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Insecticidal activity of Asteraceae species against *Spodoptera* spp. (Lepidoptera: Noctuidae): a review

Atividade inseticida de espécies de Asteraceae contra *Spodoptera* spp. (Lepidoptera: Noctuidae): uma revisão

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ABSTRACT

Plant extracts can be effective as crop protectants against pests and, therefore, can be used as an alternative to synthetic insecticides for the control of insect pests. The advantage of using natural insecticides is that they degrade rapidly and are generally less toxic to mammals than are traditional synthetic ones. Recent studies indicate the biological potential of Asteraceae species, which have, for example, repellent, antifeedant, acaricidal, antifungal and insecticidal activities. Among the numerous insect pests of economically important crops, the genus *Spodoptera* bears some of the most destructive in the world due to the worldwide distribution of the different species and their wide host ranges. Thus, in this review, we present data on the insecticidal effect against *Spodoptera* spp. caused by pure metabolites and crude extracts obtained from Asteraceae plants.

Keywords: botanical insecticides, crops, armyworm, secondary metabolites, natural products.

RESUMO

Extratos vegetais podem ser eficazes na proteção de lavouras contra pragas e, por esta razão, podem ser utilizados como uma alternativa aos inseticidas sintéticos no controle de pragas de insetos. A vantagem do uso de inseticidas naturais é que eles se degradam rapidamente e geralmente são menos tóxicos para mamíferos do que os sintéticos tradicionais. Estudos recentes indicam o potencial biológico de espécies da família Asteraceae, que apresentam, por exemplo, atividades repelente, antialimentar, acaricida, fungicida e inseticida. Entre as inúmeras pragas de insetos de culturas economicamente importantes, o gênero *Spodoptera* possui algumas das mais destrutivas do mundo devido à distribuição mundial das diferentes espécies e sua ampla gama de hospedeiros. Assim, nesta revisão, apresentamos dados sobre o efeito inseticida contra *Spodoptera* spp. causado por metabólitos puros e extratos brutos obtidos de plantas da família Asteraceae.

Palavras-chave: inseticidas botânicos, cultivos agrícolas, lagarta, metabólitos secundários, produtos naturais.

INTRODUCTION

The Asteraceae family is one of the largest flowering plant families, including over 1,600 genera and 25,000 species worldwide (Tahtiharju et al., 2012). Asteraceaeous plants are distributed all over the world and are mostly common in the arid and semi-arid regions of subtropical and lower temperate latitudes. Since these flowers have various colors, a number of species are popular garden plants. These plants typically have hairy and aromatic leaves and flat clusters of small flowers on the top of the stem. It includes several well-known species, such as chicory, sunflower, lettuce, coreopsis, dahlias and daisy. Most of the Asteraceae family members are used as medicinal plants that have therapeutic applications, such as wormwood, chamomile and dandelion (Achika et al., 2014; Nikolic and Stevovic., 2015).

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

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 (European and Mediterranean Plant Protection Organization, 2015).

More than 1,000 cases of resistance for synthetic insecticides have been reported in the *Spodoptera* genus (Arthropod Pesticide Resistance Database, 2022). Therefore, providing a management method using botanical insecticides is an alternative to control this pest. In this work, our interest is centered on the study of possible insecticidal activities against *Spodoptera* spp. of plants belonging to the Asteraceae family.

SCREENING OF EXTRACTS OF PLANTS OF ASTERACEAE AGAINST *SPODOPTERA*

Plants produce a vast and diverse assortment of compounds and most of them do not participate directly in growth and development. These phytochemicals, traditionally referred to as secondary metabolites, are often differentially distributed within the plant Kingdom (Koul, 2008). For these to be practical and economical, the selected species must meet some requirements, such as being cultivable and having a potent active principle, high stability and a good yield.

