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Mini-Review

Use of plant extracts as an alternative control method against phytophagous mites in South America

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ABSTRACT

Most mite species causing damage to important crops worldwide are included in the families Eriophyidae, Tetranychidae, Tenuipalpidae and Tarsonemidae. In order to reduce economic losses caused by mite pests, there is a need for establishing management approaches aimed at keeping population levels under the economic damage threshold. In Latin America, conventional pesticides have become an indispensable tool in controlling pests economically, rapidly and effectively. However, extensive use of pesticides may lead to a number of undesirable side effects including the development of pesticide resistance and resurgence of primary and secondary pest outbreaks. They can also exert adverse effects on non-target organisms and contribute to environmental pollution. Thus, interest in alternative control methods including the use of botanical pesticides for crop protection is increasing. Many researchers are developing alternative plant extracts as pesticides to control mites. As botanical pesticides (powders and ethanolic or aqueous extracts) derived from different plant species have proven effective in pest control at low costs, and with low risk to humans and the environment, their usage as a control method for pest mite population management has increased worldwide. In this paper, we review selected scientific works involving the use of plant extracts to manage phytophagous mites in tropical crops in South America.

KEYWORDS: tetranychidae, tenuipalpidae, botanical pesticides

1. Introduction

Agricultural pests, which include a wide range of organisms such as plants, fungi, bacteria, insects and mites, lead to reductions in crop yield or even to complete crop losses [1]. Furthermore, the damage inflicted by these pests can reduce crop quality and the economic value of agricultural products [2]. Pest damage has affected growers since the beginning of agriculture, and the history of efforts to reduce pest damage is equally long. The use of chemicals has been the dominant paradigm for pest control in recent decades and has succeeded greatly in reducing crop losses [3]. The use of chemical pesticides has been one of the fastest and most effective means of reducing damages caused by pests. However, the excessive use of these chemicals has been counterproductive, causing damage to the environment and humans [4]. Thus, the problems caused by synthetic pesticides and their residues have increased the need for effective biodegradable pesticides that present greater selectivity.

Pest management in agriculture is facing the challenge of developing suitable agents to kill pests while ensuring economic and ecological

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sustainability, given that the majority of chemical pesticides are known to be hazardous both to humans and the environment [5]. New insect control agents, many with novel mechanisms of action, have been and are being developed to fit a variety of insect pest management needs. Alternative strategies have included the search for new types of pesticides, which are often effective against a limited number of specific target species, are biodegradable into non-toxic products, and are suitable for use in integrated pest management programs [6]. Natural plant products effectively meet these criteria and have enormous potential to influence modern agrochemical research [7]. The chemicals that are extracted from plants, denominated as botanical pesticides, are now emerging as one of the prime means to protect crops and their products, and also the environment from pesticide pollution [8, 9].

Some of the advantages of biopesticides are their compatibility with beneficial and non-target organisms, short environmental persistence, low mammalian toxicity, lack of harvest and reentry restrictions, minimum risk for pest resistance development, and compatibility with integrated pest management (IPM) programs in general [10]. Thus, biopesticides may constitute an environmentally friendly and rational alternative to the intensive use of synthetic pesticides in orchards [11].

2. Classification of botanical pesticides

According to their physiological effects on herbivores, botanical pesticides are conventionally classified into the following six groups: repellents, feeding deterrents/antifeedants, toxicants, growth retardants, chemosterilants, and attractants [12]. However, we discuss only five of these, which are related to such plant mites as Tetranychidae and Tenuipalpidae.

a. Antifeedants/feeding deterrents: feeding deterrence is perhaps the most studied mode of action for plant derivatives used for insect pest management. Strictly speaking, a feeding deterrent is a compound that once ingested by the insect, causes it to stop feeding and starve to death. Many compounds showing this activity are terpenes. Probably the most effective and versatile plant component that deters herbivore feeding is azadirachtin [12]. Neem extract is also a potent repellent, growth regulator and oviposition deterrent affecting more than 200 species of pests [13].

b. Repellents: the use of plants as repellents is a very ancient practice but unfortunately has not received the deserved attention for large-scale production [14]. Repellents not only drive away the pest from the treated materials by stimulating olfactory or other receptors but also offer protection with minimal impact on the ecosystem [15]. Repellents of plant origin are considered safe in pest control, minimize pesticide residue and ensure the safety of people, food and the environment [16]. Even though the Varroa mite [*Varroa jacobsoni* Oudeman] and the tracheal mite [*Acarapis woodi* (Rennie)] are not phytophagous, their management via fumigation of beehives using plant essential oil constituents has been highly effective in the control of these economically important honeybee parasites [17].

