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Insecticidal and antifungal chemicals produced by plants. A review

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ABSTRACT

Leaf-cutting ants (tribe of *Attini*) are one of the most important pest species of agricultural and forestry productions in the New World and economic losses caused by these ants were estimated at several million dollars per year. These ants need to live in symbiosis with a basidiomycete fungus, and due to their mutualistic interaction with the symbiotic fungus, management of *Attini* ants may be considered at the insecticidal or at the fungicidal level, individually, or as a combination of both strategies to increase the efficiency of an integrated control. Until now, synthetic pesticides were the main control mean for these ants, but with high injurious effects on the environment. Very few studies deal with alternative methods for the control of leaf-cutting ants including the use of insecticidal and fungicidal plants extracts. There is then a need of knowledge on phytochemicals and plants that can be possibly used as general insecticides and fungicides.

Here we review chemicals of plant origin and species with insecticidal and fungicidal activities in order to establish a listing of plants and phytochemicals, which can possibly manage leaf-cutting ants, but also other groups of insects that utilize fungus-based agriculture or any insects or fungi pests. An exhaustive literature search of 1965 references (from 1923 to 2010) was conducted using scientific databases, chemical databases, botanical databases and books to identify published papers related to insecticidal and fungicidal chemical compounds stemmed from plant species. The major points are the following: 1) 119 and 284 chemical compounds have been cited in the literature as to have respectively insecticidal and fungicidal activities; 2) 656 and 1064 plant species were identified as to have respectively significant insecticidal and fungicidal activities; 3) 3 main chemical classes were most cited for these activities: alkaloids, phenolics, and terpenoids; 4) 20 interesting chemicals with the both activities were found; and 5) 305 plant species containing these chemicals were cited.

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In conclusion, the data presented in this study showed that 20 interesting chemicals (caryophyllene oxide, cinnamaldehyde, eugenol, helenalin, linalool, menthone, myristicin, pulegone, thymol, anethole, anisaldehyde, elemicin, isopimpinellin, plumbagin, podophyllotoxin, psoralen, xanthotoxin, anonaine, solamargine, and tomatine), 2 notable plant families (Lamiaceae and Apiaceae), and 17 species of these families were particularly interesting for leaf-cutting ants' pest-management.

Key Words

Insecticide, fungicide, plants phytochemicals, natural pesticides, *Attini* ants, integrated pest management, environmental chemistry, green chemistry.

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1. Introduction

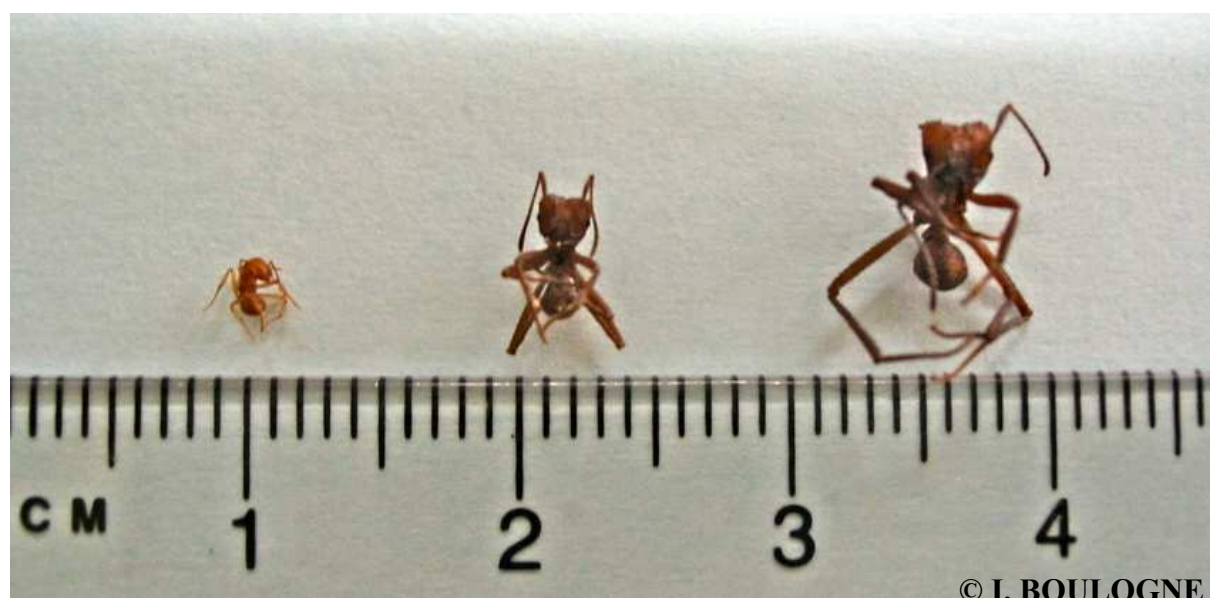
1.1 Consequences of synthetic chemical pesticides

Insect pest management is nowadays a worldwide ecological challenge mainly due to environmental pollution caused by extensive use of synthetic chemical pesticides (Rattan 2010). Synthetic pesticides have been used since 1945 in order to reduce crop damages due to plant pathogens. However, the use of pesticides has some detrimental consequences on environment, such as groundwater pollution, river eutrophication, soil erosion, excessive water use, and the development of weeds and diseases resistant to chemical control (Lichtfouse et al. 2009). It also has negative impact on health with human poisonings and their related illnesses. In 1997, the United Nations Environmental Program estimated that 26 million persons suffer from pesticide poisoning each year, around 3 million persons were hospitalized due to pesticides, and about 220,000 persons died due to pesticide poisonings (Paoletti and Pimentel 2000). In the French West Indies, organochlorine insecticides that were used to control banana weevils (*Cosmopolites sordidus*) and leaf-cutting ants (*Acromyrmex octospinosus*) were responsible for long-term pollution of soils, river water, wild animals, and vegetables cultivated in polluted zones. These pesticides also were shown to cause hepatic tumors in laboratory and probably increased the risk of prostate cancer (Multigner et al. 2010).

1.2 Major herbivores in the Neotropics: leaf-cutting ants

Ants represent the half of the global insect biomass and leaf-cutting ants are a high percentage of the worldwide ant societies (Benckiser 2010). Leaf-cutting ants, also called ‘Gardening ants’ (tribe *Attini*, genera *Acromyrmex* and *Atta*) (photo 1), are among the most damaging invertebrates in the Neotropics (Fowler 1978). Their geographic distribution ranges from southern United States to northern Argentina, including the West Indies (Bacci et al. 2009). Because of their voraciousness and the large amount of plant material they collect, these ants cause substantial losses to agricultural and forestry productions. Some nests of the *Attini* tribe may contain millions of workers and consume hundreds of kilograms of leaves per year (Mikheyev 2008). Economic losses caused by these ants were estimated at several million dollars per year (Bacci et al. 2009). Consequently, they are considered as the major herbivore in the Neotropics, the main agricultural pest of the New World and the most important pest species in South America (Mikheyev 2008; Erthal et al. 2004).

Photo 1 Workers of a leaf-cutting ant, *Acromyrmex octospinosus* (Reich) (left to right: minor, medium and major workers). © I. Boulogne



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There is a binding mutualistic symbiosis between *Attini* ants and a Basidiomycota fungus cultivar (Mikheyev 2008). Several authors suggested that a unique fungus species (*Leucocoprinus gongylophorus* (Heim) Moeller) (photo 2) is cultivated by the *Attini* according to observations on *Acromyrmex* and *Atta* nests and DNA analysis studies (Silva-Pinhati et al. 2004; Silva-Pinhati et al. 2005). The fungus grows inside the nests on parts of plants (leaves, flowers,...) collected by the ants. This is an obligate relationship where the fungus metabolizes polysaccharides, such as xylan, starch, pectin, and cellulose, derived from the plants, into nutrients assimilable by the ants; in return, the ants protect the fungus from parasites and potential competitors. The fungus is the unique food source for the ant queens, male ants, larvae and nymphs and supplements the plant sap diet of adult workers (Silva et al. 2006). A colony of ants is composed of various castes of workers, which cooperate, in the nest, in an 'assembly line' mode. The major workers cut and bring the vegetation back to the nest. They are also known as foragers and porters. The medium-sized workers cut the plant material into smaller pieces. The smallest workers (the gardeners) implant fungal strands by applying their own fecal material on these pieces of plant material and care for the fungus as it grows. Strong relationships between ants and fungus are obvious; they are schematized in figure 1.

Photo 2 Symbiotic fungus of leaf-cutting ants, *Leucocoprinus gongylophorus* (Heim) Moeller. © I.Boulogne

