# Essential oils isolated from Myrtaceae family as natural insecticides

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**ABSTRACT (ARIAL, BOLD, 11 FONT, LEFT ALIGNED, CAPS)**

An interest in natural products from plants has been increased due to the disruption of natural biological control systems, undesirable effects on non-target organisms, environmental hazards, and the development of resistance to synthetic insecticides, which are applied in order to reduce the populations of insects. Essential oils (EOs) from plants may be an alternative source of insect control agents, since they constitute a rich source of bioactive compounds that are biodegradable into nontoxic products and potentially suitable for use in integrated management programs. These materials may be applied to food crops shortly before harvest without leaving excessive residues. Furthermore, medically safe of these plant derivatives has emphasized also. For these reasons, much effort has been focused on plant EOs and their constituents as potential sources of insect control agents. In this context, Myrtaceae family would rank among the most important families of plants. In the last few years more and more studies on the insecticidal properties of EOs from Myrtaceae family have been published and it seemed worthwhile to compile them. Therefore, the subject matter of this paper lies on the insecticidal effects of EOs from Myrtaceae and their compounds in insect pest's control. Natural essences of Myrtaceae plants owe its insecticidal action to the presence in its composition of terpenic derivatives such as 1.8-cineole, limonene, linalool, myrcene, terpineol, thymol and α-pinene, which have introduced as potential insecticides. These review indicated that pesticides based on Myrtaceae essential oils could be used in a variety of ways to control a large number of insect pests.

*Keywords: Myrtaceae family; essential oils; chemical constituents; natural insecticides*

## 1. INTRODUCTION

Nowadays control of insect pests is primarily dependent upon synthetic insecticides such as organophosphates, carbamates, pyrethroids and neonicotinoids. Controlling pests is not an easy task although synthetic chemicals are apparently available for use. Although synthetic organic chemicals have been used as an effective means of insect pest control for many years, their repeated use for decades has disrupted biological control by natural enemies and led to outbreak of insect species, undesirable effects on non-target organisms. These insecticides are often associated with residues that are dangerous for the consumer and the environment and at certain doses are toxic to humans and other animals, and some insecticides are suspected to be carcinogens [1,2]. The number of insect species with confirmed resistance to synthetic pesticides has continued to rise, apart from the risks associated with the use of these chemicals [3,4]. Moreover, it has been estimated that about 2.5 million tonnes of pesticides are used on crops each year and the world wide damage caused by pesticides reaches $100 billion annually [5]. Furthermore, for the possibility of producing quality foodstuffs, it is necessary, among other things, to reduce the risks

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associated with excessive application of high pesticide doses in primary agricultural production. The current trend is the search for and use of alternative methods to manage pests, which, in the economic context, are effective without presenting the risks associated with the use of conventional pesticides.

Plants have acquired effective defense mechanisms that ensure their survival under adverse environmental factors. In addition to morphological mechanisms, plants have also developed chemical defense mechanisms towards organisms such as insects that affect biochemical and physiological functions [7]. The use of botanical pesticides to protect plants from pests is very promising because of several distinct advantages. Pesticidal plants are generally much safer than conventionally used synthetic pesticides. Pesticidal plants have been in nature as its component for millions of years without any ill or adverse effect on the ecosystem. In addition, plant-based pesticides are renewable in nature and cheaper. Also, some plants have more than one chemical as an active principle responsible for their biological properties. Phytochemicals degrade rapidly, are unlikely to persist in soil and leach into groundwater, often have a reduced impact on non-target populations and are important components of integrated pest management systems used by organic farmers. Many botanicals may be applied to food crops shortly before harvest without leaving excessive residues. For these reasons, researchers in pest control have recently concentrated their efforts on the search for active natural products from plants as alternatives to conventional insecticides [7,8].

