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Review
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Insecticidal activity of essential oils from Asteraceae species against Lepidopteras: a review

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Abstract
Botanical insecticides, in the form of plant extracts or essential oils, are an excellent alternative for pest management, with the advantage of being generally less toxic to mammals than are traditional synthetic ones. Considering the insecticidal potential presented by the Asteraceae species, this work aimed to present data on the insecticidal effect against Lepidopteras caused by essential oils from Asteraceae plants. Searches were carried out in the Web of Science, Scopus and PubMed databases for works published up to April 2023. As a result, 15 Asteraceae species were described regarding the insecticidal potential of their essential oils against lepidopteran pests, as well as the toxicity of the most effective essential oils and their chemical composition.

Keywords: bioinsecticide, secondary metabolites, *Spodoptera*, *Artemisia*.

Atividade inseticida de óleos essenciais de espécies de Asteraceae frente à Lepidopteras: uma revisão

Resumo
Os inseticidas botânicos, na forma de extratos vegetais ou de óleos essenciais, são uma excelente alternativa para o manejo de pragas, com a vantagem de serem geralmente menos tóxicos aos mamíferos do que os inseticidas sintéticos tradicionais. Considerando o potencial inseticida apresentado por espécies de Asteraceae, este trabalho teve como objetivo apresentar dados sobre o efeito inseticida de óleos essenciais obtidos de plantas desta família frente à Lepidopteras. Foram realizadas buscas nas bases de dados Web of Science, Scopus e PubMed por trabalhos publicados até abril de 2023. Como resultado, 15 espécies de Asteraceae foram descritas quanto ao potencial inseticida de seus óleos essenciais contra pragas de lepidópteras, bem como a toxicidade dos óleos essenciais mais eficazes e sua composição química.

Palavras-chave: bioinseticida, metabólitos secundários, *Spodoptera*, *Artemisia*.

Introduction

The Order Lepidoptera is fixed by butterflies and moths that are easily distinguishable from other insects (Lima, 1945) due to the scales on the wings, which come off like dust on one's fingers when handled (Triplehorn and Johnson, 2016). The exact number of species in the world is not known, yet it is estimated that 160,000 cataloged species of Lepidoptera have considerable economic importance (Mitter et al., 2017).

The larvae of most species are phytophagous and many are pests of cultivated plants. Some feed on tissues, while others feed on stored grains or flour (Triplehorn and Johnson, 2016). Larvae occur at population peaks, sometimes causing total loss in crops, especially in annual crops. There are microlepidoptera, which due to their larvae being small, feed in galleries between the upper and lower epidermis of the leaves and the xylem, causing damage to palm trees that produce edible oil and fruit plants angiosperms dependant on insects to reproduce (Rafael and Melo, 2012).

New strategies for pest and disease control to be used in rotation with or in replacement of conventional pesticides are required. Essential oils (EOs) are very attractive products for insect control because they have low persistence under field conditions, which favors their compatibility with biological control agents and pollinators. Furthermore, they tend to be relatively nontoxic to birds, fish and other wildlife and their low persistence enhances farm workers´ safety and suggests little or no residues on foods (Isman, 2020).

EOs are a diverse group of natural aromatic compounds isolated mostly from non-woody plant materials by hydro-distillation, solvent-solvent extraction and liquid CO_2 extraction. They contain terpenoids, especially monoterpenes (C10), sesquiterpenes (C15) and diterpenes (C20), along with a variety of aliphatic hydrocarbons (low molecular weight), acids, alcohols, aldehydes and esters (Majeed et al., 2015).

Many species of Asteraceae demonstrate various pharmacological activities, which have been attributed to their phytochemical components, including essential oils, lignans, saponins, polyphenolic compounds, flavonoids and terpenoids (Koc et al., 2015; Tapia et al., 2004). Several studies demonstrated the antibacterial, antifungal, anti-inflammatory, antitumor and insecticide capacities of Asteraceaes species (Medeiros-Neves et al., 2018).

In this context, the aim of this work was to investigate the literature for the species of the Asteraceae family whose essential oils present insecticidal activity against Lepidopteras.

Materials and Methods

The databases Web of Science, Scopus and PubMed were used to collect the necessary materials for the development of this work. The keywords used were “Asteraceae”, “essential oils” and “Lepidoptera”. No limits were set on language, year or type of publication. The publications were selected as a more accurate description of the search and selection process for their consistency with the theme proposed for this work. Finally, a descriptive analysis was carried out about the insecticidal activity of essential oils from Asteraceae species against Lepidopteras.

