Tropical and Subtropical Agroecosystems

REVIEW [REVISIÓN]

SECONDARY METABOLITES OF THE ANNONACEAE, SOLANACEAE AND MELIACEAE FAMILIES USED AS BIOLOGICAL CONTROL OF INSECTS

[METABOLITOS SECUNDARIOS DE LAS FAMILIAS ANNONACEAE, SOLANACEAE Y MELIACEAE USADAS COMO CONTROL BIOLÓGICO DE INSECTOS]

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SUMMARY

Given the problems that synthetic insecticides cause to the environment as well as to human health, there has been an up surging on research for plant extracts for insect control. Specialized literature is revised on published studies about different plant extracts obtained from the Annonaceae, Meliaceae and Solanaceae families, describing the compounds or mixtures of compounds obtained, as well as their modes of action that present on insects. The plant species of the three revised families present very polar compounds. The Meliaceae family is the most studied one, with azadirachtyne as the most important active compound. Acetogenins, squamocyn and annonacyn from the Annonaceae family, display the strongest impact; whereas in the Solanaceae family, the alkaloids and steroidal glycosides are the ingredients with more bioactivity. The biological activity of secondary metabolites has been higher when extracts are tested, which consist of complex mixtures of secondary compounds. Most of the investigations revised herein have consisted of *in vitro* bioassays for insecticidal activity: therefore, the field effectiveness of these extracts is unknown.

Key words: Pest insects; plant extracts; biological activity; secondary compounds.

RESUMEN

Debido a los problemas que ocasionan los insecticidas sintéticos tanto en el ambiente como en la salud humana existe un resurgimiento en investigaciones sobre los extractos de origen vegetal para el control de insectos. Se presenta una revisión de literatura especializada de los trabajos publicados de los diferentes extractos vegetales obtenidos de las familias Annonaceae, Meliaceae y Solanaceae, describiendo los compuestos o mezcla de compuestos obtenidos, así como sus mecanismos de acción que presentan sobre insectos. Las especies vegetales de las tres familias presentan compuestos muy polares. La familia Meliaceae es la más estudiada, con la azadiractina como el compuesto activo más importante. Las acetogeninas, squamocin y annonacin de la familia Annonacea, son las de mayor impacto, mientras que en la familia Solanaceae son los alcaloides y glicósidos esteroidales los principios con mayor bioactividad. La actividad biológica de los metabolitos secundarios ha sido mayor cuando se prueban los extractos, que son mezclas complejas de compuestos secundarios. La mayoría de las investigaciones revisadas han sido bioensayos *in vitro* para la actividad insecticida, por lo que se desconoce la efectividad de los extractos en campo.

Palabras clave: insectos plaga; extractos vegetales; actividad biológica; compuestos secundarios.

INTRODUCTION

From the second half of the XX century, the agricultural modernization has focused on using new techniques which aim to increase the food production for the ever-growing human population (Iannacone *et al.*, 2005). The increase on the food production is owned to the scientific breakthroughs and technological innovations which include developing new plant varieties, the increase of irrigation facilities and the use of fertilizers and pesticides (Gliessman, 2002). The use of the monoculture has brought as a consequence, the use of synthetic insecticides, which reduce the biodiversity of agroecosystems, provoking their instability (Gliessman, *op. cit.*) and cause harmful effects, such as: environmental pollution, human health issues (Hilje, 2001), insect resistance to pesticides (Denholm *et al.*, 1998), natural pest predators (Aggarwal and Brar, 2006), parasitoids (Iannacone and Lamas, 2003) and pollinators (Desneux *et al.*, 2007) loss.

As a consequence of these environmental security and health issues (Karunamoorthi *et al.*, 2008), nowadays, new strategies for pest insects control which are less hazardous and more environmentally friendly are searched for; such as the use of plant extracts, one of the most attractive methods for this aim (Salvadores *et al.*, 2007).

The practice of using plant extracts in agriculture for pest control is not new; it has been used for at least two millennia, when botanical insecticides were considered important products for pest management in Ancient China (Long *et al.*, 2006), Egypt, Greece and India (Isman, 2006). Even in the United States and some European countries, botanical insecticides were predominantly used, before the discovery of organochlorated and organophosphorated insecticides in the late 1930's and early 1940's (Isman, 1997).

In the last 30 years, there has been an increasing research on plant extracts (Clemente *et al.*, 2003), due to the numerous problems that synthetic insecticides cause; leading to what could be considered a second era of the botanical insecticides (Silva *et al.*, 2002).

