in Al. A comparison of the components of the two EOs revealed a number of differences, with carvacrol (22, 37.35%), thymol (21, 24.56%), and *p*-cimene (64, 15.62%) being abundant in EO from PO, whereas 64 (33.7%) and 22 (18.32%) were abundant in EOs from Al (Table 19) [77].

### Table 19. Plant extracts from Mexican flora with insecticidal activity against *Zabrotes subfasciatus*.

| Species/Family       | Plant Part | Extract (Toxicity)                                                                 | Ref. |
|----------------------|------------|-----------------------------------------------------------------------------------|------|
| *Senecio salignus*   | Roots      | Powder (male: LC$_{50}$ = 0.03%, 3–6 days; LT$_{50}$ = 1.31 days) (female: 0.08% 3–6 days; LT$_{50}$ = 3.2 days) | [76] |
| *Lippia palmeri* *   | Leaves     | EOs Puerto del oregano (LC$_{50}$ = 1.35 µL/g mortality, 48), 22 (37.35%), 21 (24.56%), 64 (15.62%) | [77] |
| *Verbenaceae*        |            | Alamos (LC$_{50}$ = 1.35 µL/g mortality, 48), 64 (33.70%), 22 (18.32%)             |      |

* Endemic; LC$_{50}$: Median Lethal Concentration; LT$_{50}$: Median Lethal Time.

3. Nematicidal Compounds and Plant Extracts

To date, very few bioprospecting studies have been performed to identify plants with nematicide effects. In this review, we identified reports describing 37 plant species with toxic activities towards plant and animal nematode parasites. These plant species belong to 21 botanical families, with those of the family Fabaceae (41%) being predominant. A total of 18 secondary metabolites were identified as active principles or presenting an active fraction against at least one of the parasitic nematodes tested in the reviewed studies, including terpenes (71–82), flavonoids (44, 69, 83, and 86), a phenylpropaoid (84), and a coumarin (85). These metabolites were obtained from *C. anuum*, *Gliricida sepium*, *Leucaena leucocephala*, *Microschium helleri*, *Sicyos bulbosus*, and *T. graveolens*.

3.1. Plant Extracts Effective against Parasitic Plant Nematodes

Although data on the subject is scarce, we focused on compiling reports on plants that have toxic effects on phytornematodes *Meloidogyne incognita*, *Meloidogyne javanica*, and *Nacobbus aberrans*. A total of twelve metabolites from *M. helleri*, *S. bulbosus*, and *C. anuum* have been purified and identified as active principles against plant parasite nematodes.

3.1.1. *Meloidogyne javanica*

Seven saponins isolated from *S. bulbosus*, namely, tacacoside B3 (71) and C (72), 16-OH tacacoside B3 (73), durantanin III (74), heteropappus saponin 7 rhamnoside (75), and heteropappus saponin 5 and 7 (76–77), were the active compounds responsible for the nematicidal effect against *M. javanica* J$_2$ (73.8–100% mortality at 0.5 µg/µL). Highly similar compounds, such as amole F-G (78, 79) and 16-OH amole F-G (80, 81), were isolated from *M. helleri* and caused lower (<8%) J$_2$ immobility at the 0.5 µg/µL
dose [78]. In addition, the hexane extract from the leaves of L. graveolens caused significant mortality against M. javanica J2 with an LC50 of 0.672 mg/mL (Table 20, Figure 11). [27].