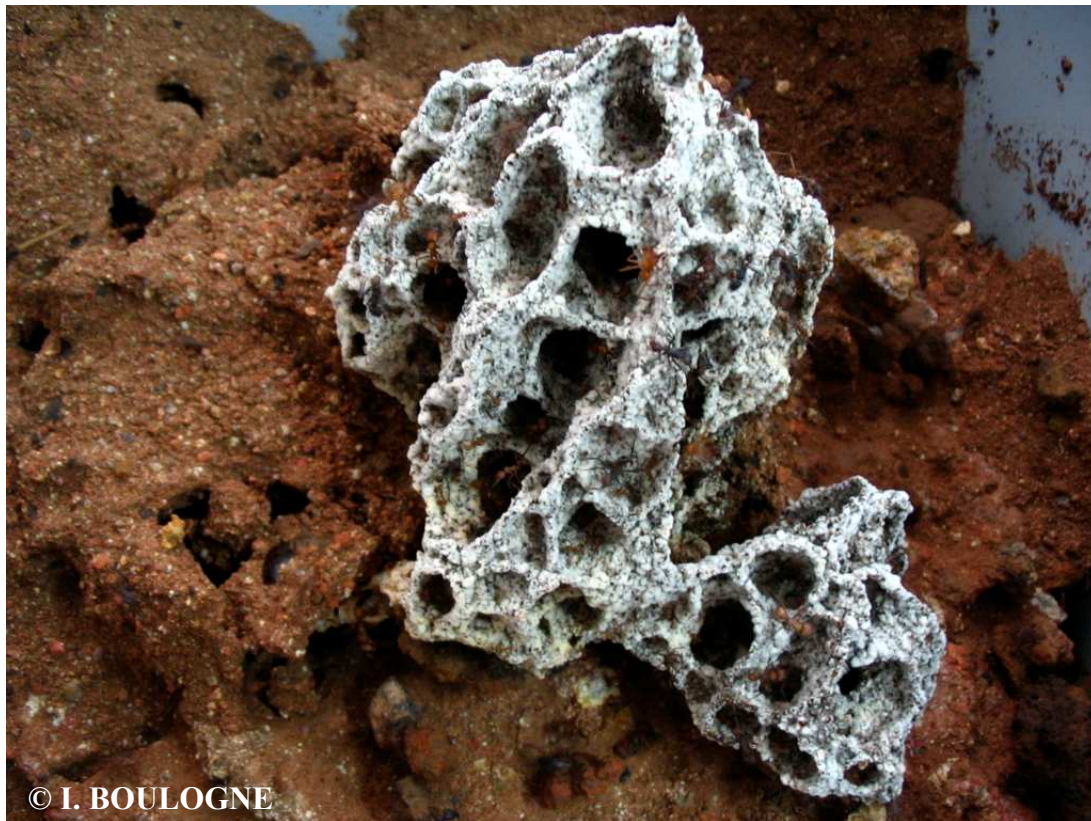
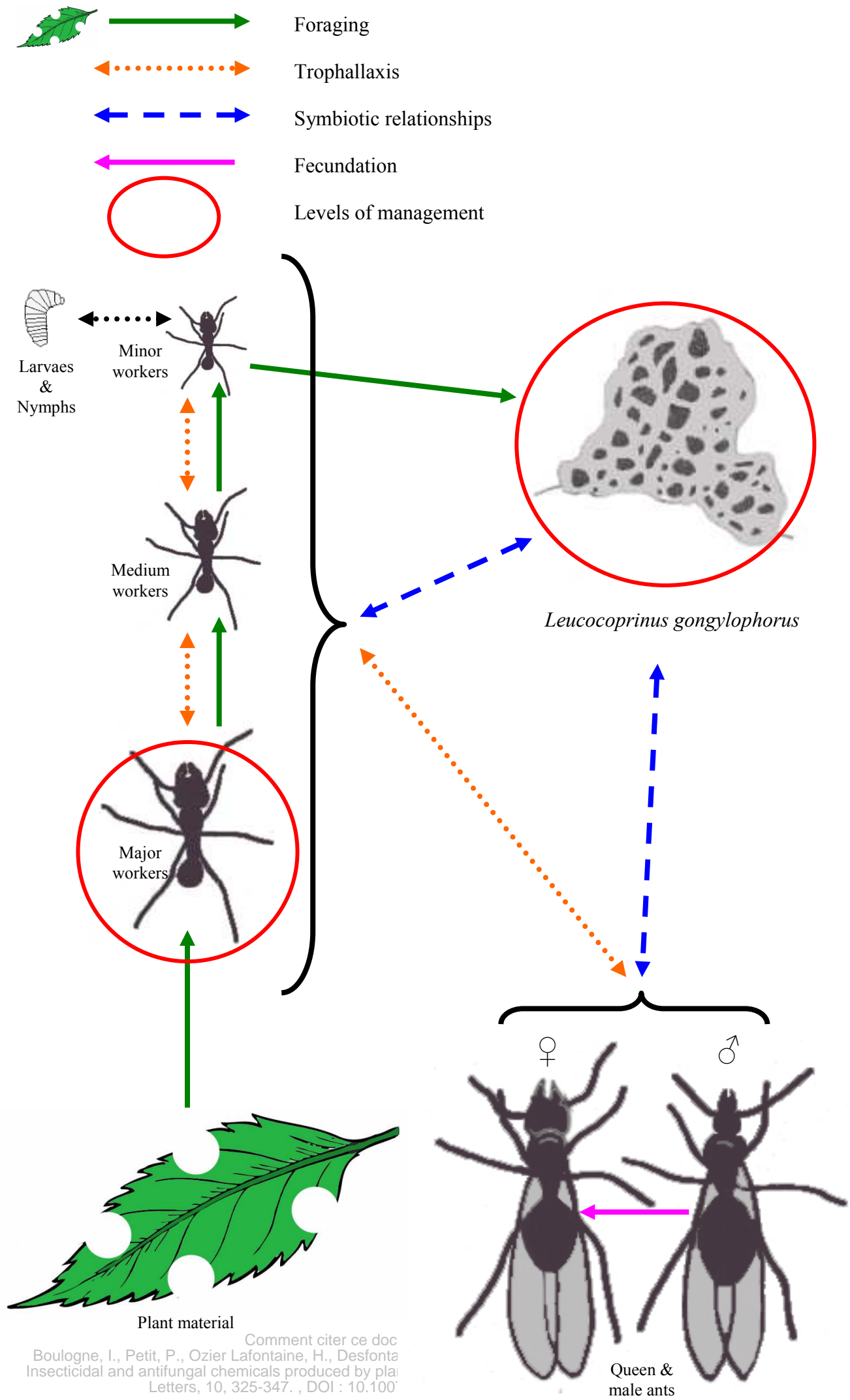


Figure 1 Relationships between ants and symbiotic fungus (*Leucocoprinus gongylophorus*) in leaf-cutting ants (*Acromyrmex* and *Atta*) nests.



Synthetic chemical pesticides have been used worldwide, and some are still recommended, for the control of leaf-cutting ants, with no success in eradication of the pest, but causing irreversible environmental injuries (Antunes et al. 2000). Pesticides against these leaf-cutting ants have essentially focused on the use of insecticides targeted at the major ant workers. Among these pesticides, we can quote perchlordecone, sulfluramid, heptachlor, malathion, chlorpyrifos, sulfluramid and fipronil (Paoletti et al. 2000; Camargo et al. 2006; Forti et al. 2007). Some of them like sulfluramid and fipronil are still frequently and worldwide used despite of their impact on human health and environment.

1.3 Natural pesticides

Many plants produce biologically active metabolites. Some of which are useful as, for example, insecticide agent or insect control agent. Thus, plants constitute a vast untapped reservoir for discovering new active natural products. Applying biopesticides should decrease both pest development and the use of toxic pesticides (Lichtfouse et al. 2009). Natural products are known to be environmentally safe; they can be then a viable alternative to the use of synthetic products that can be harmful toward the environment (Regnault-Roger et al. 2003). Because of their non-phytotoxicity and systemicity as well as biodegradability, plant-derived products can be potent and valuable reagents in pest management (Javaid et al. 2006; Xuan et al. 2006; Ameziane et al. 2007). These phytochemicals are mainly biodegradable and, more importantly, they are renewable. The efficient use of such renewable natural resources is becoming increasingly an important worldwide concern (Kubo 1993) and nowadays, the green and environmental chemistry has an international success (Lichtfouse et al. 2011). Applying these biopesticides should also be an economical strategy for farmer because besides being less pollutant, they are less expensive than synthetic pesticides.

Natural insecticides and fungicides may serve as alternatives to synthetic compounds to develop safer control agents of leaf-cutting ants, as shown by some precedent studies conducted on lignans of Myristicaceae (Pagnocca et al. 1996), ricine of *Ricinus communis* (Bigi et al. 2004), amides of Piperaceae (Pagnocca et al. 2006; De Paula et al. 2000), rotenoids of *Lonchocarpus* sp (Petit 2004) or TRAMIL's plant extracts (Boulogne 2011; Boulogne et al. 2011).

Due to their mutualistic interaction with the symbiotic fungus, management of *Attini* ants may be considered at the insecticidal or at the fungicidal level, individually, or as a combination of both strategies to promote a more efficient integrated control. In the literature, there is a lack of information available on molecules and plants that can be possibly used as general insecticides and fungicides. The aim of this paper was to establish a list of plants and chemicals that can possibly be used for best management of leaf-cutting ants, based on the literature available. Plant species with both insecticidal and antifungal chemicals properties were voluntarily favored here. The present work, which lies within the scope of sustainable development, aim at selecting plants whose chemicals can be potentially used to control leaf-cutting ants that devastate the crops in many tropical areas. This review could also help for management of other groups of insects that utilize fungus-based culture like ambrosia beetles and termites or any insects and fungi pests. It deals with ecological pest control and biopesticides from plants origin.

An exhaustive literature search of 1965 references (from 1923 to 2010) was conducted using scientific databases (Sciencedirect, Springerlink and Wiley), chemical databases (Amicbase 2010; Duke 2010), botanical databases (Tropicos 2010) and books (Duke 1992; Bruneton 1999) to identify published papers related to insecticidal and fungicidal chemical compounds stemmed from plant species. Information was further analyzed to select plant species, plant families and chemicals worthy in pest-management of leaf-cutting ants.

2. Insecticidal Activity

2.1 Chemical Compounds

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So far, 119 chemical compounds have been cited in the literature as to have an insecticidal activity. These chemical compounds were distributed in 11 types (Figure 2). Among these 11 types, 3 were identified as holding strong insecticidal activity: the terpenoids (43 chemical compounds), the alkaloids (38 chemical compounds), and the phenolic compounds (21 chemical compounds) counting for 37, 30, and 20% of the chemicals cited, respectively (Table 1).

Figure 2 Frequency (%) of chemical compounds types in plants with insecticidal activity (data obtained from literature search of 1965 references). Terpenoids, alkaloids and phenolic compounds were the most regularly cited as holding insecticidal activity with respectively 37, 30, and 20% of the chemicals.

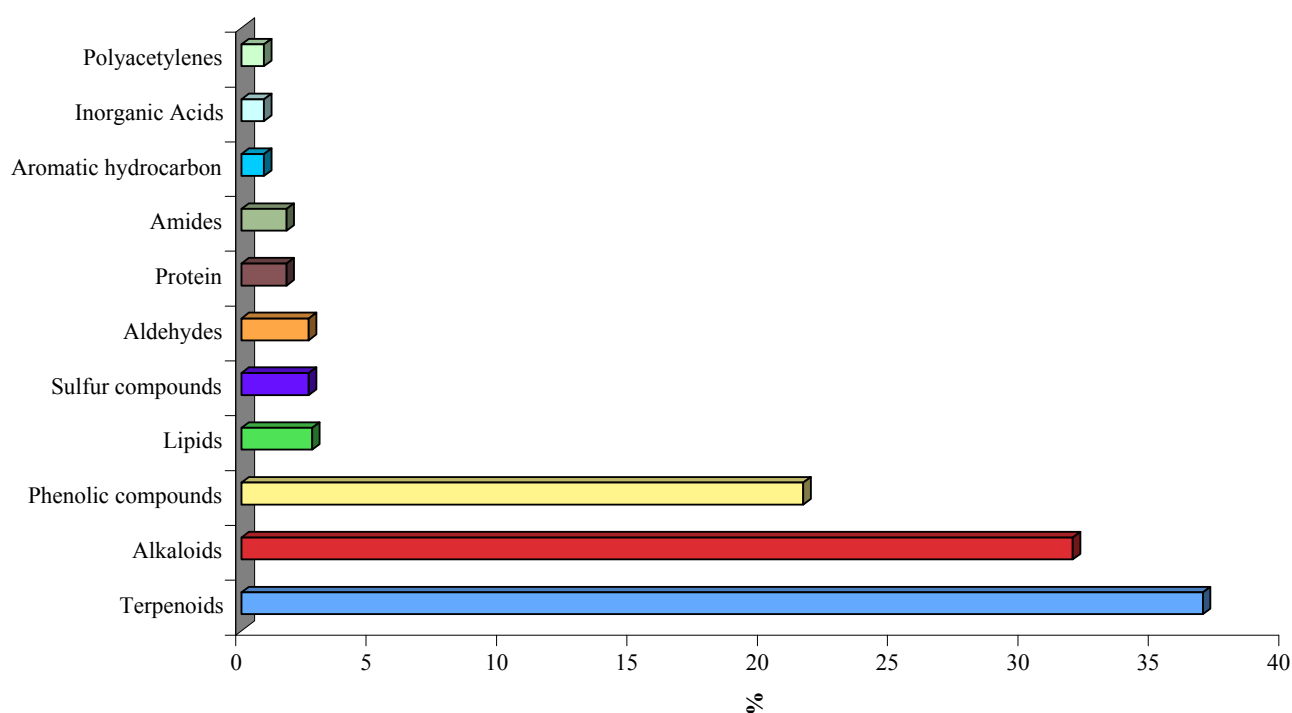


Table 1: Terpenoids, alkaloids and phenolic compounds produced by plants with insecticidal activity (data obtained from literature search of 1965 references).