The plants that present biological activity against insects owe this feature to the presence of secondary metabolites (García *et al.*, 2004), some of which have been widely investigated (Álvarez *et al.*, 2007; Salvadores *et al.*, 2007; Chandra *et al.*, 2008). The process of knowing and obtaining secondary metabolites against insects is by means of plant extracts, which can have variations; sometimes aqueous extracts can be obtained (Bobadilla *et al.*, 2005), solvents can be used to obtain different compounds depending on their polarity (Bobadilla *et al.*, 2002), essential oils can also be obtained (Pérez *et al.*, 2004), or dehydrated plant parts to be used as powders (Silva *et al.*, 2003).

Secondary metabolites feature several properties against insects, like insecticidal activity (Cavalacante *et al.*, 2006), considered as that substance or mixture of substances that exert biocide action due to the nature of their chemical structure (Celis *et al.*, 2008). However, most of the plants used against insects have an insectistatic effect, rather than insecticidal. This refers to the inhibition of the insect's development and behavior (Celis *et al.*, 2008), and it is divided into: Repellence (Viglianco *et al.*, 2006), anti-feeding activity (Eriksson *et al.*, 2008), growth regulation (Wheeler and Isman, 2001), feed deterrents (Koul, 2004), and oviposition deterrents (Banchio *et al.*, 2003).

Repellent activity is presented in plants that have compounds with fowling odor or irritating effects, which cause insects to get away from them (Peterson y Coats, 2001). Anti-feeding activity is exerted by compounds that once ingested by the insect, causes it to stop feeding and eventually die of starvation (Isman, 2006). Growth regulating compounds inhibit metamorphosis or provoke precocious molting. They alter the growth regulating hormones and cause malformations, sterility or death in insects (Celis *et al.*, 2008).

To the present, there are more than 2000 plant species known to have insecticidal properties, where the Euphorbiaceae, Asteraceae, Labiatae, Fabaceae, Meliaceae and Solanaceae families stand out (García *et al.*, 2004). Among the metabolites with biological activities against insects, flavonoids, terpenoids, alkaloids, steroids and phenols stand out (Orozco *et al.*, 2006).

Three plant families that draw attention as promising sources of insecticidal compounds are: Annonaceae, Solanaceae and Meliaceae. These families have been selected to be studied for the following reasons: 1) they possess different chemical groups for insect control; 2) they are common families in the tropics and are cultivated in various regions; 3) there is research that have shown biological activity against insects and are highlighted as potential plants for their use in the tropics.

The objective of the present work is to revise literature on different plant extracts from the Annonaceae, Meliaceae and Solanaceae families, the compounds or mixtures of compounds obtained as well as their modes of action against insects.

Annonaceae

The Annonaceae family has drawn a lot of attention since the 1980's, due to the presence of acetogenins, of which their structural characteristics feature a variety of biological activities, where the insecticidal activity stands out (Ocampo and Ocampo, 2006).

Among the *Annona* genus, two species stand out for their insecticidal properties, *Annona muricata* L. and *Annona squamosa* L. the acetogenines found in *A. muricata* include: annocatalin, annohexocin, annomonicin, annomontacin, annomuricatin, annomuricin, annonacin, coronin, corossolin, corossolone, gigantetrocin, gigantetronenin, montanancin, muracin, muricatalicin, muricin, robustosin, solamin, squamocin, uvariamicin, among others (Raintree Nutrition, 2004).

Regarding their structure, the acetogenins comprise a series of natural products C-35/C-37 derived from C-32/C-34 fatty acids combined with a 2-propanol unit (Alali *et al.*, 1999). The acetogenins are found in leaves, branches and mostly in seeds of annonaceous plants, and *A. muricata* has been the most widely studied species (Table 1). From the wide variety of acetogenins, squamocin and annonacin have shown the highest impact on insects (Álvarez *et al.*, 2008).

Acetogenins block the respiratory chain at NADH ubiquinone reductase (Complex I) and cause a decrease in ATP levels, affecting directly the electron transport in the mitochondria, causing apoptosis (Alali, *et al.*, 1999). The annonaceous extracts have been evaluated in several groups of insects of both medical and agricultural importance. Among the agricultural pests, chewing insects like Lepidoptera larvae (Laetamia e Isman, 2004; Álvarez *et al.*, 2007), and sap sucking like *Myzus persicae* S. (Guadaño *et al.*, 2000) can be found. Among the human health related insects, blood sucking insects can be found, such as the *Aedes aegypti* L, mosquito, dengue fever and yellow fever vector in tropical areas (Domínguez *et al.*, 2003; Bobadilla *et al.*, 2005).