Extracts of 12 Asteraceae were tested on *S. frugiperda* and on its eggs parasitoids *Telenomus remus* and *Trichogramma pretiosum*. The plants *Lychnophora ericoides* and *Trichogonia villosa* were toxic for one-day-old eggs of *S. frugiperda* and *Lepidaploa lilacina* for two-day-old eggs of this insect. Extracts of *Vernonia holosenicea*, *Lychnophora ramosissima* and *Chromolaena chaseae* had higher impact on *S. frugiperda.* All the extracts, except for *Lepidaploa lilacina* and *Ageratum fastigiatum*, caused mortality of *T. pretiosum* lower than 5.5%. *Eremanthus elaeagnus* and *V. holosenicea* were more selective to this parasitoid, with 0.7 and 0.8% mortality, while those of *L. lilacina* and *A. fastigiatum* were more harmful, with 10.4% and 8.2%, respectively. The extract of *Tagetis erecta* Linnaeus (Asteraceae) did not reduce the number of eggs parasitized, the percentage of adult emergence or the development of *T. pretiosum*. This indicates higher selectivity of Asteraceae extracts in areas with releases of *Trichogramma* spp. (Tavares et al., 2009).

In 2011, Pavella (2011) evaluated methanol extracts of 134 plant species of the Eurasian region against *S. littoralis*. Among the Asteraceae species evaluated, the extracts from *Artemisia campestris*, *Buphtalmum salicifolium* and *Eupatorium cannabinum* caused 100% larval mortality and growth inhibition higher than 75% after the application of a 15 mg dose of the extract in 1 g of food. Lethal doses (LD) and the effect of median lethal dose (LD_{50}) on growth inhibition and antifeedant effects were estimated in order to determine the differences in efficiency of the selected extracts based on the mortality results.

The methanol extracts of Cannabinaceae, Umbelliferae, Ericaceae, Solanaceae, Ranunculaceae and Asteraceae species were tested against *S. littoralis* larvae by Karakok and Gokce (2012). *Tanacetum zahlbruckneri* (Asteraceae) appears to be the most toxic plant extract among the ones tested. In the second part of the study, contact toxicity of *T. zahlbruckneri* stem and flower extracts (hexane, ethyl acetate and methanol) were tested on S. *littoralis* larvae. The greatest toxicity was recorded with *T. zahlbruckneri* flower-methanol extract by 91% mortality, followed by stem-ethyl acetate (57%) and stem hexane extracts.

Based on the results presented above, Karakok and Gokce (2013) evaluated nine plant extracts on *S. littoralis*. Antifeedant effects of plant extracts varied from 22.44% to 68.96%. The most active plant extracts were *Delphinium consolida* (Ranunculaceae) (68.96%) and three Asteraceas: *Chrysanthemum segetum* (62.67%), *Artemisia vulgaris* (61.09%) and *Tanacetum mucroniferum* (55.87%). *C. segetum* was the most toxic extract with 74.24% mortality. It was followed by *D. consolida* and *T. mucroniferum* with 70.53% and 67.04% mortality, respectively.

Studies presenting the insecticidal activity of plants of the Asteraceae family have been carried out in several parts of the world. Ethanol extracts obtained from aerial parts of 64 native plants from Central Argentina were tested against *Epilachna paenulata* and *S. frugiperda*. Extracts derived from *Achyrocline satureioides* (Asteraceae), *Baccharis coridifolia* (Asteraceae), *Baccharis flabellata* (Asteraceae), *Ruprechtia apetala* (Polygonaceae) and *Vernonanthura nudiflora* (Asteraceae) showed more than 97% inhibition of the feeding of *E. paenulata* at 100 µg/cm^2. All these extracts, except for that derived from *A. satureioides*, showed antifeeding index (AI) greater than 80% for *S. frugiperda* at 100 µg/cm^2 (Del Corral et al., 2014).