Terpenoids	Alkaloids	Phenolic compounds
β -amyrine	5-hydroxytryptamine	anethole
β -asarone	aconine	anisaldehyde
α -pinene	aconitine	asarinin
α -terpinene	ajaconine	bergapten
α -terpineol	anabasine	canelline
α -thujone	anonaine	deguelin
10-hydroxy-asimicine	aphylline	deoxypodophyllotoxin
24-methylene-3,22-dihydroxycholesterol	aristolochine	desoxypodophyllotoxin
24-methylenecycloarta-3-ol	atropine	dillapiol
absinthin	benzaconine	elemicin
apiole	caffeine	isopimpinellin
ascaridol	camptothecin	mammein
asimicine	castanospermine	methyl-chavicol
azadirachtin	celabenzine	methyl-cinnamate
bisabolangelone	cevadine	plumbagin

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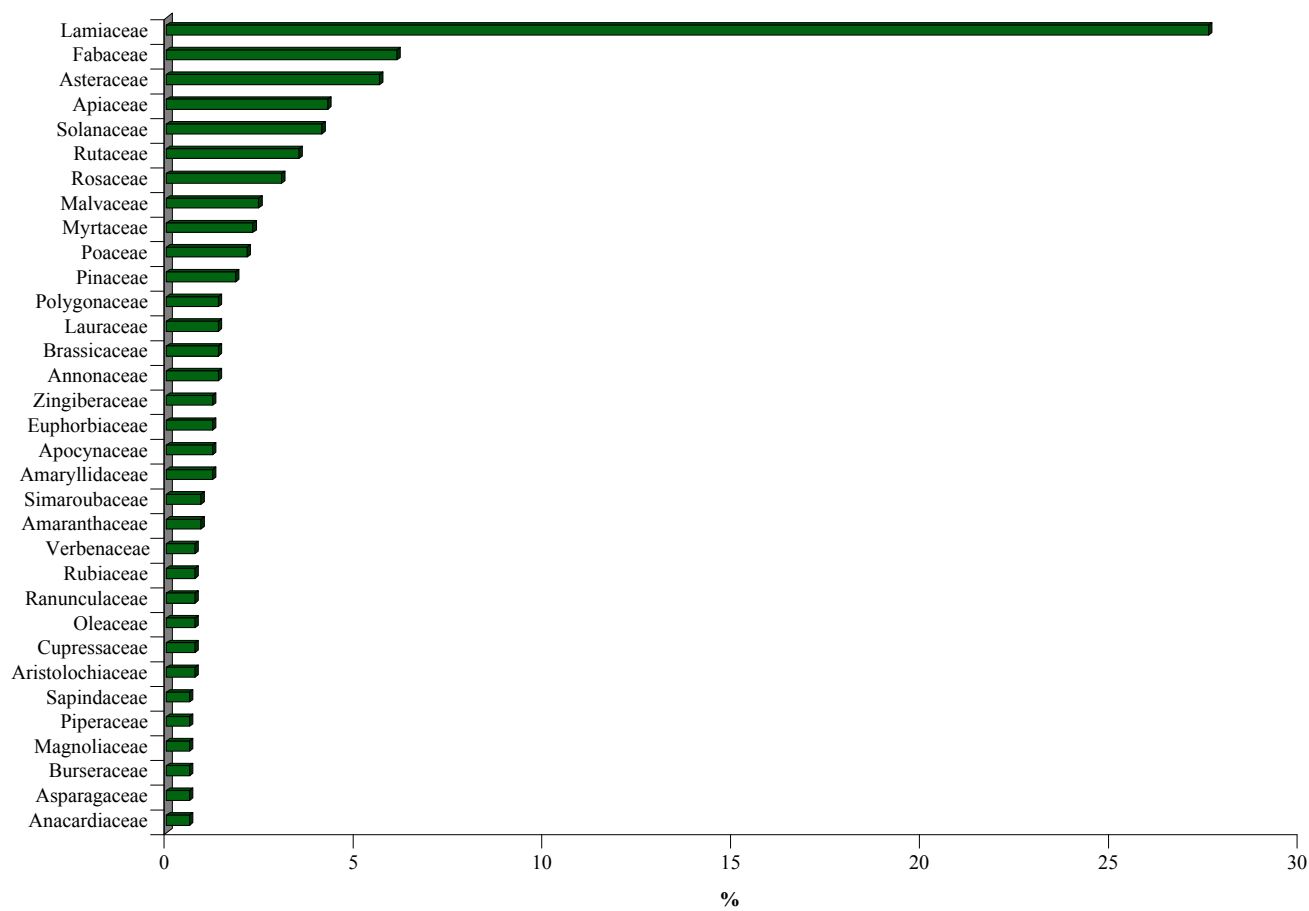
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carvone	ephedrine	podophyllotoxin
carvone	delcosine	sesamin
caryophyllene-oxide	delsoline	psoralen
cinerins	donaxerine	rotenone
cinnamaldehyde	galanthamine	rutin
estragole	gramine	xanthotoxin
eugenol	hypaconitine	
gedunine	jervine	
geranyl-linalool	mesaconitine	
glaucarubinone	myosmine	
helenalin	napelline	
himachalol	neoline	
iridomyrmecin	neopelline	
L-carvone	nicotine	
limonene	physostigmine	
limonene-oxide	piperine	
linalool	ricinine	
menthone	solamargine	
myristicin	solasonine	
neriifolin	sparteine	
ocimene	tomatine	
picrotoxinin	wilfordine	
piperitenone-oxide	wilforine	
pulegone		
quassin		
terpineol		
thymol		
zingiberene		

2.2 Plant Families

Similarly, 656 plant species worldwide, distributed into 110 families, were identified as to have a significant insecticidal activity. The most cited family is the Lamiaceae, with 181 species distributed into 48 genera, counting for 28% of the plant families with an insecticidal activity (Figure 3). Within this family nine genera were the most often cited: *Pycnanthemum*, *Teucrium*, *Thymus*, *Satureja*, *Micromeria*, *Origanum*, *Mentha*, *Monarda*, and *Ocimum*.

Figure 3 Frequency (%) of plant families with insecticidal activity (plants families presented have a frequency over or equal to 1%). The most cited family is the Lamiaceae counting for 28% of the plant families cited.



3. Fungicidal Activity

3.1 Chemical Compounds

From the literature, 284 chemical compounds distributed in 11 types have fungicidal activity. Of these chemical compounds types, three were the most regularly cited: the phenolic compounds (47% of the chemicals cited), the terpenoids (29% of the chemicals cited), and the alkaloids (11% of the chemicals cited) (Figure 4).

123 phenolic compounds, eighty terpenoids and thirty alkaloids with fungicidal activity were mentioned in the literature (Table 2).

Figure 4 Frequency (%) of chemical compounds types with fungicidal activity (data obtained from literature search of 1965 references). Phenolic compounds (47%), terpenoids (29%), and the alkaloids (11%) were the most regularly cited.

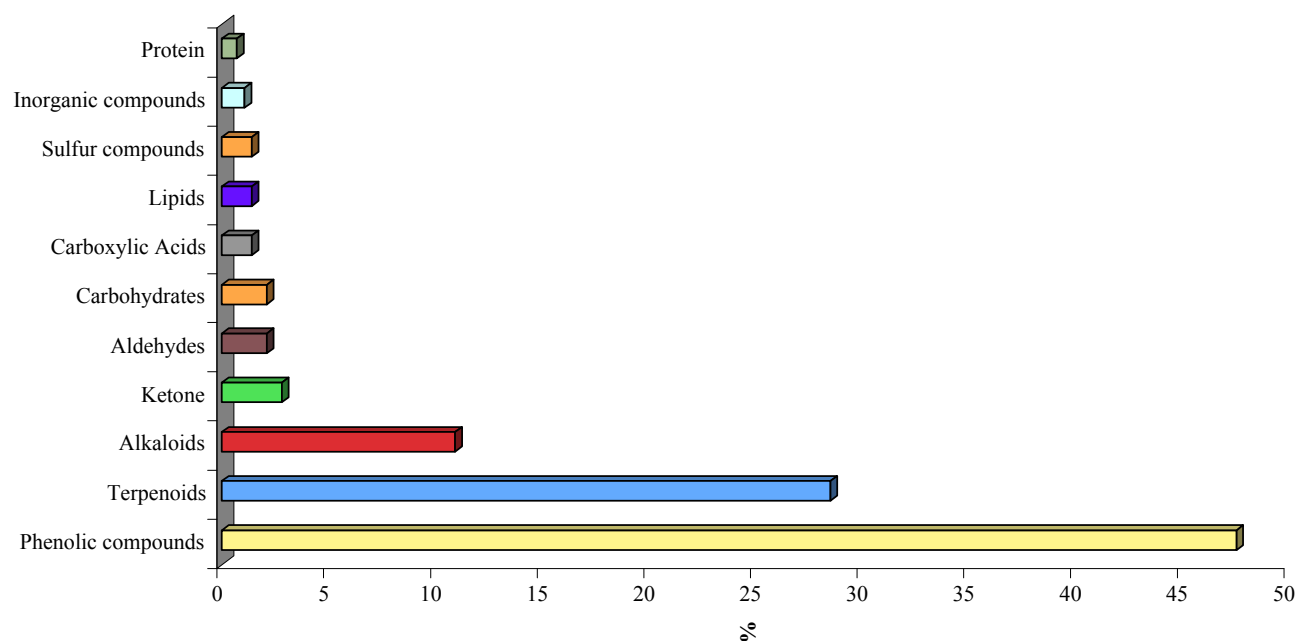


Table 2: Terpenoids, alkaloids and phenolic compounds produced by plants with fungicidal activity (data obtained from literature search of 1965 references)