Among natural products certain highly volatile essential oils (Eos) currently used in the food, perfume, cosmetic and pharmaceutical and agricultural industries show promise for controlling insect peats, particularly in confined environments such as greenhouses or granaries. It has been suggested that EOs are less hazardous than synthetic compounds and rapidly degraded in the environment [7]. EOs are defined as any volatile oil(s) that have strong aromatic components and that give distinctive odour, flavor or scent to a plant. These are the by-products of plant metabolism and are commonly referred to as volatile plant secondary metabolites [9]. In general, they are complex mixtures of organic compounds that give characteristic odour and flavour to leaves, flowers, fruits, seeds, barks and rhizomes. Their components and quality vary with geographical distribution, harvesting time, growing conditions and method of extraction [10]. Because of this, much effort has been focused on plant EOs as potential sources of commercial insect control agents [8]. EOs from more than 13 plant families used in this type of research are obtained from different parts (leaves, stems, flowers, etc) of plant either by distillation or other extraction methods. These EOs contain a variety of chemicals which are, known to aid the plants' defense mechanisms against plant enemies [11]. The interest in EOs has regained momentum during the last decade, primarily due to their fumigant and contact insecticidal activities and the less stringent regulatory approval mechanisms for their exploration due to long history of use. It is primarily because EOs are easily extractable, ecofriendly being biodegradable and get easily catabolized in the environment, do not persist in soil and water and play an important role in plant protection against pests [12,7].

Among the families of plants investigated to date, one of showing enormous potential is Myrtaceae family. Myrtaceae, the myrtle family, placed within the order Myrtales comprises at least 133 genera and 3,800 species of woody shrubs to tall trees. It has centers of diversity in Australia, Southeast Asia, and tropical to southern temperate America, but has little representation in Africa. The family is distinguished by a combination of the following features: entire aromatic leaves containing oil glands, flower parts in multiples of four or five, ovary half inferior to inferior, numerous brightly coloured and conspicuous stamens, internal phloem, and vestured pits on the xylem vessels. The main genera are *Eucalyptus*, *Eugenia*, *Leptospermum*, *Malaleuca*, *Myrtus*, *Pimenta*, *Psidium* and *Syzygium*. Species of the myrtle

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family provide many valuable products, including timber (e.g. *Eucalyptus* spp), essential oils and spices (e.g. *Melaleuca* spp), and horticultural plants (such as *Callistemon* spp, *Leptospermum* spp) and edible fruits (such as *Eugenia* spp. *Myrciaria* spp. and *Syzygium* spp). Several members of this family are used in folk medicine, mainly as an antidiarrheal, antimicrobial, antioxidant, cleanser, antirheumatic, and anti-inflammatory agent and to decrease the blood cholesterol [13,14].

Although a number of review articles have published in the past on the various aspects of essential oils bioactivities [8,15,16,17,18], the present paper emphasizes on the potential of Myrtaceae EOs in insect pest management. On the other hand, present study attempted to compile the effects of some of the more toxic of the essential oils isolated from Myrtaceae and their components on the insect pest management.

## 2. ESSENTIAL OILS ISOLATED FROM MYTACEAE FAMILY TO INSECT PEST MANAGEMENT

Recent studies demonstrated that the wide range of insects affected by EOs from Myrtaceae family. These oils have knockdown and repellent activity, and act as feeding and/or oviposition deterrents. Also, they have had other activities such as developmental inhibition to a wide variety of insect pests. For example, the effects of the Eos from *Eucalyptus citriodora, Eucalyptus globulus* and *Eucalyptus staigerana* on oviposition and number of emerged insects of *Zabrotes subfasciatus and Callosobruchus maculatus* was tested. The concentrations were 5, 10, 15, 20 and 25 oil µl/0.0017 $m^3$. The EOs reduced the percentage of viable eggs and emerged insects of the two coleopterans species [19]. The use of *Syzygium aromaticum* essential oil exhibited inhibition of F1 progeny from 61.08 to 91.52% against *Sitophilus oryzae*. Inhibition of the F1 progeny due to clove oil treatment ranged from 50.42% to 72.5%. When the oil was applied to the medium at the rate of 25 to 500 ppm, no insect infestation was observed at 500 ppm applications of clove and sweet flag oils [20]. Our earlier studies demonstrated that EOs of *Eucalyptus globulus* had strong fumigant toxicity against eggs, larvae, pupae and adults of *Tribolium castaneum*, adults of *Lasioderma serricorne* and *Rhyzopertha dominica* [21,22,23]. Moreover, contact toxicity and antifeedant activity of *Eucalyptus globules* essential oil were found in our studies [21,24]. All studies related to insecticidal activities of Myrtaceae EOs were summarized in the Table 1. The genera of *Angophora*, *Callistemon*, *Eucalyptus*, *Eugenia*, *Leptospermum*, *Melaleuca*, *Myrcianthes*, *Myrtus*, *Pimenta*, *Psidium* and *Syzygium* were found as good insecticide agents (Table 1). According to Table 1, many EOs from Myrtaceae plants have insecticidal effects against several insect pests and can be considered as bioinsecticides.