The Artemisia genus is one of the most studied of the Asteraceae family. Ethanolic extract of aerial parts of *Artemisia annua* L. and artemisinin were evaluated as anti-insect products. In a feeding deterrence assay on *Epilachna paenulata* larvae, complete feeding rejection was observed at an extract concentration of 1.5 mg/cm^2 on pumpkin leaf tissue. The same concentration produced feeding inhibition of 87% in *S. eridania*. In a no-choice assay, both species ate less and gained less weight when fed on leaves treated with the extract. Complete mortality in *E. paenulata* and 50% mortality in *S. eridania* were observed with the extract at 1.5 mg/cm^2. Artemisinin exhibited a moderate antifeedant effect on *E. paenulata* and *S. eridania* at 0.03 mg/cm^2 - 0.375 mg/cm^2. However, a strong effect on survival and body weight was observed when *E. paenulata* larvae were forced to feed on leaves treated at 0.03 and 0.075 mg/cm^2 (Maggi et al., 2005).

Another genus of the Asteraceae family rich in insecticidal substances is the genus *Chrysanthemum*, which is very common in the Mediterranean basin countries. The effect of the methanol extracts of five *Chrysanthemum* species on the feeding and performance of *S. littoralis* larvae has been investigated *in vitro* by Haouas et al. (2010). The extracts exhibited antifeeding and phagostimulating activities against cotton leaf worm larvae when applied either on leaf discs or incorporated into an artificial diet. Toxicity of the extracts was assessed according to a high mortality, reduced growth rates and low weight gain by larvae fed on diets containing 1,000 and 10,000 ppm of the extract. None of the larvae treated with *Chrysanthemum macrotum* leaf crude extract survived to pupation at the two higher concentrations. The time to pupation increased for *Chrysanthemum grandiflorum* flowers crude extract from 11.40 ± 0.93 to 28.93 ± 10.92 days as the extract concentration in the diet increased from 0 to 10,000 ppm. The ingestion of crude extract by the third instar larvae significantly reduced the consumption, growth and utilization of the ingested and digested food, and reduced digestibility. The crude extract of the leaves of *C. macrotum*, dissolved in acetone and topically applied on sixth instar larvae, showed a rather high mortality (95%).

Tanacetum species have been used as insecticides in folk medicine for centuries. Pyrethrum, which is obtained from the dried flower extracts of *Tanacetum* (*Pyrethrum*) *cinerariifolium*, is known as a neurotoxic non-hormonal agent that is used against insects (Susurluk et al., 2007). Antifeedant activities of *Tanacetum cadmeum* ssp. *cadmeum*, *Tanacetum parthenium*, *Tanacetum corymbosum* ssp. *cinereum*, *Tanacetum chiliophyllum* var. *chiliophyllum*, *Tanacetum kotschyi* and *Tanacetum cadmeum* ssp. *Orientale* were assessed on *S. littoralis* third instar larvae. The highest antifeedant activities were found as 62% and 55.05% in the extracts of MeOH with *T. cadmeum* ssp. *cadmeum* aerial parts, and MeOH with *T. corymbosum* ssp. *cinereum* flowers, respectively. Bioassay-guided investigations on *T. cadmeum* ssp. *cadmeum* yielded sesquiterpene lactones of the eudesmanolide and germacranolide types, coumarin and flavonol derivatives (Susurluk et al., 2007).

The bioinsecticidal activity of organic extracts of *Tagetes erecta* was evaluated on neonate larvae of *S. frugiperda* by Salinas-Sánchez et al. (2012). The acetone leaf extract (500 ppm) of *T. erecta* induced an antifeedant effect, causing a 50% reduction of larval weight in comparison with the control. Larval weights were drastically reduced in 7 days, but even more so in 14 days, when *T. erecta* extracts also caused substantial mortality. Three leaf extracts of *T. erect*a caused high larval mortality: hexane (48%), acetone (60%) and ethanol (72%). Further *T. erecta* leaf extracts caused pupal mortalities of 40%-80%.