Results and Discussion

The insecticidal activity of essential oils from Asteraceae species against Lepidopteras has been reported by authors from Algeria (Bouzeraa et al., 2019), Argentina (Alva et al., 2012), Brazil (Seixas et al., 2018; Menezes et al., 2020), Canada (Sangha et al., 2017), China (Liu et al., 2021; Huang et al., 2018), Egypt (Saleh, 1984), France (Gabel and Thiery, 1994), Turkey (Kesdek et al., 2020) and Uruguay (Umpiérrez et al., 2012, 2017). Table 1 was constructed based on the data found in 12 research papers. Fifteen (15) plant species belonging to the Asteraceae family were described as well as the toxicity of the most effective EOs, their chemical composition and the major chemical features of their pure compounds.

Table 1. Summary of reports indicating insecticidal effects of Asteraceae essential oils against Lepitopteran insect pests.

Plant species	Effects and tested insects	Major constituents (%)	Reference
Acanthospermum hispidum	Growth inhibitory and disturbance of oviposition *Spodoptera frugiperda*	(*E*)-β-Caryophyllene (35.2) α-Bisabolol (11.4%) Germacrene D (11.1)	Alva et al. (2012)
Achillea biebersteinii	Larvicidal against *Thaumetopoea pityocampa*	1,8-Cineole (38.1) Camphor (23.6) Borneol (5.9) α-Terpineol (5.2)	Kesdek et al. (2020)
Artemisia abrotanum	Ovicidal effects, larvicidal effects, larval feeding deterrence and adult oviposition deterrence against *Plutella xylostella*	Davanone (isomer) (31.1) Davanone (isomer) (14.8) Davana ether (6.4) Eucalyptol (5.1) 6-Methyl-5-octen-2-one (4.0) cis-Carvone oxide (3.2) Caryophyllene oxide (3.8)	Sangha et al. (2017)
Artemisia absinthium	Contact toxicity against *Tuta absoluta*	β-Thujone (56.3) (Z)-Epoxy-ocimene (14.8) (Z)-β-ocimene (4.6) Camphor (3.7) Sabinene (2.0) α-Thujone (1.7)	Umpiérrez et al. (2012; 2017)
Artemisia absinthium	Contact toxicity against *Diaphania hyalinata*	Z-isocitral (22) Myrcene (18) β-Pinene (15)	Seixas et al. (2018)
Artemisia annua	Contact toxicity against *Diaphania hyalinata*	Camphor (32) Germacrene D (21)	Seixas et al. (2018)
Artemisia camphorata	Contact toxicity against *Diaphania hyalinata*	Germacrene D-4-ol (22) 1,8-Cineole (12) Ascaridole (10) Borneol (10)	Seixas et al. (2018)

Table 1. *Continuation.*

Plant species	Effects and tested insects	Major constituents (%)	Reference
Artemisia dracunculus	Contact toxicity against *Diaphania hyalinata*	ND	Seixas et al. (2018)
Artemisia herba alba	Repellency and fumigant toxicity against *Ephestia kuehniella*	ND	Bouzeraa et al. (2019)
Artemisia lavandulaefolia	Contact and fumigant toxicity *Plutella xylostella*	Eucalyptol (35.60) (*R*)-4-Methyl-1-(1-methylethyl)-3-cyclohexen-1-ol (16.25) π-Trimethyl-3-cyclohexene-1-methanol (6.83) 3-Methyl-6-(1-methylethyl)-2-cyclohexen-1-one (6.63) (1*S*)-1,7,7-Trimethyl-bicyclo[2.2.1] heptan-2-one (4.72)	Huang et al. (2018)
Artemisia monosperma	Toxicity against *Spodoptera littoralis*	3-methyl-3-phenyl-1,4-pentadlyne	Saleh (1984)
Artemisia nakaii	Fumigant toxicity and antifeedant activity against *Spodoptera litura*	Feropodin (26.01) (+)-Camphor (24.42) 1,8-Cineole (17.77) Rishitin (10.53) Borneol (6.82) β-Selinene (4.24)	Liu et al. (2021)
Artemisia vulgaris	Contact toxicity against *Diaphania hyalinata*	Methyleugenol (57) β-Thujone (31) β-Pinene (26) 1,8-cineole (19)	Seixas et al. (2018)
Eremanthus erythropappus	Toxicity against *Spodptera frugiperda*	β-Bisabolol (86.54) (*E*)-Caryophyllene (1.78) Isovaleric acid (1.65) β-Bisabolene (0.86) α-Bisabolol oxide B (0.73) α-Bisabolol oxide A (0.70)	Menezes et al. (2020)
Eupatorium buniifolium	Contact and toxicity against *Tuta absoluta*	α-Pinene (22.0) (*E*)-β-Guaiene (10.0) β-Elemene (6.7) β-Pinene (6.1) Sabinene (5.9) β-Caryophyllene (5.8) Limonene (4.6)	Umpiérrez et al. (2012; 2017)
Tanacetum vulgare	Disturbance of oviposition, egg hatching and toxicity against *Lobesia botrana*	ND	Gabel and Thiery, 1994
Tanacetum vulgare	Ovicidal effects, larvicidal effects, larval feeding deterrence, and adult oviposition deterrence against *Plutella xylostella*	β-Thujone (92.4) Artemisia Ketone (1.6) Eucalyptol (1.5) 4-Terpineol (1.2)	Sangha et al. (2017)