| Nematode Species/Family | Plant Part | Compound/Extract (Toxicity) | Ref. |
|-------------------------|------------|----------------------------|------|
| Meloidogyne javanica    | Lippia graveolens Verbenaceae | Leaves | Hexane (LC50 = 0.672 mg/mL) 21 (70.6%), 22 (22.8%) |
|                        |            | Tacacose B3 (71) (0.5 µg/µL: 93% J2 I) tacacose C (72) (0.5 µg/µL: 97% J2 I) 16-OH-tacacose B3 (73) (0.5 µg/µL: 100% J2 I), durantalin III (74) (0.5 µg/µL: 74% J2 I) heteropappusaponin 7 rhamnoside (75) (0.5 µg/µL: 80% J2 I), heteropappusaponin 5 (76) (0.5 µg/µL: 91% J2 I) heteropappusaponin 7 (77) (0.5 µg/µL: 93% J2 I) |
| Sicyos bulbosus * Cucurbitaceae | Roots | Amole F (78) (0.5 µg/µL: 4.78% J2 I) amole G (79) (0.5 µg/µL: 7.83% J2 I) 16-OH-amole F (80) (0.5 µg/µL: 6.52% J2 I) 16-OH-amole G (81) (0.5 µg/µL: 6.34% J2 I) |
| Microsechium helleri * Cucurbitaceae | Roots | Capsidiole (82) (1 µg/mL: >80% J2 I, 72 h) |
| Nacobbus aberrans Capiscium annuum Solanaceae | Roots | Capsidiole (82) (1 µg/mL: >80% J2 I, 72 h) |
| Meloidogyne incognita Calea urticifolia Asteraceae | Roots | Ethanol (250 ppm: 80% larval mortality, 72 h) |
|                        |            | Water (50% w/v): 72% decrease eggs formation; 50% galling reduction |
| Eugenia winzerlingii * Myrtaceae | Leaves | Ethanol (ED50 = 133.4 ppm) |
| Tephrosia cinerea Fabaceae | Stem | Ethanol (250 ppm: 85% larval mortality, 72 h) |

* Endemic; ED50: Median Effective Dose; I: Immobility; LC50: Median Lethal Concentration.

Figure 11. Metabolites effective against Meloidogyne javanica and Nacobbus aberrans.

3.1.2. Nacobbus aberrans

The capsidiole (82) produced by C. annuum (Solanaceae) was reported to affect N. aberrans (Table 19). Pure capsidiole caused an 80% immobility in the J2 of N. aberrans after exposure for 72 h at a concentration of 1 µg/mL and caused a nematostatic effect (Table 20, Figure 11) [79].
3.1.3. *Meloidogyne incognita*

Plant extracts from *Calea urticifolia*, *E. winzerlingii*, and *Tephrosia cinerea* were shown to have lethal activities against *M. incognita* (Table 20). An aqueous extract from the roots of *C. urticifolia* was tested on second-stage *M. incognita* juveniles under greenhouse conditions. The results showed that 50% (w/v) of the *C. urticifolia* root extract effectively reduced gall formation (50%) and the number of eggs (72% reduction) on tomato seedlings that had been inoculated with 1000 eggs and 130 *M. incognita* J2 [80]. Ethanol extracts from the roots of *C. urticifolia*, the stems of *T. cinerea*, and the leaves of *E. winzerlingii* produced immobility in *M. incognita* J2 (>80%) when applied at 250 ppm. Finally, the ethanol extract from *E. winzerlingii* leaves was very active against *M. incognita* and had the lowest LC50 (133.4 ppm) of the tested extracts [81].

3.2. Plant Extracts with Activity against Parasitic Animal Nematodes

To date, 27 plant species have been identified with an effect against animal nematodes, 12 of which belong to the family Fabaceae (43%). The relevant studies primarily focused on the control of *Haemonchus contortus* (93%): one study investigated *Haemonchus placei*, and three investigated *Trichostrongylus colubriformis*, zooparasites of sheep. In addition, three studies focused on *Cooperia punctata* and *Cyathostomin* sp., zooparasites of grazing cattle and horses, respectively, and one focused on *Ascaridia galli*, a bird parasite. Herein, the active plant extracts are included, as well as some fractions or subfractions, with the predominant compounds described by the authors. Only five natural compounds were reported to have an anthelmintic activity against animal nematodes, two of which were purified and identified from plant species and the remaining two as enriched fractions, with compound rutin (35) assayed as a commercial standard.