Phenolic compounds	Terpenoids	Alkaloids
ϵ -viniferin	α -bisabolol	α -chaconine
2,6-dimethoxy-p-benzoquinone	α -hederin	α -solanine
2'-hydroxygenistein	β -ionone	4-methoxybrassinin
5-methoxy-psoralen	α -phellandrene	actinidine
6- α -hydroxymaackiain	β -phellandrene	alstonine
6- α -hydroxymedicarpin	1- tuliposide-B	amphibine
8-methoxy-psoralen	1,8-cineole	anonaine
aloe-emodin	1-tuliposide-A	arecoline
amentoflavone	acetophenone	berberastine
anacardic acid	agropyrene	berberine
anethole	alantolactone	canthin-6-one
anisaldehyde	anemonin	chelerythrine
baicalein	arteannuin-B	dehydroglauicine
benzoic-acid	asarone	dictamnine
biochanin-A	ascaridole	emetine
caffeic-acid	atractylodin	franguloline
cajanin	bayogenin	isoboldine
catechin	borneol	jatrorrhizine
chavicol	butyl-phthalide	liriodenine
chlorogenic acid	camphor	methoxybrassinin
chrysarobin	capsidiol	reticuline
chrysin	carene	rubijervine
chrysophanic acid	carnosol	sanguinarine
chrysophanic-acid-9-anthrone	carvacrol	serpentine

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cinnamic acid	caryophyllene	solamargine
cis-3,5,4'-trihydroxy-4-isopentenylstilbene	caryophyllene-oxide	solanine
cis-resveratrol	casbene	solasodine
coumestrol	cinnamaldehyde	theaflavin
curcumin	cis-ocimene	
cyclokievitone	citral	tomatine
daidzein	citronellal	tryptanthrin
daidzin	citronellol	
demethylvesritol	cnidilide	
dihydropinosylvin	coniferyl-alcohol	
elemicin	convallamarside	
esculetin	cuminaldehyde	
falcarindiol	dehydroisoeugenol	
ferulic acid	epipolygodial	
flavone	escin	
formononetin	eugenol	
furocoumarin	fulvoplumierin	
genistein	gentiopicrin	
genistin	geraniol	
glyceollin-I	glutinosone	
glycitein	gossypol	
herniarin	hardwickic acid	
homogentisic acid	hederagenin	
homopisatin	hederasaponin-C	
honokiol	helenalin	
humulone	isoalantolactone	
hydroxyphaseollin	kawain	
isoliquiritin	linalool	
isomucronulatol	medicagenic-acid	
isopimpinellin	menthone	
isoxanthohumol	methyl-eugenol	
juglone	muzigadial	
kaempferol	myrcene	
kievitone	myristicin	
kuwanon-G	nimbidin	
kuwanon-H	nimbin	
lapachol	paenonol	
lawsone	parthenolide	
licoisoflavone-A	patchouli-alcohol	
liquiritigenin	p-cymene	
liquiritin	perillaldehyde	
lupulone	perillyl-alcohol	
magnolol	pinene	
mangostin	plumericine	
medicagol	pogostone	
medicarpin	protoanemomin	

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methyl-salicylate	pulegone
naringenin	rishitin
nepodin	sclareol
nobiletin	solavetivone
o-coumaric acid	terpinen-4-ol
odoratol	terpinolene
oxypeucedanin	thymol
p-coumaric acid	tuliposide-C
phaseol	vanillin
phaseollidin	withaferin-A
phaseollin	
phenol	
phloroglucinol	
phylloquinone	
piceatannol	
piceid	
pimpinellin	
pinocembrin	
pinostrobin	
pinosylvin	
pisatin	
plumbagin	
p-methoxy-cinnamic acid	
podophyllotoxin	
protocatechuic acid	
prunetin	
prunin	
psoralen	
psoralidin	
pyrogallol	
quercetin	
resorcinol	
resveratrol	
rhein	
sakuranetin	
scopoletin	
seselin	
sinapic acid	
sinensetin	
tangeretin	
taxifolin	
tectorigenin	
tetrahydroxystilbene	
trans-3,5,4'-trihydroxy-4-isopentenylstilbene	
trans-resveratrol	
trichocarpin	

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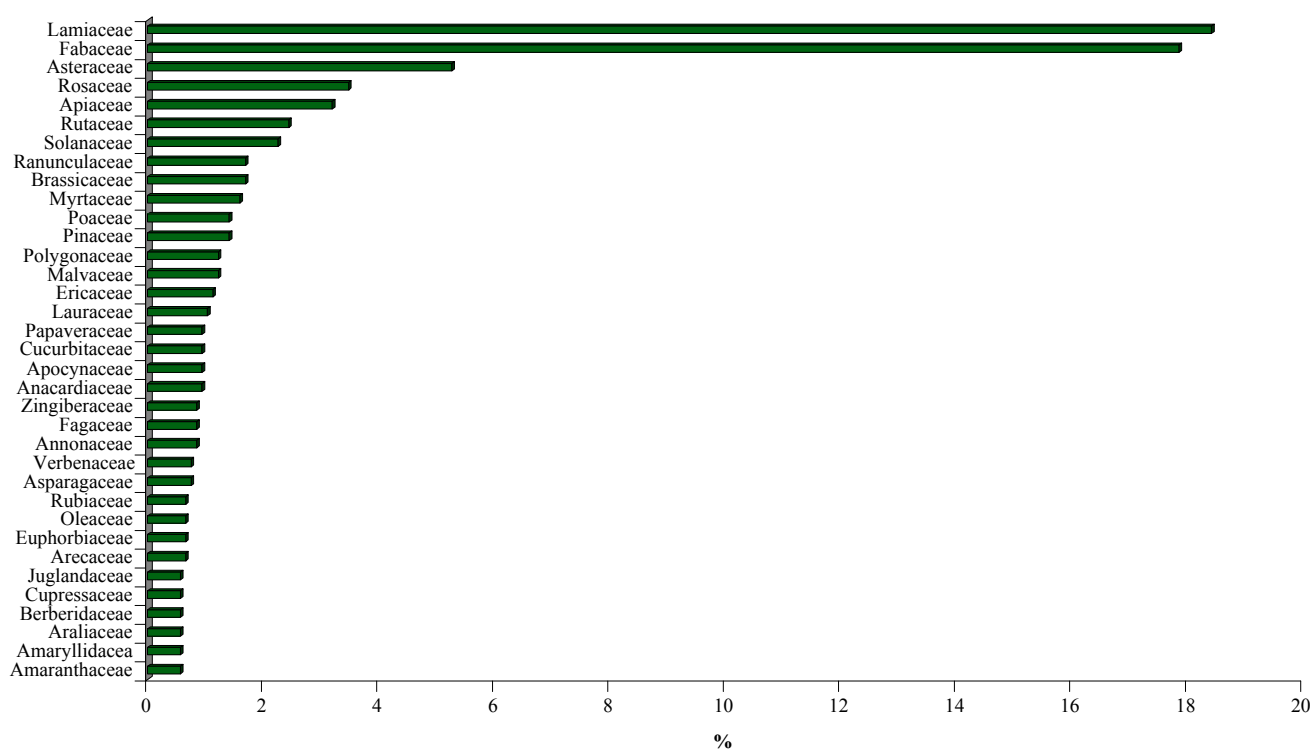
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trifolirhizin
tuberosin
umbelliferone
vanillic acid
verbascoside
xanthohumol
xanthotoxin

3.2 Plant Families

From the literature, 1064 plant species worldwide, distributed into 150 families, have fungicidal activity. The families most often cited are the Lamiaceae and the Fabaceae, representing 19 and 18% of the plant families with a fungicidal activity, respectively (Figure 5). Within the Lamiaceae, 196 species with a fungicidal activity are distributed into 48 genera. Among these genera, 9 were regularly cited: *Teucrium*, *Pycnanthemum*, *Thymus*, *Satureja*, *Origanum*, *Micromeria*, *Mentha*, *Monarda*, and *Ocimum*. Similarly, within the Fabaceae 190 species with a fungicidal activity are distributed into 94 genera. Among of them, 8 were most often cited: *Genista*, *Rhynchosia*, *Canavalia*, *Trifolium*, *Acacia*, *Chamaecytisus*, *Cytisus*, and *Vigna*.

Figure 5 Frequency (%) of plant families with fungicidal activity (plants families presented have a frequency over or equal to 1%). The families most often cited are the Lamiaceae and the Fabaceae, representing respectively 19 and 18% of the plant families.



4. Chemicals and plants species of interest for management of leaf-cutting ants

This literature review pointed out that twenty chemical compounds are of particular interest in the perspective of management of *Attini* ants, as they showed both strong insecticidal and fungicidal activities. Nine of these chemical compounds are from the terpenoid family (caryophyllene oxide, cinnamaldehyde, eugenol, helenalin, linalool, menthone, myristicin, pulegone and thymol), eight from the phenolic family (anethole, anisaldehyde, elemicin, isopimpinellin, plumbagin, podophyllotoxin,

psoralen, and xanthotoxin) and three from the alkaloid family (anonnaine, solamargine, and tomatine) (Table 3, Figure 6).

Table 3: Twenty chemical compounds (phenolics, alkaloids, and terpenoids) produced by plants with both insecticidal and fungicidal activity and that have particular interest in the perspective of management of *Attini* ants. Some insects and fungi tested, methods of extraction and method of identification most cited were also given.