ND = Not Determined.

Insecticidal activity of essentials oils of Asteraceaes against *Spodoptera*

Spodoptera littoralis (cotton leaf worm), *Spodoptera litura* (tobacco cutworm), *Spodoptera frugiperda* (fall armyworm) and *Spodoptera eridania* (southern armyworm) are important lepidopterans of Noctuidae family, pest species that are highly polyphagous. More than 100 species of host plants are reported, many of which are of economic importance. *Spodoptera littoralis* is present in the Palearctic region from Africa and Southern-Europe, the Arabian Peninsula into Iran. *Spodoptera litura* has its range covering Oriental and Australasian areas with some Palearctic overflows in the region of Iran. *Spodoptera eridania* occurs in the South Eastern United States from Maryland south to Florida and west to Kentucky and Texas; in the Neotropics, it ranges from Mexico, throughout the Caribbean, and south through Central America to Argentina. *Spodoptera frugiperda* is widely distributed in the Americas, occurring from South Central to Eastern Canada, coast to coast in the United States, south to Argentina and throughout the Caribbean (OEPP/EPPO, 2015).

One of the first works that reported insecticidal activity of Asteraceaes on Lepidoptera was Saleh (1984). In this work, the EO of *Artemisia monosperma* obtained by steam distillation of the aerial parts of the plant was shown to have insecticidal activity against house fly (*Musca domestica* L.), cotton leaf worm (*Spodoptera littorallis*) and the rice weevil (*Sitophilus oryzae*). The LD_{50} of the steam distillation products of the fresh aerial parts and the column chromatographic fractions of the steam distillate from *A. monosperma* were determined with house fly, cotton leaf worm and rice weevil. The LD_{50} of cotton worm (steam distillation) was 64 mg/g topical applications. The chemical structure of the active compound from the steam distillate was shown to be 3-methyl-3-phenyl-1,4-pentadlyne.

Other authors have reported the insecticidal activity of EOs from Asteraceae. Alva et al. (2012) studied the essential oil of *Acanthospermum hispidum* DC. This presented the sesquiterpenoids (*E*)-β-caryophyllene (35.2%), α-bisabolol (11.4%) and germacrene D (11.1%) as major constituents. The EO produced alteration of the feeding and oviposition behavior of the polyphagous insect *Spodoptera frugiperda* Smith when incorporated in the larval diet at 250 μg/g. Diets treated with 250 μg of EO per g of diet, dissuaded 53.3 ± 0.25% (antifeedant index = AI%) larval feeding. The same dose produced 65.9% decrease in the larval growing rate (GR). The GR of treated larvae was 6.10 ± 1.79 mg/d while the control GR was 17.91 ± 3.63 mg/d. The diet consumption rate (CR) dropped by 49.3% (CR = 29.04 ± 5.69 mg/d for treated) compared with the control (CR = 57.28 ± 6.33 mg/d for control). When the EO was incorporated in the larval diet at 250 μg/g, oviposition capacity (determined by the number of eggs) of treated females decreased by 70% compared with control females.

Menezes et al. (2020) obtained the EOs from *Eremanthus erythropappus* and from three Lamiaceae species (*Ocimum selloi*, *Hyptis suaveolens*, and *Hyptis marrubioides* aiming to evaluate its insecticidal effect against *S. frugiperda*. The EOs were incorporated into an artificial diet (at 1, 2 and 4 mg/mL) and offered to *S. frugiperda* caterpillars. The major compounds of the EOs were methyl chavicol for *O. selloi*, α-bisabolol for *E. erythropappus*, bicyclogermacrene for *H. suaveolens* and β-thujone for *H. marrubioides*. The treatments including 4 mg/mL of *E. erythropappus* essential oils, even 72 h after the start of the bioassay, did not affect the mortality rate of *S. frugiperda* (13.34 ± 0.6%) and showed results similar to those of the negative control. The essential oil of *E. erythropappus* consisted of six chemical compounds that accounted for 92.26% of the total chemical composition. The alcoholic sesquiterpene α-bisabolol was the major constituent, at 86.54%.

