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REVIEW ARTICLE

Plant secondary metabolites as alternatives in pest management. II: An overview of their potential in Cuba

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ABSTRACT: This review covers the historical use of plant secondary metabolites in agricultural practices in Cuba and their potential in pest management. The Cuban flora has not yet been fully studied as a source of pesticides, partly due to its great diversity. Nevertheless, up to date, several plants are used by Cuban farmers as repellents and/or as raw material for the preparation of botanical pesticides in an artisan manner, and more than 60 plants have demonstrated their pesticidal activity under laboratory, semicontrolled and field conditions. *Meliaceae*, *Asteraceae*, *Fabaceae*, *Solanaceae*, *Clusiaceae*, *Piperaceae*, *Lamiaceae*, *Apiaceae*, and *Mirtaceae* are among the most important involved plant families. From the chemical point of view, promising results have been achieved with alkaloids, terpenoids, coumarins and essential oils. The efficient practical application of pesticidal properties of plants in crop rotation, polycrops, and intercropping, and as barrier or traps requires further research from the chemical ecology point of view. As botanical pesticides, plant secondary metabolites may be applied in protected crops, nurseries, seed treatments in protected and field-grown crops, storage pest management among others. Innovative products can be developed by using them in mixtures with other phytosanitary products and as resistance inducers. The use of known botanicals and the identification of local candidates for developing new products offer alternatives that may combine efficiency and safety for the Cuban agriculture in pest management. Multidisciplinary and multiinstitucional research-development, and innovation programmes will play an important role in the increase of the scientific and socioeconomic impact of these phytosanitary products for contributing to a sustainable food production.

Key words: Cuban flora, botanical pesticides, pest management, secondary metabolites.

Metabolitos secundarios de origen botánico como alternativas en el manejo de plagas. II: Visión general de su potencial en Cuba

RESUMEN: Esta revisión abarca el uso histórico de los metabolitos secundarios de origen botánico en prácticas agrícolas y su potencial en el manejo de plagas en Cuba. La flora cubana aún no se ha estudiado totalmente como fuente de plaguicidas, en parte debido a su gran diversidad. Sin embargo, hasta la fecha, numerosas plantas son utilizadas por los campesinos cubanos como repelentes y/o materia prima para la preparación de extractos de manera artesanal y se ha demostrado la actividad plaguicida de más de 60 plantas en condiciones de laboratorio, semicontroladas y campo. Entre las familias botánicas involucradas más importantes se encuentran: *Meliaceae*, *Asteraceae*, *Fabaceae*, *Solanaceae*, *Clusiaceae*, *Piperaceae*, *Lamiaceae*, *Apiaceae* y *Mirtaceae*. Desde el punto de vista químico, se han logrado resultados promisorios con alcaloides, terpenoides, cumarinas y aceites esenciales. La aplicación práctica eficiente de las propiedades plaguicidas de las plantas en la rotación, asociación y el intercalamiento de cultivos y como barreras y trampas requiere de la ejecución de investigaciones desde el punto de vista de la ecología química. Como plaguicidas botánicos se pueden aplicar en cultivos protegidos, viveros, tratamientos de semillas, manejo de plagas de almacén; entre otros. Productos novedosos se pueden desarrollar utilizando metabolitos secundarios en mezclas con otros productos fitosanitarios y como inductores de resistencia. El uso de extractos vegetales conocidos y la identificación de candidatos locales para el desarrollo de nuevos productos, ofrecen alternativas que pueden combinar eficiencia y seguridad en el manejo de plagas en la agricultura cubana. Programas de investigación-desarrollo e innovación multidisciplinarios y multiinstitucionales desempeñarán un rol importante en el incremento del impacto científico y socioeconómico de estos productos fitosanitarios para contribuir a una producción sostenible de alimentos.

Palabras clave: flora cubana, plaguicidas botánicos, manejo de plagas, metabolitos secundarios.

INTRODUCTION

In Cuba, the search for new alternatives for pest management is a first priority task in agricultural sciences to reduce economic losses in crops, pest resistence development and the agroecosystem pollution (1, 2). The country is engaged in developing a model of agriculture where biopesticides (microorganisms, macroorganisms and botanicals) play a key role in obtaining good yields with a high ecological value in a sustainable food production (1, 2, 3, 4, 5).

In order to ensure the practical achievement of such objectives, the Integrated Pest Management was adopted as a policy of the Cuban State since the eighties; and in 1988, the National Programme for the Production of Biopesticides established their use within the Cuban strategy devised for a sustainable agricultural production (1, 2, 3, 6, 7). In 1997, the Cuban Goverment policy was officially stated in the Law of Environment (8). The ninth title of this law, «Rules for a Sustainable Agriculture», Article 132, subsections b and d, in relation with pest management, expresses: b) the rational use of biological and chemical products, according to the characteristics, conditions and local resources that minimize environment pollution, d) preventive and integrated management of pests, with special attention to the use of biodiversity resources for these purposes. The National Environmental Strategy 2007-2010, approved by the Ministry of Science, Technology and Environment (CITMA), established as goal that «80% of pest and disease control in crops in the country must be done using natural products or biopesticides» and that «100% of the areas of agricultural production must be maintained under integrated pest management schemes» (5, 9).