Chemicals	Insects	Fungi	Extraction	Identification
Anethole (Phenolics)	tobacco cutworm, <i>Spodoptera litura</i> (Akhtar and Isman, 2003), <i>Blattella germanica</i> (Chang and Ahn 2002)	<i>Aspergillus parasiticus</i> (Karapinar 1990)	hydro-distillation (Osei-Safo et al. 2010)	gas chromatography–mass spectrometry (GC-MS) (Osei-Safo et al. 2010)
Anisaldehyde (Phenolics)	larvae of <i>Lycoriella ingenua</i> (Park et al. 2006)	blue mould of pear, <i>Penicillium expansum</i> (Neri et al. 2005)	hydro-distillation (Park et al. 2006)	GC-MS (Park et al. 2006)
Anonnaine (Alkaloids)	black bean aphid, chrysanthemum aphid and the aphid <i>Macrosiphum solanifolii</i> (Harper et al, 1947), <i>Callosobruchus chinensis</i> (Kotkar et al. 2002)	<i>Candida</i> spp (Agnihotri et al. 2008)	hexane and MeOH and subjected to column chromatography over silica gel (Simas et al. 2001)	purified by preparative thin-layer chromatography (TLC) (Simas et al. 2001)
Caryophyllene oxide (Terpenoids)	termite <i>Coptotermes formosanus</i> (Cheng et al. 2004)	white-rot fungi : <i>Lenzites betulina</i> , <i>Pycnoporus coccineus</i> , <i>Trametes versicolor</i> and <i>Laetiporus sulphureus</i> (Cheng et al. 2004)	hydro-distillation (Cheng et al. 2004)	GC-MS (Cheng et al. 2004)
Cinnamaldehyde (Terpenoids)	stored product beetle, <i>Callosobruchus maculatus</i> (Hubert et al. 2008; Islam et al. 2009), Formosan subterranean termite, <i>Coptotermes formosanus</i> (Zhu et al. 2001)	<i>Malassezia furfur</i> , <i>Candida albicans</i> (Ferhout et al. 1999)	hydro-distillation (Islam et al. 2009)	GC-MS (Islam et al. 2009)
Elemicin (Phenolics)	Coleopterans (Paneru et al. 1997)	yeasts, dermatophytes and <i>Aspergillus</i> spp (Tavares et al. 2008)	hydro-distillation (Tavares et al. 2008)	GC-MS (Tavares et al. 2008)
Eugenol (Terpenoids)	maize weevil, red flour beetle, grain weevil and larger grain borer (Huang et al. 2002), american cockroach <i>Periplaneta americana</i> (Ngoh et al. 1998)	wood-rot fungi (Basidiomycetes), yeasts belonging to <i>Candida</i> species (Saccharomycetes), <i>Penicillium</i> sp (Ascomycetes) and other dermatophyte fungi (Vasquez et al. 2001; Gayoso et al. 2005; Cheng et al. 2008; Jianhua and Hai, 2001)	methanol (Zhu et al. 2001; Borg-Karlson et al. 2006)	GC-MS (Zhu et al. 2001; Borg-Karlson et al. 2006)
Helenalin (Terpenoids)	vector of Chagas' disease (Maya et al. 2007)	yeasts (Ascomycetes) (Picman 1984)	chloroform (Staneva et al. 2010)	spectrophotometric, RPLC, GC, and GC–MSD and NMR spectroscopy (Staneva et al. 2010)
Isopimpinellin (Phenolics)	African Cotton Leafworm, <i>Spodoptera littoralis</i> (Hadacek et al. 1994)	<i>Cladosporium herbarum</i> , <i>Botrytis cinerea</i> , <i>Alternaria brassicicola</i> , <i>Dreschslera sorkiniana</i> , <i>Alternaria</i> spp. <i>Bipolaris</i> spp. and	petroleum ether-diethyl ether or hexane-diethyl ether-	thin-layer chromatography (TLC) and high-performance liquid and

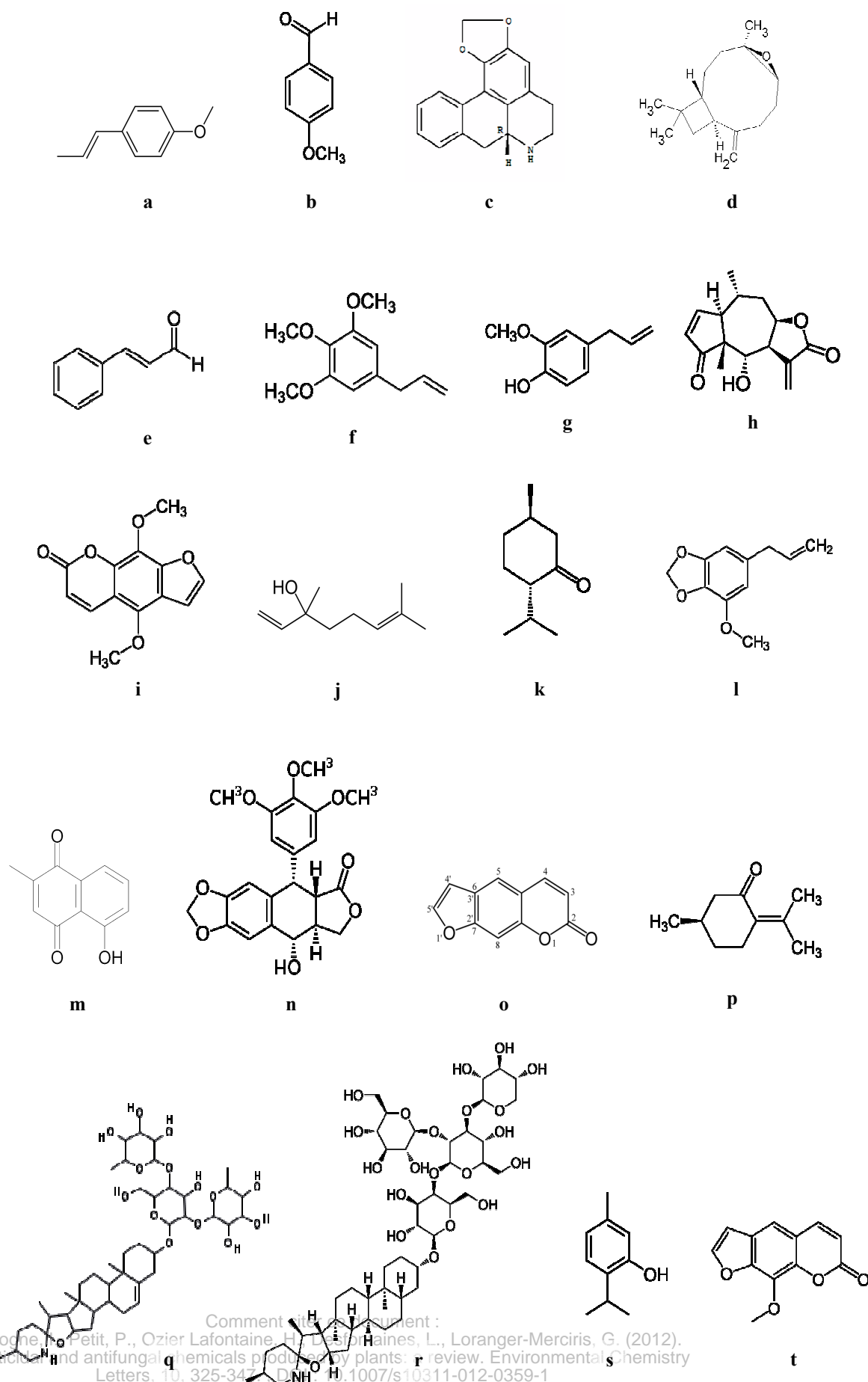
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		<i>Fusarium</i> spp. (Al-Barwani and Eltayeb 2004)	methanol (Hadacek et al. 1994)	chromatography (HPLC) (Hadacek et al. 1994; Al-Barwani and Eltayeb 2004)
Linalool (Terpenoids)	adult coleopteran (Shaaya et al. 1991), mediterranean fruit fly (Salvatore et al. 2004), mosquito <i>Culex pipiens molestus</i> (Traboulsi et al. 2002)	several species of <i>Aspergillus</i> , <i>Cladosporium</i> , <i>Penicillium</i> , <i>Trichoderma</i> , <i>Chaetomium</i> , <i>Paecilomyces</i> and <i>Stachybotrys</i> (Rakotonirainy and Lavedrine 2005)	ethanol (Keszei et al. 2010)	GC-MS (Keszei et al. 2010)
Menthone (Terpenoids)	red flour beetle, <i>Tribolium castaneum</i> , rice weevil, <i>Sitophilus oryzae</i> , sawtoothed grain beetle, <i>Oryzaephilus surinamensis</i> , house fly, <i>Musca domestica</i> and German cockroach, <i>Blattella germanica</i> (Lee et al. 2003)	<i>Fusarium verticillioides</i> (Dambolena et al. 2008), <i>Botrytis</i> spp., <i>Sclerotinia</i> spp. (Martinez-Romero et al. 2008), <i>Botrytis cinerea</i> , <i>Fusarium solani</i> var. <i>coeruleum</i> and <i>Clavibacter michiganensis</i> subsp. <i>michiganensis</i> (Daferera et al. 2003)	hydro-distillation (Daferera et al. 2003)	GC-MS (Lee et al. 2001, Daferera et al. 2003)
Myristicin (Terpenoids)	fly, aphid, beetle, and caterpillar species (Dussourd 2003); coconut leaf beetle, <i>Brontispa longissima</i> (Qin et al. 2010)	soil fungus, <i>Gaeumannomyces graminis</i> (Monsalvez et al. 2010)	hydro-distillation (Monsalvez et al. 2010; Qin et al. 2010)	GC-MS (Monsalvez et al. 2010; Qin et al. 2010)
Plumbagin (Phenolics)	subterranean termite, <i>Odontotermes obesus</i> (Ganapaty et al. 2004; Adfa et al. 2010), larvae of <i>Aedes aegypti</i> (Sreelatha et al. 2010)	<i>Aspergillus fumigatus</i> , <i>Aspergillus flavus</i> , <i>Aspergillus niger</i> , <i>Candida parapsilosis</i> , <i>Candida tropicalis</i> , <i>C. albicans</i> , <i>C. neoformans</i> , <i>T. mentagrophytes</i> , <i>S. schenckii</i> , <i>Trichoderma viride</i> , <i>Microsporium gypseum</i> , <i>Absidia ramosa</i> , <i>Pseudallescheria boydii</i> and <i>Saccharomyces</i> (Mishra et al. 2010)	chloroform (Ganapaty et al. 2004), petroleum ether and ethanol (Mishra et al. 2010)	characterized by its EI mass spectra, H NMR spectra, IR data, and melting point and identified by a search in AntiBase (Ganapaty et al. 2004)
Podophyllotoxin (Phenolics)	vinegar fly <i>Drosophila melanogaster</i> , diamondback moth <i>Plutella xylostella</i> and common house mosquito <i>Culex pipiens pallens</i> , silkworm <i>Bombyx mori</i> and cabbage butterfly <i>Pieris rapae</i> (Di et al. 2010); northern armyworm <i>Mythimna separata</i> (Xu and He 2010); larvae of <i>Pieris rapae</i> (Gao et al. 2004)	<i>Aspergillus niger</i> , <i>Geotrichum flavo-bnmneum</i> , <i>Microsporum canis</i> , <i>Fusarium culmorum</i> , <i>Trichophyton erinacei</i> (Figgitt et al. 1989)	hydro-distillation (Gawde et al. 2009)	HPLC (Gawde et al. 2009)
Psoralen (Phenolics)	beet armyworm <i>Spodoptera exigua</i> (Diawara et al. 1993)	<i>Fusarium oxysporum</i> , <i>Fusarium solani</i> , <i>Penicillium digitatum</i> , <i>Penicillium italicum</i> (Asthana et al. 1993); <i>Alternaria alternata</i> ,	ethanol (Bafi-Yeboa et al. 2005)	HPLC (Bafi-Yeboa et al. 2005)