### 3.2.1. *Ascaridia galli*

Only one study investigated the effect of metabolites from *T. graveolens* (Amaranthaceae) against *A. galli*. Flavonoid 69 (Figure 9) was the active ingredient isolated from the aerial parts of *T. graveolens*, and it had an LC50 of 623.49 µg/mL against *A. galli* (Table 21) [69].

| Nematode       | Species/Family     | Plant Part | Compound/Extract (Toxicity) | Ref.   |
|----------------|-------------------|------------|-----------------------------|--------|
| *Ascaridia galli* | *Teloxys graveolens* Chenopodiaceae | Aerial part | Pinocembrine (69) (LC50 = 623.49 µg/mL) | [69] |
| *Cooperia punctata* | *Leucaena leucocephala* Fabaceae | Fresh Leaves | Water (LC50 = 7.93 mg/mL EHI) Fraction LIC1F3 (LC50 = 0.06 mg/mL EHI) Quercetin (83, 82.21%), caffeic acid (84, 13.42%) | [82, 83] |
| *Gliricidia sepium* Fabaceae | Fresh Leaves | Acetone (LC50 = 1.03 mg/mL EHI) 2H-Chromen-2-one (85) (EC50 = 0.024 mg/mL EHI) | [84] |
| *Cyathostomin* sp. | *Diospyros anisandra* Ebenaceae | Leaves Bark | Methanol bark (LC50 = 10.28 µg/mL EHI in rainy season) Methanol leaves (LC50 = 18.48 µg/mL EHI in rainy season) | [86] |
| *Petiveria alliacea* Petraceae | Stem | Methanol (LC50 = 28.27 µg/mL EHI in rainy season) | [86] |

EC50: Median Effective Concentration; LC50: Median Lethal Concentration. EHI: Egg Hatching inhibition.
3.2.2. Cooperia punctata

Plant species with ovicidal activity against C. punctata included G. sepium and L. leucocephala. These plants were extracted with water, acetone–water 30:70, and acetone solvents, and all of these fractions were tested. For each plant, at least one of the extracts showed ovicidal activity. The most effective were the acetone extract from G. sepium and the aqueous extract from L. leucocephala, which showed significant LC_{50} values of 1.03 and 7.93 mg/mL on egg hatching inhibition (EHI), respectively. The addition of a tannin inhibitor (polyethylene glycol) in all of the extracts showed that, with the exception of the G. sepium acetone extract, all exhibited enhanced ovicidal effects. Next, an aqueous extract of L. leucocephala was fractionated using chromatographic methods. Among the fractions obtained, the highest ovicidal effect was observed in LIC1F3, with an LC_{50} value of 0.06 mg/mL detected on Cooperia spp. The analytical data indicated that the majority of components in LIC1F3 were quercetin (83, 82.21%) and caffeic acid (84, 13.42%) [82,83].

In contrast, the metabolite 2H-chromen-2-one (85) was purified from the acetone extract of G. sepium by bio-guided fractionation. Metabolite 85 had the highest ovicidal effect (EC_{50} of 0.024 mg/mL), EHI, and embryonic development against C. punctata [84]. A second metabolite isolated from the leaves of G. sepium was identified as oxytroside (86) which inhibited the C. punctata exsheathment process at 2400 µg/mL (Table 21, Figure 12) [85].

![Figure 12. Metabolites from Gliricida sepium and Leucaena leucocephala with activity on Cooperia sp.](image)

3.2.3. Cyastotomin sp.

An investigation on the control of the zooparasitic nematode Cyastotomin sp. using plant extracts was recently reported [86]. The authors indicated that methanol extracts from the leaves and bark of Diospyros anisandra (Ebenaceae) and the leaves and stems of P. alliacea, which were collected in the rainy season, showed promising activities in controlling the eggs and the development of L₁ Cyastotomin sp. larvae. The highest ovicidal activity was produced by the bark extract of D. anisandra, followed by the leaf extract, both of which were collected in the rainy season. These extracts presented LC_{50} values of 10.28 and 18.48 µg/mL on the EHI, respectively, while extracts from P. alliacea exhibited lower lethal activities (LC_{50} ≥ of 28.27 µg/mL). However, P. alliacea stems, which were also collected in the rainy season, induced the failed eclosion of larvae (90.7% at 75 µg/mL). The continued study of both plant species was highly recommended (Table 21) [86].
3.2.4. Haemonchus sp.

**Haemonchus placei**

A hydroalcoholic extract with significant activity against *H. placei*, was obtained from *Caesalpinia coriaria*. In this case, the extracts from fruits presented a greater activity than the leaves, with LC$_{50}$ values of 3.91 and 11.68 mg/mL, respectively [87].