On this basis in many crops, the use of biological products (botanicals in a lesser proportion) makes an important contribution to the reduction of the presence of the main pests, the costs of importing large amounts of synthetic pesticides and their polluting effects in agroecosystems (2, 3). During the last 20 years, several changes in pest management led to reduce the national use of pesticides in more than 50% (3, 4).

Tropical plants, which grow under climatic conditions favouring microbial or insect attack, have developed a great variety of defence molecules. They constitute therefore a particularly rich source of substances which can find an application, directly or as lead compounds, for the development of new pest control agents (10, 11). It is thus highly likely that safe, efficient new molecules with new modes of action will find a place in agriculture for many decades to come (12).

Cuba is considered as one of the most biodiverse countries in the world in terms of sheer numbers of species and has the richest plant biodiversity of all the islands in America, with an estimated 6,500 vascular plant species of which 50% are endemic (6, 13). Partly due to its great diversity, the Cuban flora has not yet been closely studied as a potential source of chemical pesticides (13, 14, 15, 16). To date, only a small fraction of the plant species has undergone systematic phytochemical or biochemical research, leaving valuable sources for commercial products undiscovered (13). This review covers the historical use of plant secondary metabolites in agricultural practices, and their potential in pest management in Cuba.

Historical use of plant secondary metabolites in agricultural practices and current researches in Cuba

There are many anecdotes of the biological activity of several Cuban plants and their popular use as natural pharmaceuticals and pesticides, but the active compounds have not been studied in most cases. Also, the available information is often only related to botanical data, medicinal use and for some plants it dates back to many years (15, 17).

Nicotine, rotenone, and pyrethrins, contained in extracts from plants belonging to *Nicotiana*, *Tephrosia* and *Chrysanthemum* genera, can be mentioned among the best known natural pesticides in Cuba since the 1940s. A common practice was the use of aqueous extracts made from tobacco crop residues or other botanical species to spray them over the crops for insect control; stored grains (for food and seed) were also protected using tobacco powder (1).

Cuban farmers use several plants as repellents and/ or as raw material for the preparation of botanical pesticides in an artisan manner (Table 1) (2, 18). These plants are maintened in borders, live fences, gardens, organoponics, intensive orchards and farms, standing out *Ocimum basilicum* L. (basil), *Tagetes erecta* L. (African marigold), *Azadirachta indica* A. Juss (neem), *Origanum vulgare* L. (origanum) and *Euphorbia lactea* Haw. (Mottled Spurge, Frilled Fan or Elkhorn) as the most frequently reported (18, 19).

Ethnobotanical studies have shown that there is a level of plant biodiversity in urban agriculture and small farms which are used by the farmers, but the capacity building and dissemination actions about their use and pest control properties, as well as the search of alternatives for *in situ* conservation must be increased (2, 19). The effects of some of these plants have not been validated with scientific rigour in our conditions and it is a disadvantage for recommending their use (21).

TABLE 1. Some plants with pesticidal properties used by Cuban farmers./ *Algunas plantas con propiedades plaguicidas utilizadas por los agricultores cubanos.*

Plant (Scientific name)	Repellent	Plant extracts	Reference
Achillea millefolium L.		X	20
Agave sobolifera Salm. Dyck		X	19, 20
Allium cepa L.	X	X	18, 19, 20
Allium sativus L.	X	X	18, 19, 20
Aloe barbadensis Mill.			19
Annona cherimolia Mill.	X		19, 20
Annona muricata L.		X	19, 20
Annona squamosa L.	X	X	19, 20
Artemisia abrotanum L.	X	X	20
Artemisia absinthium L.	X	X	19
Asclepia curassavica L.	X	X	19, 20
Asparagus officinalis L.	X	X	19
Azadirachta indica A. Juss.	X	X	18, 19
Bixa orellana L.		X	19
Brassica oleracea L.		X	19
Bursera graveolens H.B.K. Triana Planch.	X		19
Bursera simaruba Sarg.		X	19, 20
Calendula officinalis L.	X	X	18, 19
Canavalia ensiformis (L.). P.D.C	X		19
Capsicum frutescens L.	X		19, 20
Carica papaya L.		X	18, 19, 20
Chenopodium ambrosiodes L.	X	X	19, 20
Chrysanthemum sp.		X	19, 20
Cinnamomum camphora L. (Siebold)		X	19, 20
Coriandrum sativum L.	X	X	19
Crescentia cujete L.		X	19
Cymbopogon citratus (D.C) Stapf.	X	X	19, 20
Cymbopogon nardus L.		X	20
Datura arborea L.	X		19
Dichrostachys cinerea (L.) Wigth.			19
Eucalyptus sp.	X	X	19, 20
Euphorbia lactea Haw.	X	X	19, 20
Equisetum bogotense Kunth		x	18
Foeniculum vulgare Mill.	X	X	19
Gliricidea sepium (Jacq) Steud.	X	X	19
Guazuma tomentosa H.B.K		X	19, 20
Helianthus annuus L.	X	X	19
Jatropha curcas L.		X	19, 20
Lactuca sativa L.	X	X	19, 20
Lantana camara L.		X	20
Lepidium virginium L.			19
Matricaria recutita L.	X	X	18, 19, 20
Melia azedarach L.		X	18, 19, 20
Mentha arvensis L.	X	X	19, 20
Mentha nemorosa Willd.	X		19
Mentha piperita L.	X	X	19, 20
Moringa oleifera Lam.			19
Nerium oleander L.	X	X	19, 20
Nicotiana tabacum L.	X	X	18, 19