Another genus of the Asteraceae family that has been studied is the *Senecio* genus. This genus comprises about 1,500 species with 165 species found in Mexico, which are known to produce many insecticidal compounds such as alkaloids, sesquiterpenes, chalcones, and flavonoids. Hexane extracts of the aerial parts of *Senecio salignus* were evaluated against first instar larvae of *S. frugiperda*. *S. salignus* extract showed insecticidal activity at 500 ppm, resulting in larval mortality of 52.5% and pupal mortality of 62.5%. The media lethal concentration (LC_{50}) was 440 ppm based on the total larval period. The juvenomimetic activity of *S. salignus* extract at 500 ppm increased the duration of the larval period to 17.3 days and of the pupal period to 1.4 days. It also reduced pupal weight by 34.7% when compared to the control (Romo-Asunción et al., 2016).

Kaur et al. (2019) evaluated the biological activity of the hexane extract of *Inula racemosa* against *S. litura*. The extract exhibited larvicidal and growth inhibitory activities. A moderate antifeedant effect was recorded with maximum feeding deterrence of 24.85% at 1,500 ppm of the extract. Diet supplemented with 1,500 - 2,000 ppm of the extract induced significantly higher mortality in *S. litura* larvae when compared to control. All concentrations showed a very strong growth inhibitory effect in a dose-dependent manner. The highest concentration extended the development of *S. litura* by 21.06 days relative to control. Due to toxicity of *I. racemosa*, the adult emergence decreased significantly at concentrations ranging between 1,500 ppm - 2,500 ppm. Sublethal effects of the extract were also seen as morphological deformities in larvae and pupae of *S. litura*.

INSECTICIDAL ACTIVITY OF COMPOUNDS ISOLATED FROM ASTERACEAE AGAINST *SPODOPTERA*

Sesquiterpene Lactones

Plant species belonging to the Asteraceae family are known for their content of sesquiterpene lactones (SLs), a class of terpenoids, which have been reported to serve as toxic or feeding deterrents to herbivore insects (Picman, 1986; Koul, 2004; Kaur et al., 2017). The antifeedant properties of these compounds were demonstrated for the first time by Burnett Junior et al. (1974) in tests with six species of Lepidopterous larvae with *Vernonia* species and a sesquiterpene lactone glaucolide-A. Significant differences between the feeding preferences of the insect species were observed. The sesquiterpene lactone, glaucolide-A, was found to reduce larval feeding when incorporated in a *Vernonia* powder-agar medium. The amount of insect feeding was inversely proportional to the concentration of glaucolide-A in the medium. Oviposition preference tests were conducted with five species of Lepidoptera on three species of *Vernonia*. *Spodoptera frugiperda*, *S. eridani* and *S. ornithogalli* all laid a significantly greater number of eggs on *V. flaccidifolia*. Additional oviposition tests, using *V. flaccidifolia* with glaucolide-A added, demonstrated that this substance influences oviposition preference only in the fall armyworm (Burnett Junior et al., 1978).

These results were confirmed by Jones Junior et al. (1979), in which sesquiterpene lactone glaucolide-A from *Vernonia*, incorporated in the rearing diets of five species of Lepidoptera, significantly reduced the rate of growth of larvae of *S. eridania*, *S. frugiperda* and *S. ornithogalli*. Quantitative feeding tests demonstrated that decreased feeding levels and reduced growth resulted from the ingestion of a sesquiterpene lactone. Ingestion of glaucolide-A increased the number of days to pupation in four of the species. In the southern armyworm, it significantly reduced pupal weight. Glaucolide-A decidedly reduced the percentage of survival of *S. eridania* and *S. frugiperda.*

Studies have demonstrated the antifeedant activity of substances in *Spodoptera*. The sesquiterpene lactone 8α-angeloyloxycostunolide isolated from the flowers of *Tanacetum argenteum* subsp. *Argenteum* showed cytotoxic activity and antifeedant activity against neonate larvae of *S. littoralis*, as demonstrated by Gören et al. (1994).

Passreiter and Isman (1997) isolated germacranolides and furanoheliangolides from the aerial parts of *Neurolaena lobata* and evaluated them as antifeedants against fifth instar larvae of *S. litura* using leaf disc bioassays. All the compounds showed strong antifeedant activities.