c. Toxicants: rotenone and pyrethrins have been the most extensively used botanical insecticides so far. However, they are currently being replaced by other natural compounds such as isobutylamides isolated from some Asteraceous and Rutaceous plant species, shown to have similar insecticide properties. Limonene, an abundant constituent of Rutaceous plant, has demonstrated effectiveness in controlling tetranychid mites. D-limonene from Rosemary oil (extracted from *Rosmarinus officinalis*) decreases fecundity, fertility and hatchability rates and the percentage of larvae reaching adulthood in *Tetranychus urticae* [18]. Rosemary oil was found to be composed of a mixture of terpenoids, acting as a contact toxicant to spider mites [19], inducing complete mortality (100%) of mites on bean and tomato plants in greenhouses when used at concentrations of 2 to 4% [18].

d. Chemosterilants/reproduction inhibitors: plant parts, oils, extracts, and powder mixed with grain have been reported to reduce insect oviposition, egg hatchability, postembryonic development, and progeny production [20].

e. Insect growth and development inhibitor: plant extracts contain compounds that prevent metamorphosis from taking place at the right time. This action has deleterious effects on the growth and development of insects, such as reducing larval, pupal and adult weight, lengthening larval and pupal periods, and reducing pupal recovery and adult eclosion [14, 15]. Studies on the effects of azadirachtin on insects have shown that it blocks the synthesis and release of molting hormones (ecdysteroids) from the prothoracic gland, leading to incomplete ecdysis in immature insects [17]. Furthermore, plant derivatives have been shown to reduce the survival rates of insects both at the immature and adult stages [21].

3. Use of botanical pesticides to manage mite populations

3.1. Tetranychid mites

Tetranychidae Donnadieu includes about 1,200 described species, of which some of them are economically important pests [22, 23]. *Tetranychus* Dufour (143 spp.) is one of the five largest genera of Tetranychidae, represented by more than 100 known species. The other large genera are *Bryobia* Koch (129 spp.), *Eotetranychus* Oudemans (184 spp.), *Oligonychus* Berlese (200 spp.) and *Schizotetranychus* Trägårdh (116 spp.) [24].

Damage by tetranychid mites is inflicted at the feeding point by disruption to the mesophyll cells of plants [25], affecting transpiration and photosynthesis [26, 27] and consequently, plant growth and fruit production [28].

3.1.1. *Tetranychus urticae* Koch

The two-spotted spider mite is considered one of the most important agricultural pests, infesting crops including cotton, tomatoes and grapes [29]. Both the intensive use of acaricides and the ability of mites to develop resistance to these compounds have hindered the effectiveness of chemical control for managing the mite population in crops. In particular, in several countries, mites have developed resistance to acaricides. Additionally, acaricide residues have shown persistence on fruits [30]. Thus, among the more sustainable strategies to manage tetranychid mite populations that have been tested, plant extracts have shown the most promise. In Brazil, although azadirachtin presented lower biological persistence (7 days) than abamectin (21 days), it was as efficient against *T. urticae* as abamectin but did not cause significant mortality of adult predatory mites (*Neoseiulus californicus* (McGregor) and *Phytoseiulus macropilis* (Banks)) when used in strawberry crops [30]. Similarly, the toxicity of Neemseto® on *T. urticae* and two other predatory mites (*Euseius alatus* De Leon and *P. macropilis*) was studied in Pernambuco, Brazil [31]. The toxicity, repellent effect and fecundity reduction of Neemseto was more evident on *T. urticae* as compared to the predatory mites. Since *P. macropilis* is one of the most efficient predatory mites found in tropical environments, the almost innocuous effect of neem products on this predatory mite species allows its inclusion in a pest management program.

In Colombia, various commercial products based on neem induced a reduction in the instantaneous rate increase in the population of *T. urticae* and *P. macropilis* even at sub-lethal doses of azadirachtin [32].

Since *T. urticae* has the ability to overcome the effects of pesticides, repeated applications are often necessary to increase control and reduce the population [30]. Previous studies have demonstrated that the persistence of azadirachtin declines 5 days after application due to the effects of temperature, ultraviolet light and rainfall [30, 33]. Thus a seven-day interval between applications is advisable in order to ensure efficient mite control in strawberry crops.

Apart from the traditional plant species used as botanical pesticides worldwide, some native or locally abundant plant species are also being evaluated for their potential to control phytophagous mites. *Protium heptaphyllum* (Aubl.) Marchand grows widely in the Amazonian region in Brazil. The family Burseraceae, which includes *P. heptaphyllum* is well known for its abundance of exudates and oil resins rich in volatile substances that are used for many purposes, including pest control [32]. The fruit oil from *P. heptaphyllum* proved to be highly toxic to mites, inducing a 63.3% mortality rate at concentrations of 10 $\mu L.L^{-1}$ of air after 72 h of exposure. In relation to fecundity, a drastic reduction was observed even at 6 $\mu L.L^{-1}$ of air, 24 h after application. Leaf ethanolic extract from *Croton sellowii* Baill induced a higher mortality rate (69%) and a greater decrease in fecundity (≈85%) than extracts obtained from other *Croton* species such as *C. rhamnifolius* Kunth, *C. jacobinensis* Baillon and *C. micans* (Baill) used as acaricides against *T. urticae* [32]. Despite the fact that ethanolic extracts from *C. jacobinensis* did not show a reduction of mite activity or fecundity, they acted as repellents [34].