TABLE 1. Continuation. Some plants with pesticidal properties used by Cuban farmers./ ***Continuación.*** *Algunas plantas con propiedades plaguicidas utilizadas por los agricultores cubanos.*

Plant (Scientific name)	Repellent	Plant extracts	Reference
Nopalea coccinellifera (L.) Salm.- Dyck.		X	19, 20
Ocimum basilicum L.	X	X	19
Origanum vulgare L.	X	X	19
Parthenium hysterophorus L.			19
Petiveria alliacea L.	X	X	19
Pinus caribaea Morelet.		X	19, 20
Piper auritum H.B.K	X	X	19
Pouteria mammosa (L) Cronquist		X	19, 20
Raphanus sativus L.		X	19
Ricinus communis L.	X	X	18, 19, 20
Rosmarinus officinalis L.	X	X	19, 20
Ruta graveolens L.	X	X	18, 19, 20
Salvia officinalis L.			19
Sesamum orientale L.	X	X	19
Solanum globiferum Dunal.		X	19, 20
Solanum mammosum L.		X	19, 20
Solanum licopersicon Mill.	X	X	19
Sorghum vulgare Pers.	X	X	19
Tagetes erecta L.	X	X	19, 20
Tagetes patula L.	X	X	20
Tephrosia cinerea (L) Pers.		X	19
Thymus vulgaris L.	X		19
Urtica urens L.	X	X	18
Vallesia antillana Woodson.		X	19, 20
Vetiveria zizanioides (L.) Nash.	X	X	19
Zea mays L.	X		19

Considering the influence of the whole plant diversity on insect pests and natural enemies, some studies have been addressed to establish the effects of the direct sowing (22) and the polycrops (23, 24, 25) on the entomophauna. The results showed that the diversity in the crop systems (achieved by direct sowing of the plant and the polycrops) reduced the incidence of the insect pests (22, 23, 24, 25) and increased the species richness of bioregulators (23). The potential role of the plant secondary metabolites in these interactions has not been established and further research from the chemical ecology point of view should be done in the frame of future multidisciplinary projects.

Endemic and exotic species in the Cuban flora are potential sources of substances with regulatory effect on populations of harmful organisms, but the real possibility of including natural products extracted from plants into national programmes was not considered until the end of the eighties and early nineties, when several research projects on this subject were initiated (2, 7). Currently, several Cuban research institutes and universities develope research lines related to bioactive secondary metabolites with potential application in agriculture. Table 2 summarises the information of some plants with a scientific description of their biological effectiveness published in the main Cuban journals related to this topic (2).

According to Alfonso *et al.* (6), the biological activity of 52 species belonging to 30 botanical families was reported until 2002. Considering both the number of species tested with positive results and the bioactivity spectrum, the *Meliaceae*, *Asteraceae*, *Fabaceae*, and *Solanaceae* were among the most important families. The most significant species were the neem tree, the chinaberry (*Melia azedarach* L.), the love apple (*Solanum mammosum* L) and the French marigold (*Tagetes patula* L.) (2, 7, 69). Other botanical pesticides have been prepared from *M. azedarach* (MELITOX 50, PARAISO-M), *Chrysanthemum cinense* Sabine, *Tagetes erecta* L, *Solanum globiferum* Dunal (SOLASOL), *Gliricidia sepium* J. (GLISEP 60) and *Indigofera suffruticosa* Mill (16, 18).

TABLE 2. Some Cuban plants with pesticidal activity determined under laboratory, semicontrolled and field conditions./ *Algunas plantas cubanas con actividad plaguicida determinada en condiciones de laboratorio, semicontroladas y campo.*