**Haemonchus contortus**

In ruminants, *H. contortus* is one of the most important gastrointestinal parasitic nematodes in sheep and goats, as well as *H. placei*, a hematophagous parasite in bovines. Several plant extracts exhibited promising activities in controlling the larval stage of *H. contortus in vitro* (Table 22). Among these extracts, the dichloromethane extract from *Phytolacca icosandra* leaves (Phytolaccaceae) was one of the most active, with an LD$_{50}$ of 0.90 mg/mL on larval migration inhibition and an LD$_{50}$ of 0.28 mg/mL on egg hatch inhibition (EHI) in *H. contortus*. Additionally, ethanolic extracts from the same plant caused >92% of EHI at a 0.9 mg/mL *in vitro* level [88]. In addition, the methanolic extract from *Giricidia sepium* (Fabaceae) displayed a good EHI effect, with an ED$_{50}$ value of 394.96 µg/mL [89]. The hydroalcoholic extract from the leaves of *Acacia cochlacantha* (Fabaceae) showed total mortality against eggs of *H. contortus*. However, this extract was used at a high concentration (100 mg/mL), and its organic fraction obtained with ethyl acetate displayed one of the lowest EHI at an LC$_{50}$ of 0.33 mg/mL. This EHI effect increased ten-fold when it was subfractionated with dichloromethane to produce soluble and precipitate subfractions, with the low LC$_{50}$ values of 0.06 and 0.04 mg/mL observed, respectively. The ethyl acetate fraction was enriched with caffeoyl and coumaroyl derivatives [90]. The hydroalcoholic extract from *C. coriaria* showed a slightly higher effect against *H. contortus* larvae than on *H. placei*. In this case, the extracts from fruits presented LC$_{50}$ values of 1.63 and 3.98 mg/mL, respectively [87]. In addition, the ethanol extract from the seeds of *C. papaya* (Caricaceae) induced an EHI of 92% at 2.5 mg/mL [91].

The extracts of partially purified tannins obtained from the leaves of *Arachis pintoi*, *L. leucocephala*, *Guzmania ulmifolia*, and *Manihot esculenta* reduced the migration of the third-stage larvae of *H. contortus* by 69.9–87.4% at 4.5 µg/mL and 74.2–100% at 45 µg/mL after 96 h of exposure. However, an ovicidal effect from these plants was not observed [92]. Alonso-Diaz [93] confirmed the role of tannins in the larvicidal effect of *L. leucocephala* and other tropical Fabaceae, *Acacia pennatula* and *Lysiloma latisiliquum*, with larval migration inhibitions (LMI) of 51–53.6% at 1200 µg/mL through the use of polyvinyl polypyrrolidine, an inhibitor of tannins. In contrast, *Piscidia piscipula* was not affected. Vargas-Magaña [94] demonstrated that tannins in a 30% acetone–water extract (3600 µg/mL PBS) from the leaves of *Laguncularia racemose* blocked the eclosion of eggs of *H. contortus* (50.29%). Besides, *Senegalia gaumeri* induced an EC$_{50}$ of 401.8 and 83.1 µg/mL of EHI and larval mortality on *H. contortus*, respectively [95].

In *in vitro* studies, other investigations reported a lesser effect (20–40 mg/mL) on *H. contortus* larval mortality, including the hexane extract from the aerial parts of *Prosopis laevigata*, an acetone extract from the stem of *B. copallifera* [96], a hydro-methanolic extract from *Larrea tridentata* and aqueous extracts from *Cydista aequinoctialis*, *Heliotropium indicum*, and *Momordica charantia* (Table 22) [97,98].