3.1.2. *Tetranychus evansi* Baker & Pritchard

The tomato red spider mite *T. evansi* is an important pest of solanaceous plants, especially tomatoes [35]. The mite is considered to be native to South America; however in the last two decades its geographical distribution has expanded to become a worldwide invasive agricultural pest [36]. Thus, *T. evansi* is considered an emerging agricultural pest requiring alternative non-chemical control strategies. In Brazil, the effects of various neem-based products were evaluated on the mortality, fertility and fecundity of the tomato red mite [37]. The efficiency in reducing the *T. evansi* population was above 95% five days after spraying. Direct mortality one day after application was responsible for a higher reduction of *T. evansi* at a concentration corresponding to LC_{95}. Although a low mortality was achieved one day after application, when sub-lethal concentrations were used, the population reduction was above 95% after about five days, when the product was given sufficient time to act. Consequently, it is important to consider the time each product requires to show acaricide action, especially neem-based products, in order to achieve a successful control using reduced concentrations.

3.1.3. *Tetranychus cinnabarinus* (Boisduval)

The carmine spider mite is reported in more than 130 plant species of economic importance, including vegetables, fruit-trees and ornamentals [22, 38]. As in *T. urticae*, synthetic acaricides have been used as the main strategy for population management of *T. cinnabarinus* resulting in increased production costs and environmental impacts [39]. Intensive pesticide use has increased the development of resistance even to newly synthesized molecules such as hexythiazox, pyridaben, and tebufenpyrad [40, 41].

In Venezuela, as in several other Latin American countries, naturally growing plants are being tested for their use in pest control as part of an initiative to make use of abundant natural resources. Wild oregano (*Lippia origanoides* Kunth.) and gliricidia (*Gliricidia sepium* (Jacq.) Kunth ex Walp.) are commonly found in arid environmental conditions in the Lara State, presenting a valuable source of extracts that exert pesticide activity. At 5% concentrations, oregano and gliricidia extracts produced diminutions of 43.7% and 57% in *T. cinnabarinus* oviposition, respectively, while at 10%, the extracts caused mortality of 42.2% and 72.5%, respectively [42]. According to these authors, the use of gliricidia and wild oregano seem to constitute a promising strategy for the management of *T. cinnabarinus*. Since both plant species are abundant in tropical countries they could be made readily available for small-scale growers to be included among other carmine mite control practices, thus reducing the dependence on synthetic pesticides and the risk of environmental pollution.

3.1.4. *Panonychus citri* (McGregor)

The citrus red mite is considered a secondary pest of citrus crops in Brazil. However, important field outbreaks have been observed as a consequence of the large number of applications of broad-spectrum insecticides, especially pyrethroids and neonicotinoids employed for control of other pests in commercial plantations [43]. In this regard, acetogenins (ACGs), a series of natural products isolated exclusively from the Annonaceae species widely distributed in tropical and subtropical regions are being employed for pest control. ACGs constitute a potent inhibitor of the mitochondrial respiratory chain complex I and exhibit a broad range of biological activities such as cytotoxic, antitumoural, immunosuppresor, antimicrobial and antiparasitic, and also pesticidal [44].

To date, information on the acaricidal effects of acetogenins remains scarce. Encouraging lethal and sub-lethal effects of ethanolic extracts from *Annona mucosa* Jacq. seeds on the citrus red mite *P. citri* were demonstrated for the first time in 2014 [11]. The authors showed that the ethanolic extract caused both high mortality among *P. citri* females (80.33, 94.44, 95.56 and 97.78% after 48, 72, 96, and 120 h of exposure, respectively) and significant oviposition deterrence (> 90%), indicating the potential of these compounds as acaricides. Although this constitutes the first report of acetogenins as miticides, this extract may be considered a pre-commercial and/or domestic tool for the low-cost management of *P. citri* in small areas, especially in domestic or agroecological orchards [11].

3.2. Tenuipalpid mites

The family Tenuipalpidae Berlese presents a worldwide distribution with over 1100 valid species belonging to 38 genera. Most of the species described are from North America (33% of the total known flat mite fauna) and Africa (13%), whereas little is known about the distribution of flat mites in the rest of the world [45]. *Brevipalpus* Donnadieu is a New World group with the most diversity occurring in the Neotropical region. The most frequently reported species in this genus are *B. californicus* (Banks), *B. obovatus* Donnadieu, and *B. phoenicis* (Geijskes) [46]. These mites feed on about 928 host plant species including fruits, ornamental plants and forest plants that are arranged in 513 genera and 139 families [46]. The main damage associated with *Brevipalpus* mites is indirect, as vectors of plant viruses [47].