Plant (Scientific name)	Extract, product	Target Pest	Biological activity	Reference
Allium porrum L	powder	*Zabrotes subfasciatus* (Boheman)	repellent	26
Allium sativum L.	aqueous extract	*Carolinaia cyperi* Ainslie	insecticidal	27
Azadirachta indica A. Juss	CubaNim SM	*Thrips palmi* Karmy	antiinsect	29
	CubaNim T	*Bemisia tabaci* Genn	antiinsect	29
	CubaNim T	*Empoasca fabae* Hans	antiinsect	29
	CubaNim T	*Thrips palmi* Karmy	antiinsect	29
	FoliarNim HM	*Thrips palmi* Karmy	antiinsect	29
	formulated oil	*Praticolella griseola* Pfeiffer	molusquicidal	28
	NeoNim 60 CE	*Diaphania hyalinata* L.	antiinsect	29
	NeoNim 60 CE	*Empoasca fabae* Hans	antiinsect	29
	NeoNim 60 CE	*Thrips palmi* Karmy	antiinsect	29
	OleoNim 50 CE	*Heliothis virescens* F.	insecticidal	30
	OleoNim 80 CE	*Bemisia tabaci* Genn	antiinsect	29
	OleoNim 80 CE	*Diaphania hyalinata* L.	antiinsect	29
	OleoNim 80 CE	*Empoasca fabae* Hans	antiinsect	29
	OleoNim 80 CE	*Heliothis virescens* F.	insecticidal	30
	OleoNim 80 CE	*Hypsipyla grandella* Zeller	insecticidal	21
	OleoNim 80 CE	*Thrips palmi* Karmy	antiinsect	29
	powder	*Zabrotes subfasciatus* (Boheman)	repellent	26
Bixa orellana L.	methanolic extract	*Xanthomonas axonopodis* pv. *manihotis* (Xam)	antibacterial	31
	methanolic extract	*Xanthomonas axonopodis* pv. *vesicatoria* Vauterin *et al*.	antibacterial	31
	methanolic extract	*Xanthomonas campestris* pv. *campestris (Pammel) Dawson*	antibacterial	31
	methanolic extract	*Xanthomonas* sp.	antibacterial	31
Bougainvillea spectabilis Willd	aqueous extract	Sugar cane mosaic virus (SCMV)	antiviral	32
	aqueous extract	Severe Cowpea Mosaic Virus (CpSMV)	resistence inducer	33
Canavalia ensiformis (L.). P.D.C	powder	*Sitophilus zeamais* Motschulsky	repellent, insecticidal	34
Canna edulis Ker	aqueous extract	*Praticolella griseola* Pfeiffer	molusquicidal	28
Carica papaya L.	aqueous extract	Severe Cowpea Mosaic Virus (CpSMV)	resistence inducer	33
Chenopodium ambrosioides L	powder	*Zabrotes subfasciatus* (Boheman)	repellent	26
Citrus sinensis (L.) Osbeck	essential oil	*Alternaria solani* Sor.	antifungal	35
Cleome gynandra L.	ethanolic extract	*Alternaria solani* Sor.	antifungal	36
Cleome viscosa L.	ethanolic extract	*Alternaria solani* Sor.	antifungal	36
Coleus amboinicus Lour	ethanolic extract	*Alternaria solani* Sor.	antifungal	36
Crescentia cujete L.	aqueous extract	*Fusarium oxysporum* Slecht.	antifungal	14
	aqueous extract	*Rhizoctonia solani* (Kühn)	antifungal	14
Curcuma longa L.	aqueous extract	*Fusarium oxysporum* Slecht.	antifungal	14
Cymbopogon citratus (DC.) Stapf	aqueous extract*	*Mycosphaerella fijiensis* Morelet.	antifungal	37
Cymbopogon nardus L.	essential oil	*Macrophomina phaseolina* (Tassi) Goid	antifungal	38
	citronellal	*Rhizoctonia solani* (Kühn)	fungicide	39

TABLE 2. Continuation. Some Cuban plants with pesticidal activity determined under laboratory, semicontrolled and field conditions./ ***Continuación.*** *Algunas plantas cubanas con actividad plaguicida determinada en condiciones de laboratorio, semicontroladas y campo.*