		<i>Aspergillus fumigatus</i> , <i>Microsporum gypseum</i> , <i>Pseudallescheria boydii</i> , <i>Rhizopus</i> <i>sp.</i> , <i>Trichophyton mentagrophytes</i> , <i>Candida albicans</i> , <i>Cryptococcus</i> <i>neoformans</i> , <i>Wangiella</i> <i>dermatitidis</i> (Bafi-Yeboea et al. 2005)		
Pulegone (Terpenoids)	german cockroach, house fly and storage pests: rice weevil, red flour beetle and sawtoothed grain beetle (Dancewicz et al. 2008); mosquito <i>Aedes aegypti</i> (Waliwitiya et al. 2009)	scab of cucurbit, an Ascomycota (Dancewicz et al. 2008)	hydro-distillation (Vagionas et al. 2007)	GC-MS (Vagionas et al. 2007)
Solamargine (Alkaloids)	mosquitos (Ribeiro et al. 2009); potato aphid, <i>Macrosiphum euphorbiae</i> (Guntner et al. 2000)	Ascomycetes plant pathogenic fungi (Fewell et al. 1994)	methanol and purified by different procedures (Vencl et al. 1999)	purity was verified by high-performance liquid chromatography (HPLC) (Hall et al. 2006)
Tomatine (Alkaloids)	potato aphid, <i>Macrosiphum</i> <i>euphorbiae</i> (Guntner et al. 2000); Colorado potato beetle, <i>Leptinotarsa decemlineata</i> (Mitchell and Harrison 1985); two-striped grasshopper <i>Melanopus bivittatus</i> , tomato fruit-worm <i>Heliothis zea</i> , ichneumonid wasp <i>Hyposoter</i> <i>exiguae</i> , beet armyworm <i>Spodoptera exigua</i> (Bloem et al. 1989); red flour beetle, <i>Tribolium castaneum</i> , rice weevil, <i>Sitophilus oryzae</i> (Nenaah 2010)	<i>Fusarium solani</i> , <i>Nomuraea rileyi</i> (Gallardo et al. 1990); <i>Fusarium</i> <i>oxysporum</i> (Ito et al. 2007)	ethanol (Nenaah 2010)	TLC, NMR and MS (Nenaah 2010)
Thymol (Terpenoids)	house fly, red flour beetle, southern corn rootworm, American cockroach and Formosan subterranean termite (Zhu et al. 2003); mosquito <i>Culex pipiens</i> <i>molestus</i> (Traboulsi et al. 2002)	17 phytopathogenic fungi (Kordali et al. 2008), <i>Penicillium</i> sp (Vasquez et al. 2001) and <i>Candida</i> sp (Braga et al. 2008)	hydro-distillation (Vokou et al. 1998)	GC-MS (Vokou et al. 1998)
Xanthotoxin (Phenolics)	<i>Spodoptera litura</i> , <i>S. exigua</i> , <i>Trichoplusia ni</i> (Akhtar and Isman 2004)	<i>Cladosporium herbarum</i> , <i>Botrytis</i> <i>cinerea</i> , <i>Alternaria brassicicola</i> , <i>Dreschslera sorkiniana</i> , <i>Fusarium</i> spp. and <i>Alternaria</i> spp. (Al- Barwani and Eltayeb 2004)	petroleum ether- diethyl ether or hexane-diethyl ether-methanol (Hadacek et al. 1994)	HPLC (Hadacek et al. 1994)

Figure 6 Twenty chemical compounds produced by plants with insecticidal and fungicidal activities that have particular interest in the perspective of management of *Attini* ants: anethole (a), anisaldehyde (b), anonaine (c), caryophyllene oxide (d), cinnamaldehyde (e), elemicin (f), eugenol (g), helenalin (h), isopimpinellin (i), linalool (j), menthone (k), myristicin (l), plumbagin (m), podophyllotoxin (n), psoralen (o), pulegone (p), solamargine (q), tomatine (r), thymol (s) and xanthotoxin (t).



Because of the co-dependence of leaf-cutting ants and its basidiomycete fungus, it was important to our study to find interesting plant species, which contained chemicals with the both activities. Our literature search displayed 305 worldwide plant species, which contained chemicals with both insecticidal and fungicidal activity; among these plant species, 148 species belong to the Lamiaceae family and 24 species belong to the Apiaceae family. Twenty-one plant species contained from four to seven chemicals compounds with both insecticidal and fungicidal activities. Eleven of these twenty-one species belong to the family of Lamiaceae and six belong to the family of Apiaceae (Table 4).

Table 4 Plant families, plant species and their chemical compounds with both insecticidal and fungicidal activity. In bold, plant which contained from 4 to 7 chemical compounds with both insecticidal and fungicidal activities

Plant Families	Plant species	Chemicals
Acoraceae	<i>Acorus calamus</i> L.	eugenol, elemicin, menthone
Amaranthaceae	<i>Chenopodium album</i> L.	xanthotoxin
Amaryllidaceae	<i>Narcissus tazetta</i> L.	eugenol
	<i>Polianthes tuberosa</i> L.	eugenol
Annonaceae	<i>Annona cherimola</i> Mill.	anonaine
	<i>Annona glabra</i> L.	anonaine
	<i>Annona montana</i> L.	anonaine
	<i>Annona reticulata</i> L.	anonaine
	<i>Annona squamosa</i> L.	anonaine
	<i>Cananga odorata</i> (Lam.) Hook. f. & Thomson	eugenol
	<i>Rollinia mucosa</i> (Jacq.) Baill.	anonaine
Apiaceae	<i>Ammi majus</i> L.	xanthotoxin, isopimpinellin
	<i>Ammi visnaga</i> (L.) Lam.	xanthotoxin, isopimpinellin
	<i>Anethum graveolens</i> L.	eugenol, elemicin, myristicin, anethole
	<i>Angelica archangelica</i> L.	xanthotoxin, psoralen, isopimpinellin
	<i>Angelica dahurica</i> Benth & Hook.	xanthotoxin, psoralen
	<i>Apium graveolens</i> L.	eugenol, thymol, menthone, myristicin, xanthotoxin, psoralen, isopimpinellin
	<i>Carum carvi</i> L.	myristicin
	<i>Coriandrum sativum</i> L.	myristicin, psoralen
	<i>Cuminum cyminum</i> L.	eugenol, caryophyllene oxide, anisaldehyde
	<i>Daucus carota</i> L.	eugenol, elemicin, caryophyllene oxide, myristicin, isopimpinellin, psoralen, xanthotoxin
	<i>Ferula alliacea</i> Boiss.	isopimpinellin
	<i>Ferula assa-foetida</i> L.	isopimpinellin
	<i>Foeniculum vulgare</i> Miller	psoralen, xanthotoxin
	<i>Glehnia littoralis</i> F. Schmidt & Miquel	psoralen, xanthotoxin
	<i>Heracleum laciniatum</i>	isopimpinellin
	<i>Heracleum lanatum</i> Michx.	isopimpinellin
	<i>Levisticum officinale</i> W.D.J. Koch	eugenol, myristicin, psoralen
	<i>Oenanthe aquatica</i> (L.) Poir.	myristicin
	<i>Oenanthe crocata</i> L.	myristicin
	<i>Oenanthe javanica</i> (Blume) DC.	eugenol, myristicin
	<i>Pastinaca sativa</i> L.	myristicin, isopimpinellin, psoralen, xanthotoxin

	<i>Petroselinum crispum</i> (Mill.) Fuss	elemicin, myristicin, isopimpinellin, psoralen, xanthotoxin
	<i>Pimpinella anisum</i> L.	eugenol, myristicin, anisaldehyde
	<i>Trachyspermum ammi</i> (L.) Sprague	thymol
Aristolochiaceae	<i>Asarum canadense</i> L.	elemicin
	<i>Asiasarum heterotropoides</i> (F. Schmidt) F. Maek.	elemicin
Asparagaceae	<i>Hyacinthus orientalis</i> L.	eugenol, cinnamaldehyde
Asteraceae	<i>Achillea millefolium</i> L.	eugenol
	<i>Ageratum conyzoides</i> L.	eugenol, caryophyllene oxide
	<i>Arnica montana</i> L.	helenalin, thymol
	<i>Artemisia annua</i> L.	caryophyllene oxide
	<i>Artemisia capillaris</i> Thunb.	eugenol
	<i>Artemisia dracunculus</i> L.	eugenol, menthone, anethole, anisaldehyde
	<i>Artemisia herba-alba</i> Asso.	thymol
	<i>Cnicus benedictus</i> L.	cinnamaldehyde
	<i>Cynara cardunculus</i> subsp. <i>cardunculus</i> L.	eugenol
	<i>Eupatorium perfoliatum</i> L.	helenalin
	<i>Helianthus annuus</i> L.	eugenol
	<i>Helichrysum angustifolium</i> DC.	eugenol
	<i>Inula helenium</i> L.	helenalin
	<i>Saussurea lappa</i> C. B. Clarke	caryophyllene oxide
Berberidaceae	<i>Podophyllum hexandrum</i> Royle	podophyllotoxin
	<i>Podophyllum peltatum</i> L.	podophyllotoxin
	<i>Podophyllum pleianthum</i> L.	podophyllotoxin
Burseraceae	<i>Boswellia sacra</i> Flueck	anisaldehyde
	<i>Canarium indicum</i> L.	elemicin, anethole
	<i>Commiphora myrrha</i> (T. Nees) Engl.	eugenol, cinnamaldehyde
Cannabaceae	<i>Humulus lupulus</i> L.	eugenol, caryophyllene oxide
Cistaceae	<i>Cistus ladaniferus</i> L.	eugenol
	<i>Juniperus communis</i> L.	caryophyllene oxide
Cucurbitaceae	<i>Citrullus colocynthis</i> (L.) Schrad.	anethole, anisaldehyde
Cupressaceae	<i>Juniperus sabina</i> L.	podophyllotoxin
	<i>Juniperus virginiana</i> L.	elemicin, podophyllotoxin
Droseraceae	<i>Dionaea muscipula</i> E.	plumbagin
Ericaceae	<i>Vaccinium corymbosum</i> L.	eugenol, pulegone, thymol, myristicin
	<i>Vaccinium macrocarpon</i> Aiton	eugenol, anisaldehyde
Euphorbiaceae	<i>Croton eluteria</i> (L.) W. Wright	eugenol
Fabaceae	<i>Acacia farnesiana</i> (L.) Willd.	eugenol, anisaldehyde
	<i>Copaifera</i> spp	caryophyllene oxide
	<i>Glycyrrhiza glabra</i> L.	eugenol, thymol, anethole, xanthotoxin
	<i>Myroxylon balsamum</i> (L.) Harms	eugenol, cinnamaldehyde
	<i>Psoralea corylifolia</i> L.	psoralen
	<i>Tamarindus indica</i> L.	cinnamaldehyde
	<i>Trifolium pratense</i> L.	eugenol
Geraniaceae	<i>Pelargonium graveolens</i> L'Hér.	eugenol, menthone
Ginkgoaceae	<i>Ginkgo biloba</i> L.	thymol
Iridaceae	<i>Iris x germanica</i> L.	eugenol
Juglandaceae	<i>Juglans regia</i> L.	eugenol
Lamiaceae	<i>Acinos alpinus</i> var. <i>meridionalis</i> (Nyman) P. W. Ball	caryophyllene oxide
	<i>Acinos suaveolens</i> G. Don	pulegone, thymol, menthone