There are seven reports on *in vivo* experiments that describe the effects of plant extracts. One of these studies included a mixture of extracts from the bulbs of *A. sativum* and the flowers of *T. erecta*. First, the extracts alone or in combination were tested in *vitro*. After 72 h, the lowest larval mortality of *H. contortus* (L$_{3}$) occurred at an LC$_{50}$ of 1.3 mg/mL, which was induced by the mixed extract (Table 22). Subsequently, it was administered in one dose of 100 µg/mL (40 mg/mL) to gerbils infected with *H. contortus* (L$_{3}$). After 13 days, the nematode in the gastric lumen of both treatment and control animals were counted. The highest larvae population reduction (LPR) was 87.5%, which was induced by the *T. erecta* and *A. sativum* mixed extracts. Each extract of these plants alone showed a lower effect in comparison with their combination in both assays, suggesting a synergistic action [99]. Similarly, Zamilpa [100] reported that a combined extract from the aerial parts of *Castela tortuosa* and
C. ambrosioides induced a 57.36% population reduction on L₃ H. contortus in infected gerbils (Table 23). In contrast, in vitro, the lowest lethal activity was produced by a hexane extract of C. ambrosioides (LC₅₀ = 1.5 mg/mL) at 72 h (Table 22). Other hexane extracts administered (100 µg/mL at 40 mg/mL) to gerbils was from Prosopis laevigata, which reduced parasite population (42.5%) [101].

Table 22. Plant extracts and metabolites from Mexican flora with in vitro activity against Haemonchus contortus.

| Species/Family          | Plant Part | Extract (Toxicity)                                                                 | Ref. |
|-------------------------|------------|-----------------------------------------------------------------------------------|------|
| Caesalpinia coriaria    | Fruits     | Hydroalcoholic (fruits: LC₅₀ = 1.63 mg/mL; leaves: LC₅₀ = 3.98 mg/mL on EHI, 48 h) | [87] |
|                         | Leaves     |                                                                                   |      |
| Phytolacca icosandra    | Leaves     | Dichloromethane (LD₅₀ = 0.90 mg/mL; LMI; LD₅₀ = 0.28 mg/mL EHI)                    | [88] |
| Phytolaccaceae          |            | Ethanol (2 mg/mL; 55.4% LMI; 1.8 mg/mL; 95% EHI)                                   |      |
| Gilrecaea sepium        | Leaves     | Methanol (ED₅₀ = 394.96 µg/mL EHI)                                                | [89] |
| Fabaceae                |            |                                                                                   |      |
| Acacia cochliacantha    | Fresh      | Hydroalcoholic (100 mg/mL: 100% EHI)                                              | [90] |
|                       | Leaves     | Ethyl acetate (LC₅₀ = 0.33 mg/mL EHI)                                             |      |
|                       |            | Dichloromethane soluble fraction (LC₅₀ = 0.06 mg/mL EHI)                           |      |
|                       |            | Dichloromethane precipitate (LC₅₀ = 0.04 mg/mL EHI)                                |      |
| Carica papaya           | Seeds      | Ethanol (2.5 mg/mL: 92% EHI)                                                      | [91] |
| Caricaceae              |            | Hydroalcoholic (2.5 mg/mL: 50% EHI)                                               |      |
| Acacia pennatula        | Leaves     | Tannins (1200 µg/mL: 51% LMI)                                                     | [92] |
| Fabaceae                |            |                                                                                   |      |
| Anacis pintoi           | Leaves     | Condensed tannins (4.5–45 µg/mL: 76.6–100% LM, 96 h)                               | [92] |
| Fabaceae                |            |                                                                                   |      |
| Guazuma ulmifolia       | Leaves     | Condensed tannins (4.5–45 µg/mL: 86.0–99.4% LM, 96 h)                              | [92] |
| Malvaceae               |            |                                                                                   |      |
| Manihot esculenta       | Leaves     | Condensed tannins (4.5–45 µg/mL: 69.9–100%, LM, 96 h)                              | [92] |
| Euphorbiaceae           |            |                                                                                   |      |