Based on the revision made, the following aspects can be observed:

1) The insecticidal effect is found as the main biological activity when using extracts or secondary metabolites from annonaceous plants (Table 1).

2) The solvents used for extracting acetogenins are varied such as: water (Pérez-Pacheco *et al.*, 2004), ethanol (Bobadilla *et al.*, 2002), acetone (Khalequzzaman and Sultana, 2006), chloroform (Parvin *et al.*, 2003), petroleum ether (Alvarez *et al.*, 2008) and hexane (Fontana *et al.*, 1998). From this information, it can be inferred that acetogenins can range from very polar, such as those extracted by water and ethanol, to non polar, which are extracted by hexane; however, if a rational management of natural products is desired, it is recommended the use of the more polar extracts (Bobadilla *et al.*, 2005).

3) The extracts have been dissolved with acetone (Khalequzzaman and Sultana, 2006) and distilled water (Pérez Pacheco *et al.*, 2004); although they can be dissolved with other substances such as dichloromethane, dimethyl sulfoxide, ethanol or Tween 20®. The criteria for choosing the solvent is focused on the least negative effect over the studied organism, obtaining thus an adequate for the plant extracts or secondary metabolites to be evaluated (Carvalho, 2008).

4) It is considered that the acetogenins found in the annonaceous plants are promising metabolites for insect control; however, it must be considered that the response obtained for each insect species will depend on the dosage to be used.

5) Finally, the metabolites found in the revision have been evaluated under laboratory conditions, which makes necessary to perform further evaluations at small or medium scale that simulate field conditions, where the real efficacy can be verified on those metabolites that present higher bioactivity under laboratory conditions.

6) There hasn't been any research found on annonaceous species where the effect of acetogenins is evaluated on beneficial insects.

Meliaceae

The Meliaceae family contains about 1400 species (Nakatani, 2001), some of which stand out for having insecticidal features; owing to the fact they contain triterpenoid limonoids (Akhtar *et al.*, 2008). This group of compounds has driven a lot of interest because of their high activity over the behavior and physiology of several phytophagous insect species (López *et al.*, 1998). Azadirachtine is the compound that has shown best results, causing mortality, anti-feeding activity and deterrence in important agricultural pests such as: *Spodoptera littoralis* Boisd., *Schistocerca gregaria* Dallas, *S. gregaria* Forskal, among others (Mordue y Nisbet, 2000).

Azadirachtine can be found in the bark, leaves, fruits and mostly in seeds of the neem tree (*Azadirachta indica* A. Juss.), therefore, most of the research (Feng and Isman, 1995; Capataz *et al.*, 2007; Chandra *et al.*, 2008) on the Meliaceae species have been focused on testing the biological activity of neem extracts on insects (National Research Council, 1992).

There have been around 18 secondary compounds identified in neem seed extract, finding azadirachtine in higher concentrations, which can range from 10% to 25% (Govindachari *et al.*, 2000) due to genetic or environmental causes (Angulo *et al.*, 2004), fruit developmental stage (Ramos *et al.*, 2004) or even because of seed storage time (González *et al.*, 2006).

Besides azadirachtine, there are other triterpenoids as salanine, meliantrol and nimbina, considered as the most significant ones, since they have proven their ability to inhibit the growth of pest insects of both agricultural and human health importance. These triterpenoids account for the total bioactivity of the neem seed extract; however, it is considered that 72 to 90% of the biological activity is because of azadirachtine, which is the major, active component (Schmutterer, 1990). That is the reason why it is used for the production of commercial insecticides such as Margosan-O®, Neem Gold®, Neemark®, Azatin®, among others (Isman, 2006).

However, Feng and Isman (1995) have proven that using azadirachtine alone for insect control can cause target organisms to develop resistance. In a laboratory experiment, they tested the biological activity of azadirachtine compared to a neem seed extract against green peach aphids (*Myzus persicae*). After 40 generations, the aphids developed a resistance level nine times higher than at the beginning. On the other hand, with the neem extract (containing the same azadirachtine concentration) at the same number of generations; there was no evidence of resistance development. Isman (1997) states that insects take longer to develop resistance to a mixture of natural active ingredients, than to any of its separate components. This could be owned to the fact that it is more difficult to detoxify a substance complex than a single molecule.

Catalayud and Múnera (2000), Valladares *et al.* (2003) and Isman (2006), explain that the bioactivity of a compound mixture is done by synergism among the different secondary metabolites acting at the same time. When they are used separately, there is a higher probability of developing insect resistance.