Plant (Scientific name)	Extract, product	Target Pest	Biological activity	Reference
Furcraea hexapetala (Jacq.) Urban	aqueous extract	*Polyphagotarsonemus latus* Banks	antimite	40
Gliricidia sepium (Jaq.) Steud	aqueous extract	*Blatella germanica* L.	insecticidal	41
	aqueous extract	*Corynespora cassiicola* (Berk and Curt) Wei	antifungal	41
	aqueous extract	*Meloidogyne* spp.	antinematode	41
	aqueous extract	*Pieris ph. phileta* Bdy	insecticidal	41
	aqueous extract	*Plutella xylostella* L.	insecticidal	41
	aqueous extract	*Corynespora cassiicola* (Berk and Curt) Wei	antifungal	42
Helianthus annuus L.	aqueous extract	*Fusarium oxysporum* Slecht.	antifungal	14
Jatropha curcas L.	ethanolic extract	*Praticolella griseola* Pfeiffer	molusquicidal	28
	formulated oil	*Praticolella griseola* Pfeiffer	molusquicidal	28
Juniperus lucayana B.	ethanolic extract	*Botrytis cinerea* Pers.:Fr.	antifungal	16
Lantana camara L.	aqueous extract	*Corynespora cassiicola* (Berk and Curt) Wei	antifungal	42, 43
	aqueous extract	*Meloidogyne incognita* (Kofoid and White) Chitwood	nematicidal	43
	aqueous extract	*Spodoptera frugiperda* Smith	antifeedant, insecticidal	43
	ethanolic extract	*Alternaria solani* Sor.	antifungal	36
	ethanolic extract	*Alternaria solani* Sor.	antifungal	36
Lippia alba (Mill.) N.E. Brown	ethanolic extract	*Alternaria solani* Sor.	antifungal	36
Lippia dulcis Trev.	ethanolic extract	*Alternaria solani* Sor.	antifungal	36
Lonchocarpus punctatus L.	powder	*Sitophilus zeamais* Motschulsky	repellent, insecticidal	44
Mammea americana L.	organic extract	*Phaedon cochleariae* Fab.	insecticidal	45, 46
	organic extract	*Tetranychus urticae* Koch	acaricidal	45
Maytenus urquiolae Mory	organic extract	*Curvularia clavata* B. L. Jain	fungicide	47
Melaleuca quinquenervia (Cav) S.T. Blake	essential oil	*Alternaria solani* Sor.	antifungal	35
	essential oil	*Alternaria solani* Sor.	antifungal	48
	essential oil	*Clavibacter michiganensis* subsp. *michiganensis* (Smith) Davis *et al.*	antibacterial	48
	essential oil	*Panonychus citri* McGregor	antimite	48
	essential oil	*Raoiella indica* Hirst	antimite	48
	essential oil	*Tetranychus tumidus* Banks	antimite	48
	essential oil	*Tetranychus urticae* Koch	antimite	48
	essential oil	*Xanthomonas albilineans* (Ashby) Dawson	antibacterial	48
Melia azedarach L.	aqueous extract	*Carolinaia cyperi* Ainslie	insecticidal	27
	ethanolic extract	*Mocis latipes* (Guenee)	insecticidal	16
	formulated oil	*Praticolella griseola* Pfeiffer	molusquicidal	28
	powder	*Rhyzopertha dominica* (F.)	insecticidal	49
Momordica charantia L.	aqueous extract*	*Mycosphaerella fijiensis* Morelet.	antifungal	37
	aqueous extract	*Fusarium oxysporum* Slecht.	antifungal	14
	aqueous extract	*Rhizoctonia solani* (Kühn)	antifungal	14

TABLE 2. Continuation. Some Cuban plants with pesticidal activity determined under laboratory, semicontrolled and field conditions./ ***Continuación.*** *Algunas plantas cubanas con actividad plaguicida determinada en condiciones de laboratorio, semicontroladas y campo.*

Plant (Scientific name)	Extract, product	Target Pest	Biological activity	Reference
Muralla paniculata L.	aqueous extract	*Fusarium oxysporum* Slecht.	antifungal	14
Nicotiana tabacum L.	aqueous extract	*Carolinaia cyperi* Ainslie	insecticidal	27
	aqueous extract	*Rhizoctonia solani* (Kühn)	antifungal	14
	tabaquina	Whiteflies, *Thrips palmi* and other insects	insecticidal	50
Ocimum basilicum L.	essential oil	*Alternaria solani* Sor.	antifungal	35
	essential oil	*Clavibacter michiganensis* subsp *michiganensis* (Smith) Davis *et al.*	antibacterial	51
	essential oil	*Xanthomonas albilineans* (Ashby) Dawson	antibacterial	51
Ocimum basilicum var *genovese* L.	essential oil	*Alternaria solani* Sor.	antifungal	35
	essential oil	*Clavibacter michiganensis* subsp. *michiganensis* (Smith) Davis *et al.*	antibacterial	51
	essential oil	*Xanthomonas albilineans* (Ashby) Dawson	antibacterial	51
Parthenium hysterosphorus L.	powder	*Zabrotes subfasciatus* (Boheman)	repellent	26
Pimpinella anisum L.	essential oil	*Alternaria solani* Sor.	antifungal	35
	essential oil	*Xanthomonas campestris* pv. *vesicatoria* Doidge (Dye)	antibacterial	52
Piper aduncum subsp. *ossanum* (C. DC.) Saralegui	essential oil	*Alternaria solani* Sor	antifungal	35
	essential oil	*Lasioderma serricorne* (F.)	repellent, insecticidal	53
	essential oil	*Xanthomonas albilineans* (Ashby) Dawson	antibacterial	54
Piper auritum Kunth	essential oil	*Acidovorax avenae* subsp. *avenae* (Manns) Willems *et al.*	antibacterial	55
	essential oil	*Alternaria solani* Sor.	antifungal	35
	essential oil	*Xanthomonas albilineans* (Ashby) Dawson	antibacterial	55
	essential oil	*Xanthomonas albilineans* (Ashby) Dawson	antibacterial	54
	powder	*Zabrotes subfasciatus* (Boheman)	repellent	26
Piper marginatum Jacq.	essential oil	*Alternaria solani* Sor.	antifungal	35
	essential oil	*Alternaria solani* Sor.	antifungal	56
	essential oil	*Xanthomonas albilineans* (Ashby) Dawson	antibacterial	56
	essential oil	*Xanthomonas albilineans* (Ashby) Dawson	antibacterial	57
	essential oil	*Xanthomonas campestris* pv. *campestris* (Pammel) Dawson	antibacterial	56
Polyscia guilfoyley Bailey	aqueous extract	*Fusarium oxysporum* Slecht.	antifungal	14
	aqueous extract	*Rhizoctonia solani* (Kühn)	antifungal	14
	ethanolic extract	*Alternaria solani* Sor.	antifungal	36
Pteridium aquilinum (L.) Kunth	aqueous extract	*Ascia monuste* L.	insecticidal	58
	aqueous extract	*Brevicoryne brassicae* L.	insecticidal	58
	aqueous extract	*Plutella xylostella* L.	insecticidal	58
Ricinus communis L.	aqueous extract	*Hipothenemus hampei* Ferr	insecticidal	59