**Table 1. Summary of reports indicating toxicity of essential oils isolated from Myrtaceae family.**

| Plant species | Insecticidal activity and tested insect | References |
|---|---|---|
| *Angophora floribunda* | Fumigant toxicity against *Sitophilus oryzae* adults. | 25 |
| *Callistemon citrinus* | Fumigant toxicity against *Sitophilus oryzae* adults. | 25 |
| | Insecticidal and repellent activities Against *Callosobruchus maculatus* adults. | 26 |
| | Repellency against *Trogoderma granarium* adults. | 27 |
| *Callistemon lanceolatus* | Repellency against larvae and moths of *Phthorimaea operculella*. | 28 |
| *Callistemon sieberi* | Fumigant toxicity against *Sitophilus oryzae*, *Tribolium castaneum* and *Rhyzopertha dominica* adults. | 25 |
| *Callistemon viminalis* | Fumigant toxicity against *Sitophilus oryzae* adults. | 25 |

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| Plant species | Insecticidal activity and tested insect | References |
|---|---|---|
| *Eucalyptus astringens* | Fumigant activity against *Ephestia kuehniella*, *Ephestia cautella* and *Ectomyelois ceratoniae* adults. | 29 |
| *Eucalyptus badjensis* | Fumigant toxicity against *Haematobia irritans* adults. | 30 |
| | Fumigant toxicity and larvicidal against *Aedes aegypti*. | 31 |
| *Eucalyptus benthamii* | Fumigant toxicity against *Haematobia irritans* adults. | 30 |
| | Fumigant toxicity and larvicidal against *Aedes aegypti*. | 31 |
| | Insecticidal and repellency activity against *Sitophilus zeamais*. | 32 |
| *Eucalyptus blakelyi* | Fumigant toxicity against *Sitophilus oryzae*, *Tribolium castaneum* and *Rhyzopertha dominica* adults. | 25 |
| *Eucalyptus botryoides* | Fumigant toxicity against *Haematobia irritans* adults. | 30 |
| | Fumigant toxicity and larvicidal against *Aedes aegypti*. | 31 |
| *Eucalyptus camaldulensis* | Ovicidal in *Tribolium confusum* and *Ephestia kuehniella*. | 33 |
| | Larvicidal against *Thaumetopoea pityocampa*. | 34 |
| | Repellent activity against *Anopheles arabiensis* and *A. pharaoensis*. | 35 |
| | Adulticidal effect on *Lipaphis pseudobrassicae*. | 36 |
| | Repellent effects on adult females of *Culex pipiens*. | 37 |
| | Larvicidal and repellent property on *Trogoderma granarium* and *Tribolium* spp. | 38 |
| | Adulticidal against *Callosobruchus maculatus*, *Sitophilus oryzae* and *Tribolium castaneum*. | 39 |
| | Fumigant and repellent effects on permethrin-resistant head lice. | 40 |
| | Larvicidal against *Aedes aegypti* and *Aedes albopictus*. | 41 |
| | Toxic to *Aedes aegypti* adults. | 42 |
| | Larvicidal activity against *Aedes stephensi*. | 43 |
| | Larvicidal and nymphicidal on *Blattella germanica*. | 44 |
| | Fumigant activity against *Ephestia kuehniella*, *Ephestia cautella* and *Ectomyelois ceratoniae* adults. | 29 |
| *Eucalyptus cinerea* | Fumigant toxicity against *Sitophilus oryzae* adults. | 25 |
| | Fumigant and repellent activities against permethrin-resistant *Pediculus humanus capitis*. | 45 |
| | Toxic to *Aedes aegypti* adults. | 42 |
| *Eucalyptus citriodora* | Ovicidal, nymphicidal, and adulticidal against *Trialeurodes vaporariorum*. | 46 |
| | Toxicity against *Sitophilus zeamais*. | 47 |
| | Larvicidal against third-instar larvae of *Aedes aegypti*, *Anopheles stephensi* and *Culex quinquefasciatus*. | 48 |
| | Effects on oviposition and number of emerged insects of *Zabrotes subfasciatus and Callosobruchus maculates*. | 19 |
| | Fumigant and repellent activities against permethrin-resistant *Pediculus humanus capitis*. | 45 |
| | Repellency against *Trogoderma granarium* adults. | 27 |
| | Repellent activity against *Sitophilus zeamais*. | 49 |
| | Insecticidal effects on egg, larva and adult phases of *Lutzomyia longipalpis*. | 50 |
| | Repellent activity against *Tribolium castaneum*. | 51 |
| | Contact toxicity and repellency to adults of *Zabrotes subfasciatus* | 52 |
| *Eucalyptus codonocarpa* | Fumigant toxicity against *Sitophilus oryzae*, *Tribolium castaneum* and *Rhyzopertha dominica*. | 25 |
| | Fumigant toxicity against *Sitophilus oryzae* adults. | 25 |
| *Eucalyptus curtisii* | Fumigant toxicity against *Sitophilus oryzae* adults. | 25 |
| *Eucalyptus dalrympleana* | Fumigant toxicity against *Haematobia irritans* adults. | 30 |
| | Fumigant toxicity and larvicidal against *Aedes aegypti*. | 31 |
| *Eucalyptus dives* | Fumigant toxicity against *Sitophilus oryzae* adults. | 25 |
| | Larvicidal against third-instar larvae of *Aedes aegypti*, | 48 |