Because of the continuous bioactivity that azadirachtine displays over a great number of insects, a search for new limonoids with insecticidal properties in other Meliaceae family members begun. Plants like *Melia azedarach* L. and some species from the *Trichilia* genus have been highlighted (Akhtar *et al.*, 2008). *M. azedarach*, contains limonoids with similar properties to those of *A. indica*, with the following compounds: meliantrol, melianol, meliacin, meliacarpin (Nakatani, 2001), azaderachine (Chun *et al.*, 1994) and meliartenin (Carpinella *et al.*, 2002). It also contains lignanes with insecticidal properties like pinoresinol bis-epi-pinoresinol, hemicetal and diacide (Cabral *et al.*, 1995).

Meliartenin, which features an anti-feeding effect, stands out among these metabolites tested in various insects (Carpinella *et al.*, 2002; Gajmer *et al.*, 2002; Bianchio *et al.*, 2003; Valladares *et al.*, 2003; Leite *et al.*, 2006; Coria *et al.*, 2008; Parra-Henao *et al.*, 2007b).

The anti-feeding activity of this compound shows that at doses of 0.8-27.6 µg/cm2 cause an inhibiting effect of over 75% and a moderate effect of 50 to 75% for most of the treated species (Carpinella *et al.*, 2002; Carpinella *et al.*, 2003).

Based on the revision made, the following aspects can be observed from the Meliaceae family:

1) The insecticidal effect of *A. indica* and the anti-feeding effect of *M. azedarach* extracts stand out (Table 2).

2) There are many studies which evaluate commercial insecticides, with azadirachtine as the main ingredient.

3) The Meliaceae derivates have been evaluated in many groups of agriculturally important insects which include chewing insects such as *Spodoptera litura* and *Tuta absoluta* (Juan *et al.*, 2000; Wheeler and Isman, 2001; Goncalves and Vendramim, 2007), sap sucking insects like *Myzus persicae*, *Bemisia tabaci* and *Aphis gossypii* (Fournier y Brodeur, 2000; Abou *et al.*, 2001; Khalequzzaman and Nahar, 2008), and stored seeds insects like *Tribolium confusum* and *Sitophilus zeamais* (Del Tío *et al.*, 1996; Silva *et al.*, 2003).

4) Many types of solvents have been used to extract limonoids such as: methanol (Abou *et al.*, 2001), water (Aliero, 2003; García *et al.*, 2006), acetone (Carrizo *et al.*, 2006), ethanol (Coria *et al.*, 2008) and hexane (Romero and Vargas, 2005); however, the composition and proportion of the four main active principles (azadirachtine, salanine, nimbine and meliartenin) depends on the solvent and extraction method used. Most of the investigations use polar solvents, to maintain a rational management of the extracts; besides, by using polar solvents, azadirachtine, which is considered a polar compound, can be obtained in a higher amount and concentration. The extraction methods are varied; however, Romero and Vargas (2005) mention that soxhlet extraction is the best to obtain the highest yield of neem oil.

Table 1. Biological activity and active compounds of different species from the Annonaceae family on insects.

Scientific name	**Active compound**	**Plant part**	**Insect**	**Biological Activity**	**LD(50) or LC(50)**	**Concentration**	**References**
Annona muricata	Gigantetrocin A	Seeds	*Blatella germanica*	I	1000 ppm		Alali et al., 1998
	Annomontacin	Seeds	*Blatella germanica*	I	1000 ppm		
	Bullatalicin	Seeds	*Blatella germanica*	I	1000 ppm		
			Anticarsia gemmatalis	F. D. y G. I.		0.25%	Fontana *et al.*, 1998
			Pseudaletis sequax	F. D. y G. I		0.25%	
	Squamocin	Seeds	*Myzus persicae*	I			Guadaño *et al.*, 2000
			Leptinotarsa decemlineata	I			
	Annonacin	Seeds	*Aedes aegypti*	I			Dominguez *et al.*, 2003.
			Aedes aegypti	I	74.7 ppm		Morales *et al.*, 2004
			Aedes aegypti	I	236.2 ppm		
			Aedes aegypti	I	0.5 mg/ml		Bobadilla *et al.*, 2005
			Aedes aegypti	I	900 ppm		Parra-Henao *et al.*, 2007a
			Rhodnius pallescens	I	1.74% p/p		Parra-Henao *et al.*, 2007b
			Rhodnius prolixus	I	1.02% p/p		
			Periplaneta americana	I y R		0.5 ml	Robledo-Reyes *et al.*, 2008
Annona squamosa	Squamocin	Seeds	*Drosophila melanogaster*	I	125 µg/ 2 g of diet		Kawazu *et al.*, 1989
		Seeds	*Tribolium castaneum*	I	0.031 µg/cm^2		Khalequzzaman y Sultana, 2003
	Annotemoyin-1	Seeds	*Tribolium castaneum*	I	579 µg/cm^2		Parvin *et al.*, 2003
	Neoannonin				140 µg/ 2 g of diet		
			Plutella xylostella	I		0.5% p/v	Laetamia e Isman, 2004
			Culex quinquefasciatus	I	0.00025%		Pérez-Pacheco *et al.*, 2004