On the other hand, the EOs of *Artemisia nakaii* were extracted and tested for biological activity and showed strong fumigant toxicity and significant antifeedant activity against the larvae of *S. litura*. The terpenes at the highest concentrations in the EOs of *A. nakaii* were feropodin (26.01%), (+)-camphor (24.42%), 1,8-cineole (17.77%), rishitin (10.53%), borneol (6.82%) and β-selinene (4.24%). Furthermore, the monoterpenes 1,8-cineole and (+)-camphor present in the oil displayed significant fumigant activity against *S. litura*. Antifeedant activity assays showed that the EOs of *A. nakaii* as well as their main sesquiterpenes (feropodin and β-selinene) exhibited significant antifeedant activity against the larvae of *S. litura* (Liu et al., 2021).

Insecticidal activity of essentials oils of Asteraceaes against other Lepidopteras

The European grapevine moth (EGVM), *Lobesia botrana* Den. & Schiff. (Lepidoptera, Tortricidae, Olethreutini), is considered as a polyphagous insect that develops on plants from different families. Tansy flowers and tansy essential oil (*Tanacetum vulgare* L.) were evaluated on females of *L. botrana*. Both tansy and its essential oil inhibit oviposition behavior and mating behavior and reduce longevity. The average number of eggs laid per female isolated with tansy flowers was reduced by up to 50% every 2 days during the 6 days of exposure. The reduction was maintained after tansy removal. In the presence of tansy essential oil, posture reduction ranged from about 30 to 80% according to odor concentration. The number of spermatophores found in females isolated with tansy flowers was also reduced by two times compared to the control treatment, indicating that the presence of tansy reduced mating activity. The mating activity is sharply reduced, by two-thirds, when adults face the highest essential oil dose compared to controls. Therefore, the reduction in oviposition has been attributed to the presence of tansy or to tansy odor, tansy flowers; tansy odor increased male mortality during exposure (10% in the control, 50% in the tansy treatment and up to 98% in odor treatment). The highest rates of male mortality occurred during the 4-to-6-day period of exposure to flowers or odor (Gabel and Thiery, 1994).

Other authors have studied the insecticidal activity of Asteraceae oils on the family Plutellidae. Diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), is the dominant insect pest of cruciferous crops around the world and is resistant to many chemical insecticides. Experiments testing ovicidal and larvicidal effects, larval feeding deterrence and adult oviposition deterrence were made in the laboratory with essential oils derived from *Artemisia abrotanum* Linnaeus and *Tanacetum vulgare* Linnaeus (both Asteraceae), as well as other plants (Pinaceae, Piperaceae, Myrtaceae, Amaryllidaceae and Lamiaceae) using concentrations of 1, 2.5 and 5% v/v. Although all essential oils had some level of bioactivity against certain *P. xylostella* life stage concentrations, the results for the Asteraceas were not significant (Sangha et al., 2017).

The chemical composition and bioactivity of *Artemisia lavandulaefolia* DC essential oil on *P. xylostella* were available by Huang and collaborators (2018). The essential oil was obtained by hydrodistillation and analyzed by gas chromatography-mass spectrometry. Thirty-five (35) constituents were identified. The LD_{50} contact toxicity of the essential oil to immature *P. xylostella* was estimated at 0.045 μL per larva. *A. lavandulaefolia* oil exhibited fumigant toxicity against *P. xylostella* adults with an LC_{50} of 0.113 mg per L after 12 h and also provided 80 to 100% repellency at a 1% v/v concentration (Huang et al., 2018).

The leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), causes large yield losses in the culture of tomato (*Solanum Iycopersicum* L.). EOs from Uruguayan specimens of the local species *Eupatorium buniifolium* and the worldwide distributed *Artemisia absinthium* were characterized in their chemical composition as insecticidal against *T. absoluta*, with antifungal activities. Even though both EOs chemically differ, they exhibit insecticidal and antifungal activities not only by direct contact but also by contact with their vapors against the tested organisms (Umpiérrez et al., 2012). In another work, the essential oils from two Asteraceae (*A. absinthium* and *E. buniifolium*) were studied. The results show that seed germination was affected at application rates needed to control the leafminer *T. absoluta* (Umpiérrez et al., 2017).