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| Plant species | Insecticidal activity and tested insect | References |
|---|---|---|
| | *Anopheles stephensi* and *Culex quinquefasciatus*. | |
| *Eucalyptus dunnii* | Toxic to *Aedes aegypti* adults. | 42 |
| | Larvicidal and nymphicidal on *Blattella germanica*. | 44 |
| | Insecticidal and repellency activity against *Sitophilus zeamais*. | 32 |
| *Eucalyptus elata* | Fumigant toxicity against *Sitophilus oryzae* adults. | 25 |
| | Fumigant toxicity against *Haematobia irritans* adults. | 30 |
| *Eucalyptus fastigata* | Fumigant toxicity against *Haematobia irritans* adults. | 30 |
| | Fumigant toxicity and larvicidal against *Aedes aegypti*. | 31 |
| *Eucalyptus fraxinoides* | Fumigant toxicity against *Haematobia irritans* adults. | 30 |
| *Eucalyptus intertexta* | Adulticidal against *Callosobruchus maculatus*, *Sitophilus oryzae* and *Tribolium castaneum*. | 39 |
| *Eucalyptus globulus* | Ovicidal, nymphicidal, and adulticidal against *Trialeurodes vaporariorum*. | 46 |
| | Fumigant toxicity against the eggs of *Acanthoscelides obtectus*. | 53 |
| | Fumigant toxicity against against *Acanthoscelides obtectus* adults. | 54 |
| | Ovicidal and adulticidal against female *Pediculus humanus capitis*. | 55 |
| | Pupicidal against *Musca domestica* | 56 |
| | Larvicidal against third-instar larvae of *Aedes aegypti*, *Anopheles stephensi* and *Culex quinquefasciatus*. | 48 |
| | Effects on oviposition and number of emerged insects of *Zabrotes subfasciatus and Callosobruchus maculates*. | 19 |
| | Fumigant toxicity against *Lycoriella mali* adults. | 46 |
| | Larvicidal on *Aedes aegypti*. | 57 |
| | Repellency against *Trogoderma granarium* adults. | 27 |
| | Repellent activity against *Blattella germanica*, *Periplaneta americana* and *Periplaneta fuliginosa*. | 58 |
| | Toxic to *Aedes aegypti* adults. | 42 |
| | Contact and fumigant toxicity against *Lasioderma serricorne* adults. | 21 |
| | Ovicidal, larvicidal, pupicidal and adulticidal against *Tribolium castaneum*. | 22 |
| | Fumigant toxicity against *Rhyzopertha dominica* adults. | 23 |
| | Insecticidal effects on egg, larva and adult phases of *Lutzomyia longipalpis*. | 50 |
| | Antifeedant activity on *Tribolium castaneum*. | 24 |
| | Toxicity against the workers of the *Odontotermes obesus* termite. | 59 |
| | Larvicidal, pupicidal and repellency to adult of *Musca domestica*. | 60 |
| | Insecticidal and repellency activity against *Sitophilus zeamais*. | 32 |
| | Larvicidal activity against *Aedes aegypti*. | 61 |
| | Contact toxicity against *Bovicola ocellatus* adults. | 62 |
| | Ovicidal activity against *Anopheles stephensi*, *Culex quinquefasciatus* and *Aedes aegypti*. | 63 |
| | Contact toxicity and repellency to adults of *Zabrotes subfasciatus* | 52 |
| | Fumigants activity against *Trogoderma granarium* larvae. | 64 |
| *Eucalyptus grandis* | Fumigant and repellent effects on permethrin-resistant head lice. | 40 |
| | Toxic to *Aedes aegypti* adults. | 42 |
| | Larvicidal and nymphicidal on *Blattella germanica*. | 44 |
| *Eucalyptus gunnii* | Toxic to *Aedes aegypti* adults. | 42 |
| *Eucalyptus lehmani* | Fumigant activity against *Ephestia kuehniella*, *Ephestia* | 29 |