| Leucaena leucocephala   | Leaves     | Condensed tannins (4.5–45 µg/mL: 71.0–98.4%, LM, 96 h)                             | [92] |
| Fabaceae                |            |                                                                                   |      |
| Lysiloma latisiliquum   | Leaves     | Tannin (1200 µg/mL: 49.1% LMI)                                                    | [93] |
| Fabaceae                | Leaves     | Tannin (1200 µg/mL: 63.8% LMI)                                                    | [93] |
| Piscidia piscipula      | Leaves     | 30% Acetone–water (3600 µg/mL: 50.29 larvae failing eclosion)                     | [94] |
| Fabaceae                |            |                                                                                   |      |
| Laguncularia racemosa   | Leaves     | Acetona–water 70:30 (EC₅₀ = 401.8 EHI; 83.1 LMI)                                  | [95] |
| Combretaceae            |            |                                                                                   |      |
| Senegalia gaumeri       | Leaves     | Acetone (20 mg/mL: 66% LM, 72 h)                                                   | [96] |
| * Fabaceae              |            |                                                                                   |      |
| Bursera copallifera *   | Stems      | Acetone (20 mg/mL: 66% LM, 72 h)                                                   | [96] |
| Burseraceae             |            |                                                                                   |      |
| Prosopis laevigata      | Aerial part | Hexane (20 mg/mL: 86% LM, 72 h postexposure)                                       | [96] |
| Fabaceae                |            |                                                                                   |      |
| Cydista aquinociottis   | Leaves     | Aqueous (20 mg/mL: 39.57% LM, 72 h)                                               | [97] |
| Bignoniaceae            |            |                                                                                   |      |
| Heliotropium indicum *  | Leaves     | Aqueous (20 mg/mL: 34.59% LM, 48 h)                                               | [97] |
| Boraginaceae            |            |                                                                                   |      |
| Momordica charantia     | Fruits     | Aqueous (20 mg/mL: 53.83% LM, 72 h)                                               | [97] |
| Cucurbitaceae           |            | Aqueous (20 mg/mL: 68.13% LM, 72 h)                                               |      |
| Larrea tridentata       | Leaves     | Hydro-methanol 30% (EC₅₀ = 36 mg/mL on exsheathed larvae, 24 h)                   | [98] |
| Zygodaphyllaceae        |            |                                                                                   |      |
| Allium sativum          | Bulbs      | Hexane (LC₅₀ = 3.8 mg/mL LM, 72 h)                                                | [99] |
| Amaryllidaceae          |            |                                                                                   |      |
| Tagetes erecta          | Flowers    | Acetone (40 mg/mL: 36.6% LM, 72 h)                                                | [99] |
| Asteraceae              |            |                                                                                   |      |
| A. sativum–T. erecta    | Combined   | Combined bulbs and flower (LC₅₀ = 1.3 mg/mL LM, 72 h)                              | [99] |
| Castela tortosa * Simaroubaceae | Aerial | Hexane (LC₅₀ = 17.3 mg/mL EGI, 72 h)                                             | [100]|
| part                    |            |                                                                                   |      |
| Chenopodium ambrosioides| Aerial part | Hexane (LC₅₀ = 1.5 mg/mL EGI, 72 h)                                              | [100]|
| Chenopodiaceae          |            |                                                                                   |      |
| C. ambrosioides-        | Combined   | Hexane (LC₅₀ = 6.5 mg/mL EGI, 72 h)                                              | [100]|
| C. tortuosa             |            |                                                                                   |      |