TABLE 2. Continuation. Some Cuban plants with pesticidal activity determined under laboratory, semicontrolled and field conditions./ ***Continuación.*** *Algunas plantas cubanas con actividad plaguicida determinada en condiciones de laboratorio, semicontroladas y campo.*

Plant (Scientific name)	Extract, product	Target Pest	Biological activity	Reference
Rosmarinus officinalis L.	essential oil	*Tetranychus tumidus* Banks	acaricidal	60
Ruta chalepensis L.	essential oil	*Alternaria solani* Sor.	antifungal	35
Salvia officinalis L.	aqueous extract*	*Mycosphaerella fijiensis* Morelet.	antifungal	37
	powder	*Zabrotes subfasciatus* (Boheman)	repellent	26
Solanum globiferum Dunal	aqueous extract	Severe Cowpea Mosaic Virus (CpSMV)	resistence inducer	33
	aqueous extract	*Praticolella griseola* Pfeiffer	molusquicidal	28
	aqueous extract	*Succinia sagra* d'Orbigny	molusquicidal	28
	ethanolic extract	*Praticolella griseola* Pfeiffer	molusquicidal	28
	ethanolic extract	*Succinia sagra* d'Orbigny	molusquicidal	28
Solanum mammosum L.	ethanolic extract	*Praticolella griseola* Pfeiffer	molusquicidal	28
	ethanolic extract	*Succinia sagra* d'Orbigny	molusquicidal	28
Stachytarpheta jamaisense Gard.	aqueous extract	*Sclerotiun rolfsii* Sacc.	antifungal	61
Tagetes erecta L.	aqueous extract	*Rhizoctonia solani* (Kühn)	antifungal	62
	aqueous extract	Severe Cowpea Mosaic Virus (CpSMV)	resistence inducer	33
	ethanolic extract	*Alternaria porri* Ell. and Cif.	antifungal	63
	ethanolic extract	*Alternaria solani* Sor.	antifungal	63
	ethanolic extract	*Cercospora beticola* Sacc.	antifungal	63
	ethanolic extract	*Cladosporium fulvum* Cooke	antifungal	63
Terminalia catappa L.	aqueous extract	*Rhizoctonia solani* (Kühn)	antifungal	62
	aqueous extract	*Rhizoctonia solani* (Kühn)	antifungal	64
	aqueous extract	*Sclerotiun rolfsii* Sacc.	antifungal	64,65
Thuja orientalis L.	ethanolic extract	*Botrytis cinerea* Pers.:Fr.	antifungal	16
	ethanolic extract	*Mocis latipes* (Guenee)	insecticidal	16
Tithonia diversifolia (Hemsl.) Gray	ethanolic extract	*Alternaria solani* Sor.	antifungal	36
	powder	*Sitophilus zeamais* Motschulsky	repellent, insecticidal	66
Tradescantia pallida (Rose) D.R. Hunt	ethanolic extract	*Alternaria solani* Sor.	antifungal	36
Tradescantia spathacea Sw.	ethanolic extract	*Alternaria solani* Sor.	antifungal	36
Trichila glabra L.	aqueous extract	*Rhizoctonia solani* (Kühn)	antifungal	14
Wedelia trilobata (L.) Hitchc	aqueous extract	*Sclerotiun rolfsii* Sacc.	antifungal	67
Zea mays L.	aqueous extract	*Panonychus citri* McGregor	antimite	68

Legend: * 90ml aq extract +10ml aceite Nim

In 1990, the agroindustrial development of neem-based pesticides was begun in Cuba; this multidisciplinary research programme included the widespread cultivation and production of bio-insecticides, veterinary, and industrial products (1). The project for the industrial development of neem and chinaberry as a second line considered 15 microforests (12 ha each, six of neem and six of chinaberry), four semiindustrial processing plants (capacity of 200 $t.year^{-1}$) and a pilot plant for the industrial production (7). The plantations were established in order to obtain natural products for agricultural use in addition to contribute to recover unproductive marginal land, increase the biomass and consequently improve the ecological environment (1).