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| Plant species | Insecticidal activity and tested insect | References |
|---|---|---|
| | *cautella* and *Ectomyelois ceratoniae* adults. | |
| *Eucalyptus leucoxylon* | Fumigant toxicity against *Sitophilus oryzae* adults. | 25 |
| | Fumigant toxicity against *Callosobruchus maculatus*, *Sitophilus oryzae* and *Tribolium castaneum*. | 65 |
| | Fumigant activity against *Ephestia kuehniella*, *Ephestia cautella* and *Ectomyelois ceratoniae* adults. | 29 |
| *Eucalyptus maidenii* | Fumigant toxicity against *Sitophilus oryzae* adults. | 25 |
| *Eucalyptus mannifera* | Fumigant toxicity against *Sitophilus oryzae* adults. | 25 |
| *Eucalyptus moorei* | Fumigant toxicity against *Sitophilus oryzae* adults. | 25 |
| *Eucalyptus nicholii* | Fumigant toxicity against *Sitophilus oryzae*, *Tribolium castaneum* and *Rhyzopertha dominica*. | 25 |
| *Eucalyptus nitens* | Fumigant toxicity against *Haematobia irritans* adults. | 30 |
| *Eucalyptus nobilis* | Fumigant toxicity against *Haematobia irritans* adults. | 30 |
| | Fumigant toxicity and larvicidal against *Aedes aegypti*. | 31 |
| *Eucalyptus nortonii* (*Eucalyptus goniocalyx*) | Fumigant toxicity against *Sitophilus oryzae* adults. | 25 |
| *Eucalyptus obliqua* | Fumigant toxicity against *Haematobia irritans* adults. | 30 |
| *Eucalyptus ovata* | Fumigant toxicity against *Sitophilus oryzae* adults. | 25 |
| *Eucalyptus polybractea* | Fumigant toxicity against *Haematobia irritans* adults. | 30 |
| | Fumigant toxicity and larvicidal against *Aedes aegypti*. | 31 |
| *Eucalyptus radiata* | Larvicidal against third-instar larvae of *Aedes aegypti*, *Anopheles stephensi* and *Culex quinquefasciatus*. | 48 |
| | Fumigant toxicity against *Haematobia irritans* adults. | 30 |
| | Fumigant toxicity and larvicidal against *Aedes aegypti*. | 31 |
| *Eucalyptus resinifera* | Fumigant toxicity against *Haematobia irritans* adults. | 30 |
| | Fumigant toxicity and larvicidal against *Aedes aegypti*. | 31 |
| *Eucalyptus robertsonii* | Fumigant toxicity against *Haematobia irritans* adults. | 30 |
| | Fumigant toxicity and larvicidal against *Aedes aegypti*. | 31 |
| *Eucalyptus robusta* | Fumigant toxicity and larvicidal against *Aedes aegypti*. | 31 |
| *Eucalyptus rubida* | Fumigant toxicity against *Haematobia irritans* adults. | 30 |
| | Fumigant toxicity and larvicidal against *Aedes aegypti*. | 31 |
| *Eucalyptus rudis* | Fumigant activity against *Ephestia kuehniella*, *Ephestia cautella* and *Ectomyelois ceratoniae* adults. | 29 |
| *Eucalyptus saligna* | Contact toxicity and repellency against *Sitophilus zeamais* and *Tribolium confusum*. | 2 |
| | Fumigant and repellent activities against permethrin-resistant *Pediculus humanus capitis*. | 45 |
| | Toxic to *Aedes aegypti* adults. | 42 |
| | Insecticidal and repellency activity against *Sitophilus zeamais*. | 32 |
| *Eucalyptus sargentii* | Adulticidal against *Callosobruchus maculatus*, *Sitophilus oryzae* and *Tribolium castaneum*. | 39 |
| | Fumigant toxicity against *Sitophilus oryzae* adults. | 25 |
| *Eucalyptus sideroxylon* | Toxic to *Aedes aegypti* adults. | 42 |
| | Larvicidal and nymphicidal on *Blattella germanica*. | 44 |
| *Eucalyptus smithii* | Fumigant toxicity against *Haematobia irritans* adults. | 30 |
| | Fumigant toxicity and larvicidal against *Aedes aegypti*. | 31 |
| *Eucalyptus staigerana* | Effects on oviposition and number of emerged insects of *Zabrotes subfasciatus and Callosobruchus maculates*. | 19 |
| | Insecticidal effects on egg, larva and adult phases of *Lutzomyia longipalpis*. | 50 |
| *Eucalyptus stellulata* | Fumigant toxicity against *Sitophilus oryzae* adults. | 25 |
| *Eucalyptus tereticornis* | Fumigant and repellent activities against permethrin-resistant *Pediculus humanus capitis*. | 45 |
| | Larvicidal, pupicidal and adulticidal activity on *Anopheles stephensi*. | 66 |
| | Fumigant and repellent effects on permethrin-resistant head lice. | 40 |