3.2.1. *Brevipalpus phoenicis* (Geijskes)

The false spider mite, *B. phoenicis*, is a cosmopolitan tenuipalpid mite that feeds on a variety of host plants. In citrus species it plays a crucial role in the transmission of the citrus leprosis virus (CiLV), a RNA virus found mainly on sweet orange and mandarin trees, which has been causing economic losses in Argentina, Brazil, Paraguay, Uruguay, Venezuela, Costa Rica, Panama and Honduras during the past 15 years [48].

In Brazil, a high toxicity of *Eremanthus goyazensis* (Gardner) leaf essential oils on *B. phoenicis* was observed even within a short exposure timeframe of 72 h. Additionally, the essential oils were sufficiently toxic to kill the entire spider mite population at the lower dose of 0.5 µL/L of air [48]. These authors stated that the toxic effect of *E. goyanensis* essential oil is mainly due to the presence of several monoterpenes that have been reported as toxic to other mite species. Thus, field dilutions of *E. goyazensis* oils could serve as a possible ‘resistance-free’ approach to stop the northward movement of *B. phoenicis* and thereby avoid endangering of orange tree fields [49].

3.2.2. *Brevipalpus chilensis* Baker

The Chilean false red mite *B. chilensis* native to Chile constitutes a quarantine pest that causes serious economic problems to grapes (*Vitis vinifera* L.), lemons (*Citrus* × *limon* (L.) Osbeck), kiwifruits (*Actinidia deliciosa* (A. Chev.) C. F. Liang & A. R. Ferguson), persimmons (*Diospyros kaki* Thunb.), and various flowers and ornamental crops [50].

High mortality rates (82%) were reported in *B. chilensis* adults exposed to different concentrations of *Acantholippia deserticola* (Phil.) Moldenke (Verbenaceae) essential oils containing a rich fraction of α and β-thujones (88.4%) [51]. The toxic effect of essential oils may be related to impairment of vital functions in target organisms since most monoterpenes are cytotoxic to plant and animal tissue, by causing a drastic reduction in the number of intact mitochondria and Golgi bodies, impairing respiration and photosynthesis and decreasing cell membrane permeability [52].

3.2.3. *Raoiella indica* Hirst

The red palm mite, *Raoiella indica*, was first reported in the Caribbean in 2004 and it later spread quickly through the region, reaching Florida (USA) and the northern part of South America [53, 54]. It has been considered a serious pest in coconut (*Cocos nucifera* L.) and areca palm (*Areca catechu* L.) in India [55, 56], and date palm (*Phoenix dactylifera* L.) in Egypt [57]. In the New World, *R. indica* inflicts serious damage to Arecaceae, primarily coconut, but also to Musaceae and to plants of a few other botanical families [58, 59]. Coconut plantlets may die from the attack, whereas older plants show discoloration and consequent yield reduction [60].

Despite the economic importance of the red palm mite in the Americas, information on control strategies is scarce. In Cuba, the essential oil of *Melaleuca quinquenervia* (Cav.) S. T. Blake (Myrtaceae) proved to be highly toxic to females of several mite species including *R. indica*, causing 100% mortality [61]. The application of different doses of ethanolic extract of *Cymbopogon citratus* (DC.) Stapf caused a higher mortality rate (92.5%) and reduction of egg production (100%) in *R. indica* under laboratory conditions, when compared to the control. In this context it is suggested that this extract may have the potential to serve as a biopesticide to control *R. indica* populations, although an evaluation of its effectiveness is required to better understand its performance under field conditions [62].

4. Final considerations

The method of chemical defense evolved by plants against herbivores has raised a renewed interest in plant products for the control of pest populations. These products have demonstrated rapid biodegradation to nontoxic compounds, minimizing accumulation of harmful residues and leading to more environmentally friendly pesticides compared to synthetic compounds.

The acaricidal activity of plant extracts offers a promising means to control pests in both open and closed environments. Besides direct mortality, botanical pesticides can cause a reduction in fertility, longevity and fecundity of mites. Thus, the evaluation of population effects of these products over time, rather than only mortality after a short period may demonstrate the possibility of employing reduced concentrations with satisfactory results. The importance of such a reduction would not only be economical but also environmentally sound, by virtue of having a low impact on natural enemies. Further studies should be conducted to evaluate the cost/benefit ratio of the use of these oils on a large scale for the protection of species cultivated in commercial greenhouses.

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interests regarding the publication of this paper.

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