* Endemic; EHI: Egg hatch inhibition; LM: Larval mortality; LMI: larval migration inhibition; LC₅₀: Median Lethal Concentration; LD₅₀: Median Lethal Dose.
Table 23. The in vivo evaluations of plant extracts against Haemonchus contortus.

| Plant Species          | Host     | Sample (Toxicity)                                                                 | Ref.       |
|------------------------|----------|----------------------------------------------------------------------------------|------------|
| Allium sativum         | Gerbils  | Oral administration extract (40 mg/mL) (100 µL: 68.7% LPR)                       | [99]       |
| Amaryllidaceae         |          |                                                                                  |            |
| Tagetes erecta         | Gerbils  | Oral administration extract (40 mg/mL) (100 µL: 53.9% LPR)                       | [99]       |
| Asteraceae             |          |                                                                                  |            |
| Allium sativum-Tagetes | Gerbils  | Oral administration combined extract (40 mg/mL) (100 µL: 87.5% LPR)              | [97]       |
| erecta 1:1 combined    |          |                                                                                  |            |
| Castela tortuosa *     | Gerbils  | Hexane extract intraperitoneally administered (40 mg/kg BW: 27.15% LPR)          | [100]      |
| Chenopodium ambrosioides| Gerbils  | Hexane extract (100 µL) intraperitoneally administered (40 mg/kg: 45.86% LPR)     | [100]      |
| castela tortuosa       |          |                                                                                  |            |
| Chenopodium ambrosioides| combined|                                                                                  |            |
| Prosopis laevigata     | Gerbils  | Hexane extract (40 mg/mL) intraperitoneally administered (100 µL: 42.5% reduced | [101]      |
| Castela tortuosa       |          |                                                                                  |            |
| Lysiloma acapulcensis *| Lambs    | Ethyl acetate fraction (25 mg/kg BW: 94.8% EHI; 62.9% EPGR)                      | [102]      |
| Oxalis tetraphylla     | Sheep    | Dried leaves (5 g/kg BW: 50.1% EPGR)                                            | [102]      |
| Oxalidaceae            |          |                                                                                  |            |
| Phytolacca icosandra   | Sheep    | Ethanol (250 mg/kg, 2 days: 72% reduction on eggs/g of faeces)                   | [103]      |
| P. icosandra           |          |                                                                                  |            |
| Oxalis tetraphylla     | Lambs    | Ethyl acetate fraction (25 mg/kg BW: 94.8% EHI; 62.9% EPGR)                      | [102]      |
| Oxalidaceae            |          |                                                                                  |            |
| Acacia cochlacantha    | Goats    | Fresh foliage (1.48 log_{10} excreted eggs per gram; control 2.18 log_{10}; 0.6 kg/animal weight gained) | [105]      |
| Pithecellobium dulce   | Goats    | Fresh foliage (1.18 log_{10} excreted eggs per gram; control 2.18 log_{10}; 2.4 kg/animal weight gained) | [105]      |

* Endemic; BW: Body weight; EHI: Egg hatch inhibition; EPGR: Egg per gram reduction; LPR: Larval population reduction.

An organic ethyl acetate fraction obtained from aqueous extracts of Lysiloma acapulcensis leaves showed a high EHI on L3 (94.85%) at 6.25 g/mL and a 100% larval mortality at 50 mg/mL after 72 h at the in vitro level. Subsequently, an organic fraction of dry and ground leaves of L. acapulcensis and the flavonol rutin (35) used to treat infected sheep were tested in vivo. The reduction in the excretion of eggs per gram (EPGR) of faeces was recorded, with 35 and the ethyl acetate fraction exhibiting a 66.2 and 62.9% EPGR at a concentration of 10 and 25 mg/kg body weight (BW), respectively. The application of the ethyl acetate fraction was more effective than dried leaves (5 g/kg BW), presenting a 62.9% EPGR. The chromatographic separation of the ethyl acetate fraction revealed the presence of the flavonol myricitrin (87) as a major component, though this enriched fraction was not tested (Figure 13). In this experiment, the larvae of Cooperia curticei, H. contortus, and Teladorsagia circumcincta and the eggs of Trichuris sp. from faeces were identified by morphological and morphometric analyses [102]. Another in vivo test was reported with the ethanolic extract from P. icosandra leaves which was encapsuled and orally administered to infected goats. Results showed a reduction of 72% in H. contortus eggs/g of faeces at two doses of 250 mg/kg BW, on day 11 post-treatment (Table 23). Fatty acids and a ketone were detected in the ethanol extract of P. icosandra as major components [103].
weight in kids noticeably increased with *G. ulmifolia* (Figure 14). The investigations on the activities of these plants have primarily focused on evaluating (1200 ppm), *Acacia pennatula* phenols and flavonoids. A mixture of extracts or their pure compounds provides a strategy in the search for natural and safer pesticides. Despite these limitations, species with a high potential for the biological activity of raw vegetable extracts or their enriched fractions, and less than 35% have led only 114 species of Mexican plants with biological activity against insects or nematode pests have been developing natural pesticides against insects and nematode pests is still in its early stages. To date, unfortunately, at present, research on bioprospecting plant species from Mexican flora with the aim of in vitro test was reported. In this investigation, kids were fed fresh leaves (10% of the total diet) of *H. contortus*. In further studies, a hydroalcoholic extract from *Oxalis tetraphylla* leaves was orally applied daily (20 mg/kg BW) for eight days to lambs infected with *H. contortus*. The results showed a 45.6% reduction in the number of eggs/gram of faeces. Flavonol compounds in *O. tetraphylla* were also detected [104].