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| Plant species | Insecticidal activity and tested insect | References |
|---|---|---|
| *Eucalyptus urophylla* | Toxic to *Aedes aegypti* adults. | 42 |
| | Larvicidal and nymphicidal on *Blattella germanica*. | 44 |
| | Larvicidal against *Aedes aegypti* and *Aedes albopictus*. | 41 |
| | Fumigant and repellent activities against permethrin-resistant *Pediculus humanus capitis*. | 45 |
| *Eucalyptus viminalis* | Toxic to *Aedes aegypti* adults. | 42 |
| | Larvicidal and nymphicidal on *Blattella germanica*. | 44 |
| *Eugenia melanadenia* | Insecticidal and repellency activity against *Sitophilus zeamais*. | 32 |
| | Larvicidal effects on *Aedes aegypti*. | 67 |
| | Larvicidal against *Culex quinquefasciatus*. | 68 |
| *Leptospermum polygalifolium* | Fumigant toxicity against *Sitophilus oryzae* adults. | 25 |
| *Melaleuca alternifolia* | Fumigant toxicity against *Tribolium castaneum* adults. | 69 |
| | Ovicidal, nymphicidal, and adulticidal against *Trialeurodes vaporariorum*. | 46 |
| | Adulticidal against Female *Pediculus humanus capitis* | 70 |
| | Fumigant toxicity against *Lycoriella mali* adults. | 71 |
| | Repellent activity against female *Culex pipiens pallens* adults. | 72 |
| | Larvicidal property against *Culex ouinquefasciatus*. | 73 |
| | Contact toxicity against Bovicola *ocellatus* adults. | 62 |
| *Melaleuca armillaris* | Fumigant toxicity against *Sitophilus oryzae*, *Tribolium castaneum* and *Rhyzopertha dominica* adults. | 25 |
| *Melaleuca cajuputi* (*Melaleuca leucadendron*) | Larvicidal and repellency against *Aedes aegypti*, *Anopheles stephensi* and *Culex quinquefasciatus*. | 48,74 |
| | Repellent effects against *Aedes aegypti*, *Aedes albopictus*, *Anopheles dirus* and *Culex quinquefasciatus*. | 75 |
| | Toxicity and repellency on *Aedes aegypti* females. | 76 |
| | Repellency, fumigant and contact toxicities against *Sitophilus zeamais* and *Tribolium castaneum*. | 79 |
| | Toxicity against *Aedes aegypti* and *Aedes albopictus*. | 78 |
| *Melaleuca dissitiflora* | Larvicidal activity against *Aedes aegypti*. | 61 |
| *Melaleuca ericifolia* (*Melaleuca Rosalina*) | Fumigant toxicity against *Sitophilus oryzae* adults. | 25 |
| *Melaleuca fulgens* | Fumigant toxicity against *Sitophilus oryzae*, *Tribolium castaneum* and *Rhyzopertha dominica* adults. | 25 |
| *Melaleuca linariifolia* | Fumigant toxicity against *Sitophilus oryzae* adults. | 25 |
| | Larvicidal activity against *Aedes aegypti*. | 61 |
| *Melaleuca quinquenervia* | Larvicidal and repellency against *Aedes aegypti*, *Anopheles stephensi* and *Culex quinquefasciatus*. | 48,74 |
| | Contact and fumigant toxicities against *Musca domestica*. | 79 |
| | Fumigant toxicity on the flightless form of the *Callosobruchus maculatus*. | 80 |
| | Larvicidal activity against *Aedes aegypti*. | 61 |
| *Melaleuca thymifolia* | Fumigant toxicity against *Sitophilus oryzae* adults. | 25 |
| *Myrcianthes cisplatensis* | Fumigant and repellent activities against permethrin-resistant *Pediculus humanus capitis*. | 45 |
| *Myrtus communis* | Ovicidal, nymphicidal, and adulticidal against *Trialeurodes vaporariorum*. | 46 |
| | Larvicidal activity and repellency against *Aedes aegypti*. | 48,74 |
| | Repellency effect against unfed females *Phlebotomus papatasi*. | 81 |
| | Insecticidal activity against the *Acanthoscelides obtectus*, *Ephestia kuehniella* and *Plodia interpunctella* adults. | 82 |
| | Larvicidal activity against *Aedes albopictus*. | 83 |
| | Repellency effects against *Anopheles stephensi* on human | 84 |