<i>Agastache foeniculum</i> (Pursh) Kuntze	anisaldehyde
<i>Agastache pallidiflora</i> (A. Heller) Rydb.	pulegone, menthone
<i>Agastache rugosa</i> (Fischer & C. Meyer) Kuntze	anisaldehyde
<i>Agastache urticifolia</i> (Benth.) Kuntze	pulegone, menthone
<i>Calamintha nepeta</i> (L.) Savi	pulegone, menthone
<i>Calamintha nepeta subsp. glandulosa</i> (Req.) P.W. Ball	eugenol, pulegone, thymol, menthone
<i>Collinsonia canadensis</i> L.	elemicin
<i>Coridothymus capitatus</i> (L.) Rchb. f.	thymol
<i>Cunila origanoides</i> (L.) Britton	thymol
<i>Dracocephalum thymiflorum</i> L.	pulegone, caryophyllene oxide, menthone
<i>Elsholtzia blanda</i> (Benth.) Benth.	eugenol
<i>Elsholtzia eriostachya var. pusilla</i>	caryophyllene oxide
<i>Elsholtzia pilosa</i> (Benth.) Benth.	thymol
<i>Elsholtzia polystachya</i> Benth.	thymol
<i>Galeopsis tetrahit</i> L.	caryophyllene oxide
<i>Hedeoma drummondii</i> Benth.	pulegone, menthone
<i>Hedeoma pulegioides</i> (L.) Pers.	pulegone, menthone
<i>Hyptis suaveolens</i> (L.) Poit.	thymol, caryophyllene oxide
<i>Hyptis verticillata</i> Jacq.	podophyllotoxin
<i>Hyssopus officinalis</i> L.	eugenol, thymol
<i>Isanthus brachiatus</i> (L.) Bsp	caryophyllene oxide
<i>Lavandula angustifolia</i> Miller	caryophyllene oxide, cinnamaldehyde
<i>Lavandula latifolia</i> Medik.	eugenol, caryophyllene oxide, cinnamaldehyde
<i>Lavandula x intermedia</i> Emeric ex Loisel.	eugenol, caryophyllene oxide, cinnamaldehyde
<i>Leonotis leonurus</i> (L.) R. Br.	caryophyllene oxide
<i>Lepechinia calycina</i> Epling	menthone
<i>Lycopus europaeus</i> L.	caryophyllene oxide
<i>Lycopus virginicus</i> L.	pulegone
<i>Melissa officinalis</i> L.	thymol, caryophyllene oxide
<i>Mentha aquatica</i> L.	pulegone, caryophyllene oxide, menthone
<i>Mentha arvensis var. piperascens</i> Malinv. ex Holmes	eugenol, pulegone, menthone, anisaldehyde
<i>Mentha longifolia</i> (L.) Huds.	pulegone, thymol, caryophyllene oxide, menthone
<i>Mentha pulegium</i> L.	eugenol, pulegone, thymol, menthone
<i>Mentha spicata</i> L.	eugenol, pulegone, thymol, menthone
<i>Mentha x piperita</i> L.	eugenol, pulegone, thymol, caryophyllene oxide, menthone, anethole
<i>Mentha x rotundifolia</i> (L.) Huds.	pulegone, menthone
<i>Micromeria congesta</i> Boiss. & Hausskn.	eugenol, pulegone, thymol, menthone
<i>Micromeria croatica</i> (Pers.) Schott	pulegone, caryophyllene oxide, menthone
<i>Micromeria dalmatica</i> Benth.	pulegone
<i>Micromeria fruticosa</i> Druce	pulegone, menthone
<i>Micromeria fruticosa subsp. barbata</i> (Boiss. & Kotschy) P.H. Davis	eugenol, pulegone, thymol, caryophyllene oxide, menthone
<i>Micromeria juliana</i> (L.) Bentham ex Reichb.	pulegone, thymol, menthone
<i>Micromeria myrtifolia</i> Boiss. & Hohen.	eugenol, pulegone, thymol, menthone
<i>Micromeria thymifolia</i> Fritsch	pulegone, caryophyllene oxide, menthone
<i>Minthostachys mollis</i> (Kunth) Griseb.	pulegone, menthone

<i>Moldavica thymiflora</i> (L.) Rydb.	pulegone, caryophyllene oxide, menthone
<i>Monarda citriodora</i> Cerv. ex Lag.	thymol
<i>Monarda clinopodia</i> L.	pulegone
<i>Monarda didyma</i> L.	pulegone, thymol
<i>Monarda fistulosa</i> L.	pulegone, thymol
<i>Monarda media</i> Willd.	thymol
<i>Monarda punctata</i> L.	pulegone, thymol
<i>Monarda russeliana</i> Nutt. ex Sims	pulegone, thymol
<i>Nepeta cataria</i> L.	pulegone, thymol, caryophyllene oxide
<i>Nepeta racemosa</i> Lam.	pulegone, thymol
<i>Ocimum basilicum</i> L.	eugenol, thymol, caryophyllene oxide, menthone
<i>Ocimum canum</i> Sims	eugenol
<i>Ocimum gratissimum</i> L.	eugenol, thymol
<i>Ocimum kilimandscharicum</i> Baker ex Gürke	eugenol
<i>Ocimum sanctum</i> L.	eugenol
<i>Ocimum suave</i> Willd.	eugenol
<i>Ocimum tenuiflorum</i> L.	caryophyllene oxide
<i>Origanum majorana</i> L.	eugenol
<i>Origanum minutiflorum</i> O. Schwarz & P.H. Davis	eugenol, thymol
<i>Origanum onites</i> L.	eugenol, thymol, caryophyllene oxide
<i>Origanum sipyleum</i> L.	linalool, thymol
<i>Origanum syriacum</i> L.	thymol, caryophyllene oxide
<i>Origanum vulgare</i> L.	eugenol, thymol, caryophyllene oxide
<i>Origanum vulgare subsp. hirtum</i> Letsw.	thymol
<i>Origanum vulgare var. hirtum</i> (Schur) Soó	thymol
<i>Origanum vulgare var. viride</i> Boiss.	thymol
<i>Perilla frutescens</i> (L.) Britton	elemicin, myristicin eugenol, caryophyllene oxide, cinnamaldehyde
<i>Pogostemon cablin</i> (Blanco) Benth.	
<i>Pycnanthemum albescens</i> Torr. & A. Gray	pulegone, menthone
<i>Pycnanthemum beadleii</i> (Small) Fernald	pulegone, menthone
<i>Pycnanthemum californicum</i> Torr. ex Durand	pulegone, menthone
<i>Pycnanthemum clinopodioides</i> Torr. & A. Gray	pulegone, menthone
<i>Pycnanthemum incanum</i> (L.) Michx.	pulegone, menthone
<i>Pycnanthemum loomisii</i> Nutt.	pulegone, caryophyllene oxide
<i>Pycnanthemum montanum</i> Michx.	pulegone, menthone
<i>Pycnanthemum muticum</i> (Michx.) Pers.	pulegone, menthone
<i>Pycnanthemum nudum</i> Nutt.	thymol
<i>Pycnanthemum pilosum</i> Nutt.	pulegone, menthone, anisaldehyde
<i>Pycnanthemum pycnanthemoides</i> (Leavenw.) Fernald	pulegone, menthone
<i>Pycnanthemum setosum</i> Nutt.	eugenol, pulegone, menthone
<i>Pycnanthemum tenuifolium</i> Schrad.	pulegone, caryophyllene oxide, menthone
<i>Pycnanthemum torreyi</i> Benth.	pulegone, menthone
<i>Pycnanthemum verticillatum</i> (Michx.) Pers.	pulegone, menthone
<i>Pycnanthemum virginianum</i> (L.) Durand & Jackson	pulegone, thymol, menthone
<i>Rosmarinus eriocalyx</i> Jordan & Fourr.	caryophyllene oxide
<i>Rosmarinus officinalis</i> L.	thymol, caryophyllene oxide
<i>Rosmarinus tomentosus</i> Huber	caryophyllene oxide
<i>Rosmarinus x lavandulaceus</i> De Noe	caryophyllene oxide

<i>Rosmarinus x mendizabalii</i> Sagredo Ex Rosua	caryophyllene oxide
<i>Salvia canariensis</i> L.	thymol, caryophyllene oxide
<i>Salvia dorisiana</i> Standl.	caryophyllene oxide
<i>Salvia gilliesii</i> Benth.	caryophyllene oxide
<i>Salvia officinalis</i> L.	thymol, caryophyllene oxide
<i>Salvia sclarea</i> L.	caryophyllene oxide
<i>Satureja cilicica</i> P.H. Davis	pulegone, thymol
<i>Satureja cuneifolia</i> Ten.	thymol
<i>Satureja douglasii</i> (Benth.) Briq.	pulegone, thymol, menthone
<i>Satureja glabella</i> (Michx.) Briq.	pulegone, menthone
<i>Satureja grandiflora</i> (L.) Scheele	pulegone, menthone
<i>Satureja hortensis</i> L.	thymol
<i>Satureja montana</i> L.	thymol, caryophyllene oxide
<i>Satureja obovata</i> Lag.	thymol, caryophyllene oxide
<i>Satureja odora</i> (Griseb.) Epling	pulegone
<i>Satureja parvifolia</i> (Phil.) Epling	pulegone, menthone
<i>Satureja subspicata</i> subsp. <i>liburnica</i> Silic	thymol
<i>Satureja thymbra</i> L.	thymol
<i>Scutellaria churchilliana</i> Fernald	caryophyllene oxide
<i>Scutellaria galericulata</i> L.	menthone
<i>Scutellaria parvula</i> Michx.	caryophyllene oxide
<i>Sideritis athoa</i> Papanicolaou & Kokkini	thymol
<i>Sideritis scardica</i> Griseb.	thymol, anethole
<i>Teucrium arduini</i> L.	caryophyllene oxide
<i>Teucrium asiaticum</i> L.	thymol
<i>Teucrium cyprium</i> Boiss.	thymol, caryophyllene oxide, anethole
<i>Teucrium divaricatum</i> var. <i>canescens</i> (Čelak.) Holmboe	thymol, caryophyllene oxide, anethole
<i>Teucrium gnaphalodes</i> L'Hér.	thymol
<i>Teucrium kotschyianum</i> Poech	thymol, caryophyllene oxide, anethole
<i>Teucrium micropodioides</i> Rouy	thymol, caryophyllene oxide, anethole
<i>Teucrium oxylepis</i> f. <i>marianum</i> Ruiz Torre & Ruiz Cast.	thymol
<i>Teucrium oxylepis</i> subsp. <i>oxylepis</i> Font Quer	thymol
<i>Teucrium polium</i> L.	pulegone
<i>Teucrium valentinum</i> Schreb.	thymol
<i>Teucrium pseudoscorodonia</i> Desf.	thymol
<i>Teucrium salviastrum</i> Schreb.	thymol
<i>Teucrium scorodonia</i> L.	thymol
<i>Thymus broussonettii</i> Boiss.	thymol
<i>Thymus capitatus</i> (L.) Hoffmanns. & Link	eugenol, thymol, caryophyllene oxide
<i>Thymus cilicicus</i> Boiss. & Balansa	eugenol, caryophyllene oxide
<i>Thymus funkii</i> Coss.	eugenol, linalool, thymol
<i>Thymus longicaulis</i> C. Presl	thymol, caryophyllene oxide
<i>Thymus mastichina</i> L.	thymol, caryophyllene oxide
<i>Thymus orospedanus</i> Huguét del Villar	thymol
<i>Thymus riatarum</i> Humbert & Maire	thymol, caryophyllene oxide
<i>Thymus saturejoides</i> Coss.	thymol
<i>Thymus serpyllum</i> L.	thymol
<i>Thymus vulgaris</i> L.	eugenol, thymol, menthone, anethole
<i>Thymus x citriodorus</i> Schreb.	thymol
<i>Thymus zygis</i> L.	thymol