Note: A. A: Antifeedant Activity, F. D: Feeding Deterrence, I: Insecticide, G. I: Growth Inhibition, R: Repellency.

Continue Table 1

Scientific name	**Active compound**	**Plant part**	**Insect**	**Biological Activity**	**LD(50) or LC(50)**	**Concentration**	**References**
Annona cherimolia	Squamocin	Seeds	*Spodoptera frugiperda*	I y A. A		50 µg/g of diet	Álvarez, *et al.*, 2007
	Itrabin	Seeds				50 µg/g of diet	
	Cherimolin-1	Seeds				50 µg/g of diet	
	Neoannonin	Seeds				50 µg/g of diet	
	Asimicin	Seeds				50 µg/g of diet	
	Squamocin	Seeds	*Oncopeltus fasciatus*	I	0.16 µg/nymph		Álvarez, *et al.*, 2008
	Almuñequin	Seeds			11.23 µg/ nymph		
	Itrabin	Seeds			14.19 µg/ nymph		
	Molvizarin	Seeds			0.34 µg/ nymph		
Annona montana	Annonacin	Leaves and branches	*Oncopeltus fasciatus*	I		10 µg/ nymph	Álvarez, *et al.*, 2008
	Cis-annonacin-10-one	Leaves and branches				10 µg/ nymph	
	Densicomacin-1	Leaves and branches				10 µg/ nymph	
	Annonacin-a	Leaves and branches				10 µg/ nymph	
Oxandra cf xylopioides	Berenjenol	Leaves	*Spodoptera frugiperda*	I	319.6 ppm		Rojano *et al.*, 2007

Note: A. A: Antifeedant Activity, F. D: Feeding Deterrence, I: Insecticide, G. I: Growth Inhibition, R: Repellency.

5) The extracts obtained from meliaceous plants have been mainly dissolved with water (García *et al.*, 2006); however, they can be dissolved with other substances such as Tween 20® (González *et al.*, 2006), dichloromethane or dimethyl sulfoxide, as long as they don't affect the biological activity to be tested (Carvalho, 2008).

6) Another important aspect to highlight, at least for *A. indica*, is the fact there are several investigations where there hasn't been any recorded harmful effects on beneficial fauna, either bees or natural enemies of pests. Therefore, *A. indica* can be used as part of integrated pest management systems because of the null negative impact on crop pollinators or insect pest predators (Iannacone and Lamas, 2002; Iannacone and Lamas, 2003).

Solanaceae

The Solanaceae family comprises nearly 102 genera and 2460 species found mostly in tropical areas. From 60 to 70% of the species produce alkaloids, which play an important role against pathogens and herbivores. They have a toxic and feed deterrent effect on insects (Eich, 2008). Among the species with toxic alkaloids, the tomato (*Lycopersicon esculentum* P. Mill.) extracts, have shown feed-inhibiting activity on *Atta cephalotes* L., caused by alkaloids like solanine and demissine (Serna and Correa, 2003). Additionally, Soule *et al.* (1999), found that steroidal glycosides isolated from *Solanum laxum* Spreng., killed more than 80% of *Schizaphis graminum* R. aphids. One of the widely known botanical insecticides is the nicotine from tobacco (*Nicotiana tabacum* L.), an alkaloid which has bioactivity on insects. Its insecticidal properties were renowned by the first half of the XVI century. Nicotine does not occur freely in the plant; it is found combined with acids forming malates and citrates (Mareggiani, 2001). It is a non persistent contact insecticide and its mode of action consist on mimetizing acetil-choline (ACH) when combined with its ACH receptor (action site) in the post synaptic membrane that reacts with ACH, altering the permeability of the neuromuscular juncture. Nicotine causes the generation of new nerve impulses that lead to spasmodic contractions, convulsions, and finally, death (Celis *et al.*, 2008). There are many insecticides up to the present known as nicotinoids, which are synthetic copies or derivates of the nicotine structure such as imidachloprid, thiachloprid, acetamiprid and thiamethoxan, among others (Tomizawa y Casida, 2005).