The acetone extract of the aerial parts of *Onopordum illyricum* L. yielded five sesquiterpene lactone guaianolides. These compounds were tested against larvae of *S. littoralis* at a concentration of 100 ppm and they showed moderate antifeedant activity against larvae of *S. littoralis* (Rosselli et al., 2012).

The insecticidal and antifeedant activities of compounds and extracts from the leaves of *Hymenoxys robusta* on *S. exigua* were evaluated by Juárez et al. (2014). The methanol extract possessed suppressive activity, high antifeedant activity and inhibited oviposition. The vermeerin, a sesquiterpene lactone isolated from *H. robusta*, showed a high antifeedant effect.

Sosa et al. (2019) studied for the first time the antifeedant and toxic effects of *Vernonanthura nebularum* natural products against *S. frugiperda* and the oviposition deterrent activity against the fruit fly *Ceratitis capitata* Wiedemann. As a result, the authors found that extracts, fractions composed of sesquiterpene lactones and pure sesquiterpene lactones altered the larval feeding behavior in the food choice test. Nutritional parameters of *S. frugiperda* larvae were also affected.

Other works have shown inhibitory growth activities of substances isolated from Asteraceae on *Spodoptera*. Smith et al. (1983) observed that sesquiterpene lactones adversely affect growth rate and survival of certain insects that feed upon plants containing them. The crude extracts of *Melampodium americanum* and *Melampodium leucanthum* and their principal sesquiterpene lactones, melampodin A and melampodinin A, significantly inhibited growth and deterred feeding of *S. frugiperda*.

Kaur et al. (2017) analyzed the insecticidal activity of sesquiterpene lactones isolated from *Inula racemosa* against *S. litura*. Alantolactone and isoalantolactone isolated from *I. racemosa* exerted growth inhibitory effects on *S. litura*. The addition of both sesquiterpenes to the larval diet extended the development period and reduced pupation as well as adult emergence.

Several compounds have been isolated from the leaves, stem and flowers of *Tittonia diversifolia*, including sesquiterpenes, diterpenes, monoterpenes and alicyclic compounds, some of which have demonstrated biological activities against different species of insects (Kerebba et al., 2019). Miranda et al. (2022) evaluated the insecticidal effect of the ethyl acetate fractions and sesquiterpene lactones from *T. diversifolia* leaf extract against *S. frugiperda*. As a result, some fractions reduced pupal weight and others increased the duration of the larval period. The sesquiterpene lactones tagitinin A, tagitinin C and 1β-methoxydiversifolin at 100 ppm, 50 ppm and 10 ppm affected the larval development with a reduction of the larval period and pupal weight.

Other Compounds

In 1991, Srivastava and Proksch (1991) assessed five chromene derivatives as well as a structurally related benzofuran, all of them natural constituents from species of the Asteraceae for contact toxicity and feeding inhibitory activity against larvae of *S. littoralis*. The chromenes exhibit varying degrees of contact toxicity and feeding inhibitory activity at concentrations well below those found in plants.

Four oxyflavones and an ent-clerodane, bacchabolivic acid, were isolated from the aerial parts of *Gutierrezia microcephala* by Calderón et al. (2001). These compounds, the synthetic methyl ester of ent-clerodane, n-hexane and MeOH extracts were evaluated against *S. frugiperda*. When tested for activity on neonate larvae into the no-choice artificial diet bioassay, MeOH and n-hexane extracts caused significant larval mortality, as well as growth reduction. Acute toxicity against adults of *S. frugiperda* was also found.

Céspedes et al. (2001) isolated the triterpenes argentatin A and B of the methanolic extract from aerial parts of *Parthenium argentatum*. These compounds were evaluated for their effect against *S. frugiperda*. Argentatin A, argentatin B and methanol extract caused significant growth inhibition and increased the development time of surviving larvae in a concentration-dependent manner. In addition, it was possible to observe in most of the treated groups a significant delay in the time of pupation, adult emergence and deformities. The MeOH extract had the most potent activity against adults of *S. frugiperda*.