Finally, an in vivo test in goats, Creole male kids, experimentally infected with *L3 H. contortus* was reported. In this investigation, kids were fed fresh leaves (10% of the total diet) of *A. cochliacantha*, *G. ulmifolia*, and *Pithecellobium dulce* (Fabaceae) for sixty days. A lower EPG was observed in kids fed with *A. cochliacantha* and *P. dulce*, with 1.28 Log$^{10}$ and 1.48 Log$^{10}$, respectively. Moreover, the total body weight in kids noticeably increased with *P. dulce* foliage in the diet, with 0.2% (control) to 2.4% kg/animal (treatment) weight gained, which was attributed to the decrease in parasite load [105] (Table 23).

3.2.5. *Trichostrongylus colubriformis*

With regards to the nematode *T. colubriformis*, the extracts from three species of the family Fabaceae (1200 ppm), *Acacia pennatula*, *L. leucocephala*, and *Lysiloma latisiliquum*, reduced the migration of *T. colubriformis* third-stage larvae by 71%, 72%, and 56%, respectively (Table 24) [106].

![Figure 13. Majority component (Myricitrin) of active extract from *Lysiloma acapulcensis* eaves.](image)

In further studies, a hydroalcoholic extract from *Oxalis tetraphylla* (Oxalidaceae) leaves was orally applied daily (20 mg/kg BW) for eight days to lambs infected with *H. contortus*. The results showed a 45.6% reduction in the number of eggs/gram of faeces. Flavonol compounds in *O. tetraphylla* were also detected [104].

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| Species/Family     | Plant Part | Extract (Toxicity)                          | Ref.   |
|-------------------|------------|---------------------------------------------|--------|
| *Acacia pennatula*| Leaves     | Tannin (1200 µg/mL: 71% Lm)                 | [106]  |
| Fabaceae          |            |                                             |        |
| *Leucaena leucocephala* | Leaves | Tannin (1200 µg/mL: 72% Lm)                 | [106]  |
| Fabaceae          |            |                                             |        |
| *Lysiloma latisiliquum* | Leaves | Tannin (1200 µg/mL: 56% Lm)                 | [106]  |
| Fabaceae          |            |                                             |        |

Lm: larval migration of third-stage larvae.

4. Conclusions

This review demonstrates the relevant pesticidal activity of several native plant species of Mexico, the majority of which were reported at the in vitro level, while some were reported in in vivo assays. Unfortunately, at present, research on bioprospecting plant species from Mexican flora with the aim of developing natural pesticides against insects and nematode pests is still in its early stages. To date, only 114 species of Mexican plants with biological activity against insects or nematode pests have been reported, most of which belong to the Asteraceae (20%), Fabaceae (15%), and Lamiaceae (11%) families (Figure 14). The investigations on the activities of these plants have primarily focused on evaluating the biological activity of raw vegetable extracts or their enriched fractions, and less than 35% have led to the purification, identification, and evaluation of the active compounds. Among the most common metabolites with activity detected against some of the tested targets are terpenes (58%), followed by phenols and flavonoids. A mixture of extracts or their pure compounds provides a strategy in the search for natural and safer pesticides. Despite these limitations, species with a high potential for effectiveness were identified for further study in the development of biotechnological products.
Although botanical pesticides are less persistent in the environment, toxicological studies on beneficial organisms and mammals should still be performed. Therefore, the use of an adequate and low-cost extract should be considered during in vitro evaluations. Although botanical pesticides are less persistent in the environment, toxicological studies on beneficial organisms and mammals should still be performed.

The high diversity of plant species in Mexico coupled with the increasing demand and urgency for new natural pesticides makes it extremely important to continue bioprospecting studies in this country. Additional studies will help generate new and alternative natural products that can improve the biological effectiveness, lower residuals, and increase the innocuousness of agricultural products as well as decrease their presence in foods. These studies will contribute to the recognition and dissemination of the importance of propagating plant species for their conservation and sustainable use.

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