Besides nicotine, other alkaloids like scopolamine, hyoscyamine and atropine, which function as neurotoxins, and attack the ACH receptor of insects (Eich, 2008). Scopolamine is produced by *Brugmansia suaveolens* Humb. & Bonpl. (Freitas *et al.*, 1996). When its leaves are eaten by *Spodoptera frugiperda* J. E. Smith larvae, they cause their death, and delay the larval development of the surviving ones (Nopper *et al.*, 2007). Species from the *Capsicum* genus have been used for pest control by farmers dedicated to traditional agriculture in various countries (Antonious y Snyder, 2005). To the present, there are patents to insecticides, control agents, and dog and cat repellents that contain capsaicinoids (Neumann, 1999). In addition, capsaicinoids have been introduced as repellents for pest management in agriculture and are used as synergists for synthetic insecticides (Hainrihar, 2000).

The fruits of the *Capsicum* genus are the mainly used parts because they have insecticidal, repellent and anti-feeding activity against insects. The effects are owned to the presence of capsaicinoids, as proven by Weissenberg *et al.*, (1986); Edelson *et al.*, (2002) and Antonious and Snyder, (2005). Based on the revision made, the following aspects can be observed from the Solanaceae family:

1) The extracts of the Solanaceae family have been tested on various groups of insects of agricultural and medical importance. In the first group, there are chewing insects like *Brevicoryne brassicae*, *Microtheca ochroloma* (Braga *et al.*, 2004; Bastos *et al.*, 2009), sap sucking insects like *Schizaphis graminum* and *Bemisia tabaci* (Soule *et al.*, 1999; Bouchelta *et al.*, 2005) and stored grain insects like *Tribolium castaneum* and *Sitophilus zeamais* (Pascual-Villalobos, 1998; Procopio *et al.*, 2003; Salvadores *et al.*, 2007). Among the human health related insects there are blood sucking insects like mosquitoes (Mohan *et al.*, 2006; Madhumathy *et al.*, 2007) (Table 3).

2) The extraction of solanaceous derivates have been obtained by various methods such as: water (Bastos *et al.*, 2008), methanol (Freitas *et al.*, 1996), ethanol (Madhumathy *et al.*, 2007), petroleum ether (Mohan *et al.*, 2006), hexane and acetone (Pascual-Villalobos, 1998).

3) To dissolve the extracts, the used substances have been ethanol (Bocuhelta *et al.*, 2005) and water (Braga *et al.*, 2004), but other solvents can be used as long as they don't affect the results of the biological activity to be tested (Carvalho, 2008).

4) No studies found have been found about the effect of solanaceous derivates on beneficial insects.

5) Compared to the other two aforementioned families, the species that conform the Solanaceae family have been little studied regarding their insecticidal effects, as shown by the present work, given the scarce literature found about plant extracts.

Table 2. Biological activity and active compounds of different species from the Meliaceae family on insects.

Scientific name	Active compound	Plant part	Insect	Biological Activity	LD(50) or LC(50)	Concentration	References
Azadirachta indica	Azadirachtine	Commercial product	*Bemisia tabaco*	I		1%	Dimetry *et al.*, 1996
	Azadirachtine	Commercial product	*Myzocallis coryli*	I		62.5 ppm	Tuncer y Aliniazee, 1998
		Seeds	*Anastrepha fraterculus*	I		11 ml/l	Salles y Rech, 1999
		Commercial product	*Myzus persicae*	I	23.95 ppm		Fournier y Brodeur, 2000
		Commercial product	*Macrosiphum euphorbiae*	I	21.22 ppm		
		Commercial product	*Nasonovia ribisnigri*	I	37.56 ppm		
	Azadirachtine		*Sesamia nonagrioides*	A. A.		1.25 ppm	Juan *et al.*, 2000
		Seeds	*Cosmopolites sordidus*	F. D. Y O. D.		5%	Musabyimana *et al.*, 2001
		Seeds	*Earias vittella*	R		10%	Gajmer *et al.*, 2002
		Seeds	*Anopheles sp*	I		10g/100 ml	Aliero, 2003
		Leaves	*Heterotermes tenuis*	R		5%	Castiglioni y Vendramim, 2003
		Seeds	*Sitophilus zeamais*	I		1%	Silva *et al.*, 2003
	Azadirachtine	Commercial product	*Bemisa tabaco*	I		10 ml/l	Kumar *et al.*, 2005
		Seeds	*Mahanarva fimbriolata*	I	0.611%		García *et al.*, 2006
		Seeds	*Tuta absoluta*	I		5%/100 ml	Goncalves y Vendramim, 2007
		Seeds	*Varroa destructor*	R		4%	González *et al.*, 2006
	Azadirachtine	Commercial product	*Bemisia tabaco*	I		17%	Kumar y Poehling, 2006
			Plutella xylostella	I Y R	0.67% y 1.66%		Leite *et al.*, 2006
	Azadirachtine	Commercial product	*Schistocerca americana*	A. A.		3%	Capinera y Froeba, 2007