The tocotrienol sargachromenol, the dihydroplastoquinone sargahydroquinoic acid and the plastoquinone sargaquinoic acid were isolated from the methanol extract from aerial parts of *Roldana barba-johannis* by Céspedes et al. (2004). These natural products and their corresponding acetylated and methylated derivatives showed insecticidal and insect growth regulatory activities against *S. frugiperda*. The most active compounds were sargachromenol and its acetylated derivative; sargahydroquinoic acid and its acetylated derivative; a mixture of sargachromenol, sargahydroquinoic acid, and sargaquinoic acid (6:3:1) and the acetylated form of this mixture. All these compounds and mixtures had significant inhibitory effects between 5.0 and 20.0 ppm in diets. Most compounds were insecticidal to larvae, with lethal doses between 20 ppm and 35 ppm.

The antifeedant activity of five coumarins isolated from *Pterocaulon polystachyum* was tested against *S. frugiperda* larvae. Two analogs, scopoletin and 2-methoxy-2-methyl-3,4,5,6,7,8-hexahydro-*3H*-chromen-5-one, were also evaluated for comparison. The compounds were added to an artificial diet at doses ranging from 50 to 200 µg per g of diet. Natural coumarins induced 100% of antifeedant activity when 200 µg was added per g of diet. Compounds 6-hydroxy-7-isoprenyloxycoumarin and 6,7-methylenedioxycoumarin, and the equimolar mixture of both, displayed the strongest antifeedant profile. Larval growing rate during the early larval instars was significantly reduced by the treatments with the methylenedioxycoumarins 6,7-methylenedioxycoumarin and 5-methoxy-6,7-methylenedioxycoumarin. Additionally, the larval period duration was significantly increased by the latter compounds (Vera et al., 2006).

Mesurado et al. (2021) tested 11 grindelanes (two as natural acids and nine as methylated derivatives) purified from the foliar tissue of *Grindelia chiloensis* against the fall armyworm, *S. frugiperda*. Remarkable alterations in the feeding behavior, larval weight, larval and pupal stage lengths, and adult fertility, as well as malformations and mortality in specimens during their life cycle, were noticed in the feeding preference tests and no-choice diet assays. All grindelanes altered the molting process, resulting in larvae with exuvia retention, pupae with retention of larval characteristics and adults with pupal characteristics evidencing an incomplete metamorphosis.

Matloub et al. (2021) evaluated the insecticidal activity of extracts and isolated compounds from *Conyza dioscoridis*. The crude extract showed a percentage of cumulative mortalities during pupal and adult stages that reached 76.6% and 83.3%, respectively, after feeding fourth instar larvae of *S. littoralis*. The compounds β-amyrenone, lupeol acetate and 5,4′-dihydroxy-6,7-dimethoxyflavone suppressed 50%, 60% and 73.3% of 4th instar larvae of *S. littoralis* at concentrations 0.3%, 0.5% and 0.5%, respectively. *C. dioscoridis* aerial parts exhibited acute toxicity on both sexes, reduced adult longevity, oviposition deterrents and reduced fertility on *S. littoralis*.

CONCLUSIONS

This review summarizes the current evidence on the insecticidal activities against *Spodoptera littoralis*, *Spodoptera litura, Spodoptera frugiperda* and *Spodoptera eridania* of plants belonging to the Asteraceae family.

Most of the pesticidal applications of Asteraceae species against *Spodoptera* spp. published in the last years show that its crude extracts have been used rather than the isolated compounds for insecticidal activities. Among the toxic effects reported for the Asteraceae species studied, the antifeedant effect stands out, which can affect the growth of the insect and be related to the mortality of *Spodoptera* spp. Sesquiterpene lactone is the class of secondary metabolites most reported among the isolated compounds from Asteraceae against *Spodoptera*.

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