The essential oils extracted from *Artemisia annua*, *A. absinthium*, *A. camphorata*, *A. dracunculus* and *A. vulgaris* were assessed against the melonworm *Diaphania hyalinata* (Linnaeus, 1758) (Lepidoptera: Crambidae) larvae. It is found in South and Central America and is considered as the major agricultural pest of Cucurbitaceae. The essential oil from *A. annua* induced a high mortality rate in *D. hyalinata* (96 %) over a 48-hour period, besides causing high mortality (86 %) in *D. hyalinata*. The insecticidal activity of *A. annua* oil was attributed to the synergism of its constituents, camphor and 1,8-cineole (Seixas et al., 2018).

In the other study, three essential oils extracted from three aromatic plants of different families, white wormwood (*Artemisia herba alba*, Asteraceae), oregano (*Origanum vulgare*, Lamiaceae) and rue (*Ruta montana*, Rutaceae), were evaluated for their repellent and fumigant toxic potential against the flour moth larvae, *Ephestia kuehniella* (Lepidoptera, Pyralidae), under laboratory conditions. The repellent activity was carried out in Petri dishes using a filter paper treated with different oil dilutions (25, 75, 100, 120, 130, 150 µL/mL). The fumigant toxicity was determined on three concentrations (50, 130, 150 µL/L air). Two plants were shown to be repellent against the *E. kuehniella* larvae. *O. vulgare* oil was the most repellent with 67% of repellency rate followed by *Artemisia* oil (46%) at 120 mu L/mL after 2 hours of exposure (Bouzeraa et al, 2019).

Another Lepidoptera of great commercial interest is the pine processionary moth, *Taumetopoea pityocampa* (Denis & Schiffermüller, 1775) (Lepidoptera: Notodontidae), an important pest of coniferous trees in the forests of Turkey and throughout the world. Kesdek et al. (2020) investigated the larvicidal effect of the essential oil obtained from *Achillea biebersteinii* Afan. in different doses (10, 15 and 20 uL /Petri^{-1}) over time (12, 24, 36 and 48 h) against *Thaumetopoea pityocampa* (Denis & Schiffermüller, 1775) (Lepidoptera: Notodontidae) larvae in laboratory conditions. At the end of the study, the larvae mortalities were observed to range from 3.33% to 100%. While the highest mortality rates (between 40% and 100%) were recorded on first and second instar larvae, the lowest mortality rates (between 3.3% and 73.3%) were determined for third, fourth and fifth instar larvae. The results showed that *A. biebersteinii* essential oil has a critical larvicidal effect on the first, second, third, fourth and fifth instar larvae of *T. pityocampa* in comparison with the controls and can be used in controlling the larvae of this pest**.**

In the field, applications of essential oils have been less satisfactory than the results obtained in the laboratory, in terms of low persistence and efficacy compared to synthetic compounds (Isman et al., 2011). Problems of limited efficacy, phytotoxicity and persistence can be overcome through microencapsulation of essential oils (Yang et al., 2009; Rani et al., 2014).

In the future, nanotechnology can be used to efficiently support the use of EOs by encapsulating them in stable nanoformulations, such as nanoemulsions (NEs), capable of improving stability and efficacy. The EO of the root of *Carlina acaulis* (Asteraceae) was recently proposed as a promising ingredient of a new generation of botanical insecticides. Benelli et al. (2020) developed a highly stable *C. acaulis*-based nanoemulsion (NE) capable of encapsulating 6% (w/w) of *C. acaulis* OE, with a mean diameter of around 140 nm and an SOR (surfactant to oil ratio) of 0.6. Its stability was evaluated over a six-month storage period and supported by an accelerated stability study. Therefore, the EO of *C. acaulis* and the base of *C. acaulis* NE were evaluated for their toxicity against first instar larvae of the European grapevine moth (EGVM), *Lobesia botrana*. The chemical composition of C. *acaulis* EO was investigated with gas-mass chromatography spectrometry (GC-MS) revealing carline oxide, a polyacetylene, as the main constituent. In toxicity, both *C. acaulis* EO and *C. acaulis*-based NE were highly toxic to *L. botrana* larvae, with LC_{50} values of 7.299 and 9.044 L/mL for *C. acaulis* OE and NE, respectively.

Conclusion

This review summarizes the current evidence on the insecticidal activity against Lepidopteras of EOs from plants belonging to the Asteraceae family. *Artemisia* is the main genera of Asteraceae with studies demonstrating insecticidal activity of its essential oils. There were 10 species of *Artemisia* studied against *Plutella xylostella*, *Tuta absoluta*, *Ephestia kuehniella*, *Diaphania hyalinata*, *Spodoptera littoralis* and *Spodoptera litura* in different assays and concentrations. The use of EOs could be a useful complementary or alternative method to the heavy use of classical insecticides. This could improve the biodegradability of insecticide treatments and therefore decrease the amount of toxic insecticide residues.

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