Note: A. A: Antifeedant Activity, O. D: Oviposition Deterrence, F. D: Feeding Deterrence, I: Insecticide, G. I: Growth Inhibition, R: Repellency.

Continue Table 2

Scientific name	Active compound	Plant part	Insect	Biological Activity	LD(50) or LC(50)	Concentration	References
	Azadirachtine	Commercial product	*Bemisia tabaco*	I		15 ml/l	Kumar y Poehling, 2007
		Leaves	*Aphis craccivora*	I		10%	Chandra *et al.*, 2008
	Azadirachtine		*Myzus persicae*	I	0.44 µg/cm^{-2}		Khalequzzaman y Nahar, 2008
	Azadirachtine		*Aphis craccivora*	I	0.41 µg/cm^{-2}		
	Azadirachtine		*Aphis gossypii*	I	0.34 µg/cm^{-2}		
	Azadirachtine		*Lipaphis erysimi*	I	0.44 µg/cm^{-2}		
		Fruits	*Tribolium confusum*	G. I.		25%	Del Tío *et al.*, 1996
		Seeds	*Sesamia nonagrioides*	A. A.			Riba *et al.*, 1996
		Fruits	*Spodoptera littoralis*	G. I.		25 ppm	Schmidt *et al.*, 1997
		Fruits	*Agriotis ípsilon*	G. I.		25 ppm	
		Leaves	*Busseola fusca*	I		10 Kg/ha	Gebre-Amlak y Azerefegne, 1999
		Fruits	*Diabrotica speciosa*	A. A.		4 g /100 ml	Ventura e Ito, 1999
Melia azedarach		Leaves and fruits	*Bemisia tabaco*	R		200 mg/ml^{-1}	Abou *et al.*, 2000
		Seeds	*Sesamia nonagrioides*	A. A.		1000 ppm	Juan *et al.*, 2000
		Leaves and fruits	*Bemisia tabaco*	R			Abou *et al.*, 2001
		Leaves	*Tuta absoluta*	I		0.1%	Brunherotto y Vendramim, 2001
		Fruits	*Bemisia tabaco*	I		3%	Souza y Vendramim, 2001
	Meliartenin	Fruits	*Spodoptera eridania*	A. A.		1µg/cm^{2}	Carpinella *et al.*, 2002
		Seeds	*Earias vittella*	R		10%	Gajmer *et al.*, 2002
	Meliartenin	Fruits	*Liriomiza huidobrensis*	F. D.		10%	Banchio *et al.*, 2003
	Meliartenin	Fruits	*Epilachna paenulata*	A. A.		0.8µg/cm^{2}	Carpinella *et al.*, 2003

Note: A. A: Antifeedant Activity, O. D: Oviposition Deterrence, F. D: Feeding Deterrence, I: Insecticide, G. I: Growth Inhibition, R: Repellency.

Continue Table 2

Scientific name	**Active compound**	**Plant part**	**Insect**	**Biological Activity**	**LD(50) or LC(50)**	**Concentration**	**References**
		Senescent leaves	*Epilachna paenulata*	A. A.		10%	Valladares *et al.*, 2003
		Fruits	*Bemisia argentifolii*	I		20 g/100 ml	Abou y McAuslane, 2006
		Fruits		I Y R	2.07% y 1.79%		Leite *et al.*, 2006
	Meliartenin	Senescent leaves	*Aedes aegypti*	I Y A. A.	0.76 g/L		Coria *et al.*, 2008
		Fruits	*Rhodnius prolixus*	I Y R	1.77%		Parra-Henao *et al.*, 2007b
		Fruits	*Rhodnius pallescens*	I Y R	1.74%		
		Leaves and fruits	*Acromyrmex lundi*	R			Caffarini *et al.*, 2008
		Senescent leaves	*Spodoptera eridania*	A. A.		10%	Rosetti *et al.*, 2008
Trichilia pallida		Branches	*Bemisia tabaco*	I		3%	Souza y Vendramim, 2000
Trichilia americana		Branches	*Spodoptera litura*	A. A.	0.18 $\mu g/cm^{-2}$		Wheeler e Isman, 2001
Trichilia pallens		Leaves	*Spodoptera frugiperda*	I		5 g/100 ml	Bogorni y Vendramim, 2003
Trichilia glauca		Leaves	*Acromyrmex lundi*	R			Caffarini *et al.*, 2008

Note: A. A: Antifeedant Activity, O. D: Oviposition Deterrence, F. D: Feeding Deterrence, I: Insecticide, G. I: Growth Inhibition, R: Repellency.