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| Plant species | Insecticidal activity and tested insect | References |
|---|---|---|
| | volunteers. | |
| | Fumigants activity against *Trogoderma granarium*. | 85 |
| | Ovicidal, nymphicidal, and adulticidal against *Trialeurodes vaporariorum*. | 46 |
| *Pimenta dioica* | Larvicidal property against *Culex ouinquefasciatus*. | 73 |
| | Fumigant antitermitic activity against *Reticulitermes speratus*. | 86 |
| *Pimenta racemosa* | Fumigant toxicity against *Tribolium castaneum* adults. | 69 |
| | Larvicidal against *Culex quinquefasciatus*. | 68 |
| *Psidium guajava* | Repellent effects against *Aedes aegypti*, *Aedes albopictus*, *Anopheles dirus* and *Culex quinquefasciatus*. | 75 |
| *Psidium rotundatum* | Larvicidal effects on *Aedes aegypti*. | 67 |
| | Larvicidal against *Culex quinquefasciatus*. | 68 |
| *Syzygium aromaticum* (*Eugenia caryophyllata*) | Oviposition deterrent activity against *Callosobruchus maculatus*. | 87 |
| | Contact and fumigant toxicity against adults of *Lasioderma serricorne*, *Sitophilus oryzae* and *Callosobruchus chinensis*. | 88,89 |
| | Pediculicidal effects against female *Pediculus capitis*. | 90 |
| | Ovicidal, nymphicidal, and adulticidal against *Trialeurodes vaporariorum*. | 46 |
| | Fumigant toxicity against *Lycoriella mali* adults. | 71 |
| | Inhibition of F1 progeny against *Sitophilus oryzae*. | 20 |
| | Contact and fumigant toxicity against *Callosobruchus maculates* adults. | 91 |
| | Contact and fumigant toxicities against adults *Musca domestica*. | 79 |
| | Ovicidal effect against *Tribolium castaneum*. | 92 |
| | Repellent activity against *Blattella germanica*, *Periplaneta americana* and *Periplaneta fuliginosa*. | 58 |
| | Larvicidal against both pyrethroid-susceptible and resistant *A. aegypti*. | 93 |
| | Repellency to adults and larvae and ovicidal, larvicidal and adulticidal against *Tribolium castaneum*. | 94 |
| | Repellent activity on *Sitotroga cerealella* and *Ephestia kuehniella* 5th instar larvae. | 95 |
| | Toxicity against the workers of the *Odontotermes obesus* termite. | 59 |
| | Contact toxicity against *Bovicola ocellatus* adults. | 62 |
| | Feeding deterrent activity against *Trichoplusia ni*. | 96 |