Till now, research results have shown that the Cuban natural products based on neem are effective in regulating insects, mites, nematodes, and molluscs that affect a large number of economically important crops for our agriculture (vegetables, rice, tomato, corn and beans) (1, 26, 28, 29, 30). Another advantage of using neem extracts is their possible production in an artisan way (7). Up to date, the following neem- based commercial products have been developed: CubaNim Sm (whole seed aqueous extract), CubaNim-t (cake aqueous extract), FoliarNim HM (leaf aqueous extract), CubaNim SM (whole grounded seed), CubaNim T (oilcake), OleoNim 80 EC and NeoNim 60 EC (seed oil emulsions), and DerNim P (cream to treat scabies) (1). The last five products are in the Official List of Authorized Pesticides in the Republic of Cuba (70)

As a result of the problems caused by whiteflies in 1989-1990, simple technologies were developed to extract nicotine from parts of leaves considered waste of the tobacco industry (7, 50). Then the product known as «tabaquina» arose, which is now widely used in the country (2). It is obtained by farmers and agricultural cooperatives and has been used to control whitefly, thrips, and other pests (18, 50). The tabaquina shows insecticidal activity and its residual effect is four days (7).

During the last years, the systematic research of more than 100 plants belonging to several botanical families, such as *Clusiaceae* (genera *Calophyllum*, *Clusia*, *Mammea*, and *Rheedia*) (13, 45, 46), *Piperaceae* (*Piper*, *Lepianthes*) (35, 53, 54, 55, 56, 71), *Lamiaceae* (*Ocimum*) (35, 51), *Annonaceae* (*Annona*) (13), *Asteraceae* (*Lescaillea*, *Vernonia*) (13), *Myrtaceae* (*Psidium*, *Melaleuca*) (35, 48), and *Poaceae* (*Arthrostilidium*, *Zea*) (13, 68), have evolved using a chemotaxonomic approach. The protocol involves the establishment of bioassay conditions, the isolation and characterisation of new bioactive compounds, the determination of structural features related to biological activity, and the semisynthesis of analogues (using classical or biotechnological techniques) (13,45, 72).

In these studies, plants were initially chosen for both their potential applications as botanical pesticides and as lead compounds. Very rare species not previously studied from a chemical or biological point of view (with great possibilities of discovering novel compounds), as well as other abundant species (enough availability of raw material for developing a botanical pesticide) were included. Under laboratory and semicontrolled conditions, promising results have been achieved with coumarins and essential oils obtained from plants belonging to the *Clusiaceae*, *Piperaceae*, *Lamiaceae*, *Apiaceae*, and *Mirtaceae* families (Figure 1) (13, 45,46, 35, 48, 51, 52, 53, 56, 57, 71).

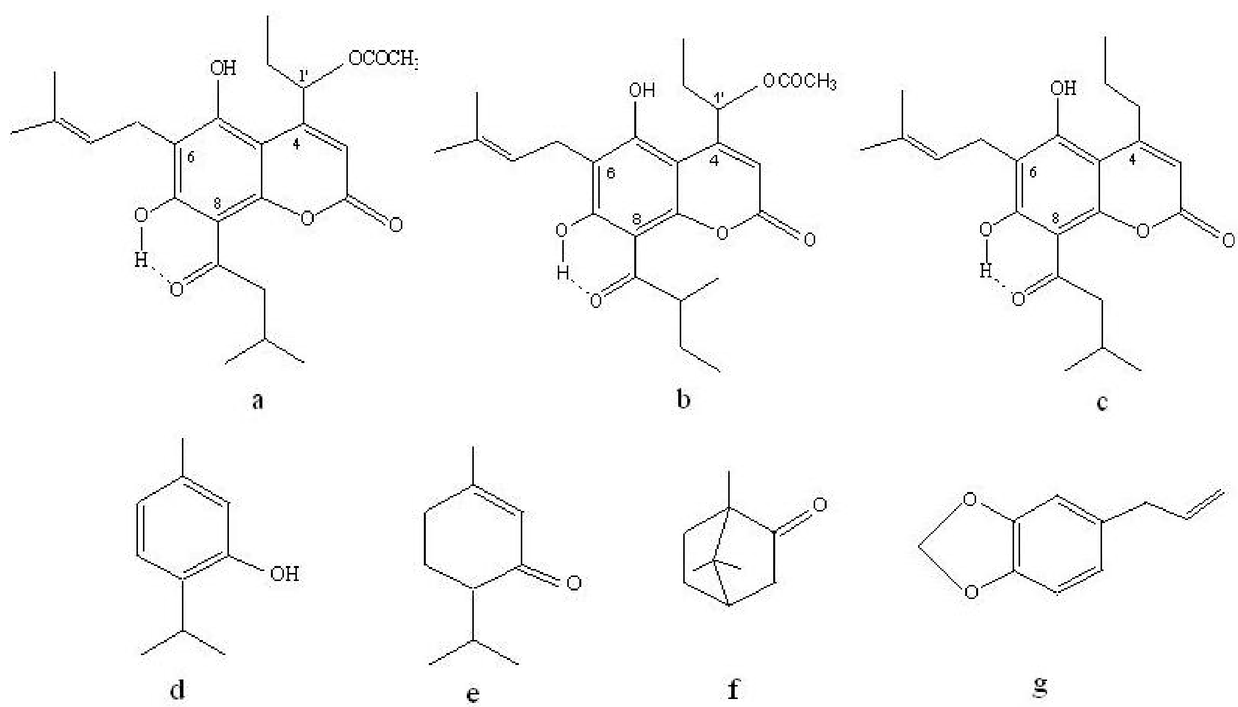

FIGURE 1. Main bioactive compounds identified in organic extracts and essential oils./ *Principales compuestos bioactivos identificados en extractos orgánicos y aceites esenciales.*

Legend: (*a*) mammea E/BA, (*b*) mammea E/BB, (*c*) mammea B/BA, (*d*) thymol, (*e*) piperitone, (*f*) camphor, (*g*) safrole.