Table 3. Biological activity and active compounds of different species from the Solanaceae family on insects.

Scientific name	Active compound	Plant part	Insect	Biological Activity	LD(50) or LC(50)	Concentration	References
Capsicum annuum		Leaves	*Liriomiza trifolii*	O. D.		35.2 μg/cm^2	Kashiwagi *et al.*, 2005
		Fruits	*Anopheles stephensi*	I	0.011%		Madhumathy *et al.*, 2007
		Fruits	*Culex quinquefasciatus*	I	0.0097%		
		Fruits	*Sitophilus zeamais*	R		2%	Salvadores *et al.*, 2007
Capsicum baccatum		Fruits	*Tetranychus urticae*	R		792 g/0.75 cm^2	Antonious y Snyder, 2005
Capsicum frutescens		Fruits	*Callosobruchus maculatus*	I	1%		Gakuru y Foua, 1996
		Fruits	*Sitophilus oryzae*	I	1%		
		Leaves	*Sitophilus zeamais*	R		0.3 g	Procopio *et al.*, 2003
	Alcaloids	Fruits	*Bemisia tabaco*	I		20 g/l	Bouchelta *et al.*, 2005
Capsicum sp	Capsaicina	Fruits	*Earias insulana*	G. I		0.2%	Weissenberg *et al.*, 1986
Lycopersicon esculentum	Solanina	Leaves	*Earias insulana*	A. A.		0.2%	
		Leaves	*Atta cephalotes*	F. D.		923.5 ppm	Serna y Correa, 2003
Nicotiana tabacum		Leaves	*Microtheca ochroloma*	I		10%	Bastos *et al.*, 2008
		Leaves	*Plutella xylolstella*	I y O. D.		10%	Bastos *et al.*, 2009
Nicotiana rustica		Leaves	*Tribolium castaneum*	I		0.25%	Pascual-Villalobos, 1998
Solanum fastigiatum		Mature fruits	*Brevicoryne brassicae*	R		5%	Braga *et al.*, 2004
		Leaves	*Brevicoryne brassicae*	I		10%	
Solanum laxum	Laxumin A	Leaves	*Schizaphis graminum*	I	4.3 μm		Soule *et al.*, 1999
Solanum xanthocarpum		Roots	*Culex quinquefasciatus*	I	41.28 ppm		Mohan *et al.*, 2006

Note: A. A: Antifeedant Activity, O. D: Oviposition Deterrence, I: Insecticide, G. I: Growth Inhibition, R: Repellency, F. D: feeding Deterrence

Perspectives of use

The active principles of the revised families: Meliaceae, with azadirachtine and meliartenin; Annonaceae, with acetogenins; and Solanaceae, with alkaloids and steroidal glycosides, have potential to be used in pest insects control and management. Given the chemical characteristics of these compounds, extractions can be made by farmers, favoring thus practices that don't depend of external inputs which cannot be found in their region. Nevertheless, before offering strategies to the producers, there is a need for specific studies of the pest that needs to be controlled, and to consider the impact that extracts can have on beneficial species in the agroecosystems. That is the reason to perform field studies and implement extraction methods that can be performed by the producers.

CONCLUSION

The three plant families possess a natural resource of great potential to be used against pest insects. The potential of the biological activity has been little studied *in vivo*, therefore, more tests are required to verify the potential of these compounds in real scenarios.

The derivates of these three plant families show a wide range of action modes, standing out the insecticidal and anti-feeding activity in the Meliaceae family, and the insecticide activity in the Annonaceae and Solanaceae families. Therefore it is likely that these compounds can be used in various insect species according to their mode of action.

From the present revision, it could be observed that the substances found in the three families range from highly polar, to non polar, and those which present bioactivity belong to the highly polar, since they are mainly extracted with solvents such as water, ethanol, methanol and acetone.

It is also pointed out that a solvent that minimizes the impact of the insect to be tested must be used for diluting the extracts.

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