	<i>Thymus zygis</i> subsp. <i>sylvestris</i> Brot. ex Cout.	thymol
	<i>Trichostemma dichotomum</i> L.	caryophyllene oxide
	<i>Vitex agnus-castus</i> L.	caryophyllene oxide
Lauraceae	<i>Cinnamomum aromaticum</i> Nees	eugenol, cinnamaldehyde
	<i>Cinnamomum camphora</i> (L.) J. Presl	eugenol eugenol, caryophyllene oxide,
	<i>Cinnamomum verum</i> J. Presl	cinnamaldehyde
	<i>Laurus nobilis</i> L.	eugenol, elemicin, caryophyllene oxide
	<i>Litsea glaucescens</i> var. <i>glaucescens</i>	caryophyllene oxide
	<i>Persea americana</i> Miller	anethole
	<i>Sassafras albidum</i> (Nutt.) Nees	eugenol, elemicin, myristicin, anethole
	<i>Umbellularia californica</i> (Hook. & Arn.) Nutt.	eugenol, thymol
Magnoliaceae	<i>Magnolia denudata</i> Desr.	caryophyllene oxide
	<i>Magnolia kobus</i> DC.	eugenol, anethole
	<i>Magnolia officinalis</i> Rehder & E.H. Wilson	anonaine
Malvaceae	<i>Hibiscus sabdariffa</i> L.	anisaldehyde
	<i>Tilia</i> sp.	eugenol
Meliaceae	<i>Melia azedarach</i> L.	eugenol
Menispermaceae	<i>Jateorhiza palmata</i> (Lam.) Miers	thymol
Monimiaceae	<i>Peumus boldus</i> Molina	eugenol
Moraceae	<i>Ficus carica</i> L.	psoralen, xanthotoxin
	<i>Morus alba</i> L.	eugenol
Myristicaceae	<i>Myristica fragrans</i> Houtt.	eugenol, elemicin, myristicin
Myrtaceae	<i>Eucalyptus citriodora</i> Hook.	eugenol
	<i>Melaleuca bracteata</i> F. Muell.	eugenol, cinnamaldehyde
	<i>Melaleuca viridiflora</i> Sol. ex Gaertn.	eugenol
	<i>Myrtus communis</i> L.	caryophyllene oxide eugenol, cinnamaldehyde, caryophyllene oxide
	<i>Pimenta dioica</i> (L.) Merr.	eugenol
	<i>Pimenta racemosa</i> (Mill.) J.W. Moore	eugenol
	<i>Psidium guajava</i> L.	caryophyllene oxide eugenol, caryophyllene oxide,
	<i>Syzygium aromaticum</i> (L.) Merr. & L.M. Perry	cinnamaldehyde
Nelumbonaceae	<i>Nelumbo nucifera</i> L.	anonaine
Oleaceae	<i>Jasminum officinale</i> L.	eugenol
	<i>Ligustrum japonicum</i> Thunb.	eugenol
	<i>Syringa vulgaris</i> L.	elemicin, anisaldehyde
Orchidaceae	<i>Vanilla planifolia</i> Andrews.	eugenol, anisaldehyde
	<i>Vanilla tahitensis</i> J.W. Moore	anisaldehyde
Passifloraceae	<i>Turnera diffusa</i> Willd. ex Schult.	thymol
Pinaceae	<i>Pinus mugo</i> Turra	anisaldehyde
	<i>Pinus sylvestris</i> L.	anisaldehyde
Piperaceae	<i>Piper betle</i> L.	eugenol
	<i>Piper nigrum</i> L.	eugenol, caryophyllene oxide, myristicin
Poaceae	<i>Cymbopogon winterianus</i> Jowitt ex Bor	eugenol
	<i>Zea mays</i> L.	eugenol, thymol, xanthotoxin
Rosaceae	<i>Prunus cerasus</i> L.	eugenol
	<i>Prunus dulcis</i> (Mill.) D.A. Webb	eugenol
	<i>Rosa centifolia</i> L.	eugenol
	<i>Rosa damascena</i> Mill.	eugenol, cinnamaldehyde

	<i>Rosa gallica</i> L.	eugenol
Rubiaceae	<i>Coffea arabica</i> L.	eugenol
Rutaceae	<i>Aegle marmelos</i> Correa	psoralen
	<i>Agathosma betulina</i> (P.J. Bergius) Pillans	pulegone
	<i>Barosma betulina</i> Bartl. & H.L. Wendl.	pulegone
	<i>Boronia megastigma</i> Nees ex Bartl.	eugenol
	<i>Casimiroa edulis</i> Llave & Lex.	isopimpinellin
	<i>Citrus aurantiifolia</i> (Christm.) Swingle	isopimpinellin
	<i>Citrus aurantium</i> L.	thymol
	<i>Citrus limon</i> (L.) Osbeck	thymol, caryophyllene oxide, isopimpinellin
	<i>Citrus reticulata</i> Blanco	thymol
	<i>Dictamnus albus</i> L.	psoralen, xanthotoxin
	<i>Limonia acidissima</i> L.	isopimpinellin, psoralen
	<i>Ruta graveolens</i> L.	isopimpinellin, psoralen, xanthotoxin
	<i>Skimmia arborescens</i> T. Anderson Ex Gamble	isopimpinellin
Santalaceae	<i>Santalum album</i> L.	eugenol
Schisandraceae	<i>Illicium verum</i> Hook. f.	anisaldehyde
Solanaceae	<i>Capsicum annuum</i> L.	eugenol, pulegone
	<i>Capsicum frutescens</i> L.	pulegone
	<i>Lycopersicon esculentum</i> Mill.	eugenol, cinnamaldehyde, tomatine
	<i>Nicotiana tabacum</i> L.	eugenol
	<i>Solanum carolinense</i> L.	solamargine
	<i>Solanum dulcamara</i> L.	solamargine
	<i>Solanum melongena</i> L.	solamargine
	<i>Solanum nigrum</i> L.	solamargine
Theaceae	<i>Camellia sinensis</i> (L.) Kuntze	eugenol, thymol
Verbenaceae	<i>Aloysia citriodora</i> Palau	caryophyllene oxide
	<i>Lantana camara</i> L.	eugenol
	<i>Lippia graveolens</i> Kunth	thymol
Violaceae	<i>Viola odorata</i> L.	eugenol
Winteraceae	<i>Drimys winteri</i> J.R. Forst. & G. Forst.	eugenol
Zingiberaceae	<i>Alpinia galanga</i> (L.) Willd.	eugenol, caryophyllene oxide
	<i>Alpinia officinarum</i> Hance	eugenol
	<i>Curcuma longa</i> L.	eugenol

Chemical compounds of the Lamiaceae family appear to be the most promising for management of leaf cutting ants (Figures 3 and 5). Indeed, several authors cited this family as one of the dominant families among aromatic plants with antifungal and insecticidal activities (Vokou et al. 1998; Kokkini et al 1988; González et al. 2011). The specific advantages of these plants are their secondary metabolites, such as terpenoids and phenolics, which are known to have strong plant chemical defense activity against insects, bacteria and fungi (Karamanoli et al. 2000). Other studies revealed that species of the Apiaceae family possess chemical compounds with diverse biological activities such as apoptosis inducers, antibacterial, antifungal, phytotoxic activity, and cyclooxygenase inhibitory (Meepagala et al. 2005) that may potentially be used for pest management.

Phenolic compounds can be divided into simple phenols, phenolic acids, quinones, flavones, flavonoids, flavonols, tannins and coumarins (Murphy Cowan 1999). The sites and number of hydroxyl groups on the phenolic compounds are thought to be related to their relative toxicity to fungi (Geissman 1963). Terpenoids occur as diterpenes, triterpenes, tetraterpenes, hemiterpenes and sesquiterpenes (Murphy Cowan 1999). Their mechanism of action against fungi is speculated to involve membrane disruption by the lipophilic compounds (Mendoza et al. 1997). Alkaloids are heterocyclic nitrogen compounds. Their antimicrobial mechanism of action is attributed to their ability to intercalate with DNA (Phillipson and O'Neil 1987).

Phytochemicals from plants include substances that are potentially useful as insect control. While synthetic insecticides have neurotoxic mode of action and promoted the rapid development of cross-resistance in insect population; phytochemical insecticides have emphasized non-neurotoxic modes-of-action such as antifeedant action, inhibition of molting, growth reduction, loss of fecundity, respiratory inhibition, etc. Standardized plant extracts containing a mixture of active phytochemicals should reduce the rate of evolution of conventional resistance compared to the selection pressure exerted by single pure toxin (Arnason et al. 1993). Studies, on relationships between chemicals structure and activity in phytochemical compounds, revealed that one important factor of insecticidal activities is related to the number of hydroxyl functions available compared to the degree of polymerization of the molecule (Regnault-Roger et al. 2003).

A choice must also be made for extraction type and solvent used. The choice would be influenced most by the degradability of total plant extract obtained. Water seems to be the best solvent. All the molecules with hydroxyl or glycosylated functions were water-soluble. Alkaloids were also miscible in aqueous solvents, but which have acid pH. Being naturally evolved ingredients such as plants and water have at least an advantage over synthetic molecules in term of ecological suitability. Their development as successful pest control products can also be economically feasible, especially if the source materials and solvent are available in abundance or with lower price (e.g., common plants with a wide distribution and water which is the least expensive extraction solvent).

Among methods for controlling *Attini* ants, the use of toxic baits is probably the most efficient. These baits should contain an active ingredient used on adult ant workers (Camargo et al. 2006). Thus, with our perspective to find efficient natural method to control leaf-cutting ants, the ingestion baits containing water plant extracts with an effective fungicidal and insecticidal action could be tested and then used.

5. Conclusion

In this study based on exhaustive literature review, we have identified twenty chemical compounds and seventeen plant species from the Lamiaceae and Apiaceae families with potential to achieve efficient pest management of leaf cutting ants. These seventeen species include four to seven chemical compounds with both insecticidal and fungicidal activities. Further biological bioassays will be conducted to evaluate the experimental effect of extracts from the plant species extracts identified from this review on *Attini* ants and their symbiotic fungus.

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