An overview of the work done in the area of research and development of botanical-based pesticides in Cuba during the last years points out that several plants may represent viable sources of alternatives for crop protection (Table 2). More than 60 plants demonstrated their pesticidal activity under laboratory, semicontrolled and field conditions. *Meliaceae*, *Asteraceae*, *Fabaceae*, *Solanaceae, Clusiaceae*, *Piperaceae*, *Lamiaceae*, *Apiaceae*, and *Mirtaceae* were among the most important families.

The analysis of all these data allows the selection of promising natural products that may go on to candidates for the development of commercial plant protection products. The identification of candidates developing new phytosanitary products offer new alternatives for the Cuban agriculture in the area of pest management in citrus, sugarcane, vegetables, forestry, and in the control of storage pests (7, 21, 34, 35, 44, 48, 51, 52, 53, 56, 66, 68). In spite of the progress achieved in the scientific screening of the Cuban flora, many plant species have not been studied yet (13, 21).

In much of the research carried out, the biological evaluation did not go along with studies on the chemical composition and the identification of the main bioactive compounds, which is a very important issue considering the close relationship between both aspects and its role in the reproducibility of biological effects. An analysis of the worldwide trends of the scientific literature on botanicals and essential oils calls attention to this aspect. It emphasises that the lack of chemical characterisation does not allow comparing the results with any previous studies with the same plant species and compromises the reproducibility of the results; this study showed that the average impact factor of papers including chemical data greatly exceeds that of papers lacking them (73). In Cuba, only ¼ of the 66 papers reviewed included the identification of the main compounds in the evaluated samples. Among the secondary metabolites studied by Cuban researches until now, essential oils and their components stand out as a promising group due to their efficacy and spectrum of action (39, 48, 51, 52, 55, 56, 60, 71).

Also, the extract concentration that provides the most efficient control has not yet been precisely determined in some experiments. Most experiments have been carried out in laboratory conditions and the biological evaluation under semicontrolled and field conditions is essential for achieving a practical application.

For these promising candidates, all the studies related to the raw material cultivation (unless the plant has a very high wild abundance), formulation of the active ingredients, scale up of the extraction process, toxicity tests, and the ecotoxicological evaluation must be conducted for commercialising the products and contributing to increase the impact of botanical pesticides on a sustainable food production in Cuba. New research and innovation projects concerning the use of secondary metabolites in pest management must be multidisciplinary and multiinstitutional to improve the scientific and socioeconomic impact of the results.

Potential of plant secondary metabolites in pest management

The analysis of the use of several alternatives (biocontrol agents, botanical pesticides, crop rotation, and others) in pest management in the Cuban agriculture led to a group of important recommendations. Regarding plants, it was recommended to study the flora species used as traps and with repellent effect, to continue research on botanical-based products considering the Cuban biodiversity, to extend the use of those most studied (like neem), to consider the potential of other promising plants, and to increase the use of plants with pesticidal properties at a small scale (7).

Concerning crop protection, the Cuban agricultural development may be benefited by using whole plants or extracting them through different processes. Plants with pest control properties can be used in crop rotation, polycrops, and intercropping, and as barrier (for example in push-pull strategies for controlling insects), or traps. Further research must be done from the chemical ecology point of view to support an efficient practical application of these alternatives in our agroecosystems. Also the plants, part of them or the residues from their harvesting or industrial proccessing may be applied as green manure for a natural pest management (7, 61).

As botanical pesticides, the main areas of application may be found in protected crops, nurseries, seed treatments in protected and field-grown crops, and storage pest management. The combination of plant extracts with other types of plant protection products traditionally used by Cuban farmers can be promoted in a near future; improvement of the effectiveness and/or stability of some biological control agents, or the reduction of the application frequency and dosis of a chemical synthetic treatment may be some of the advantages of the new combined formulations. Additionally, the potential of plant secondary metabolites as resistance inducers may allow the management of complex phytosanitary problems by using some plant extracts in different agricultural systems.

General Comments

The Cuban flora has not yet been fully studied as a potential source of pesticides, partly due to its great diversity. Nevertheless, up to date, the use of known botanicals and the identification of local candidates for developing phytosanitary products offer alternatives that may combine efficiency and safety for the Cuban agriculture in pest management. Multidisciplinary and multiinstitucional research, and development and innovation programmes will play an important role in the scientific and socioeconomic impact of these plant protection products for contributing to a sustainable food production.

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