## 3. RELATIONSHIP BETWEEN CHEMICAL COMPOSITION AND INSECTICIDAL ACTIVITY OF ESSENTIAL OILS

EOs are natural products that contain natural flavors and fragrances grouped as monoterpenes and sesquiterpenes (hydrocarbons and oxygenated derivatives), and aliphatic compounds such as alkanes, alkenes, ketones, aldehydes, acids and alcohols that provide characteristic odors [97]. The essential oil of a plant may contain hundreds of different constituents but certain components will be present in larger quantities. For example, 1,8-cineole was predominant in the EOs of *Callistemon citrinus* (77.0%), *Callistemon viminalis* (65.0%), *Eucalyptus blakelyi* (56.9%), *Eucalyptus cinerea* (62.1%), *Eucalyptus maidenii* (57.1%), *Eucalyptus robertsonii* (61%), *Eucalyptus saligna* (93.2%) and *Eucalyptus smithii* (78%) (Table 2).

**Table 2. Summary of reports on the major constituents in the introduced essential oils as insecticides isolated from Myrtaceae family.**

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| Plant species | Major constituents | References |
|---|---|---|
| *Angophora floribunda* | α-Pinene (27.8%), limonene (25.9%), and β-pinene (8.6%). | 98 |
| *Callistemon citrinus* | 1,8-Cineole (77.0%), α-terpineol (8.9%) and myrcene (3.3%). | 99 |
| *Callistemon lanceolatus* | β-Pinene (51.2%) and 1,8-cineole (11.7%). | 100 |
| *Callistemon sieberi* | α-Pinene (12.81%), 1,8-cineole (58.99%) and α-terpineol (14.20%). | 25 |
| *Callistemon viminalis* | 1,8-Cineole (65.0%), α-terpineol (13.0%) and α-pinene (12.0%). | 99 |
| *Eucalyptus astringens* | α-Pinene (25.1%), Trans-pinocarveol (15.0%) and 1,8 cineole (13.9%). | 29 |
| *Eucalyptus badjensis* | 1,8-Cineole (71.7%), α-pinene (5.9%), p-cymene (2.4%). | 31 |
| *Eucalyptus benthamii* | α-Pinene (54%), viridiflorol (17%), 1,8-cineole (9%). | 32 |
| *Eucalyptus blakelyi* | 1,8-Cineole (56.9%), p-cymene (5.4%) and α-terpineol (4.4%). | 25 |
| *Eucalyptus botryoides* | p-Cymene (19.9% ), 1,8-cineole (13.3% ) and α-pinene (4.2% ). | 31 |
| *Eucalyptus camaldulensis* | α-Pinene (22.5%), *p*-cymene (21.6%) and α-phellandrene (20.0%). | 41 |
| *Eucalyptus cinerea* | 1,8-Cineole (62.1%), *p*-cymene (11.2%) and Terpinen-4ol (4.2%). | 45 |
| *Eucalyptus citriodora* | Citronellal (40%), isopulegol (14.6%) and citronellol (13%). | 51 |
| *Eucalyptus codonocarpa* | p-Cymene (22.78%), piperitone (53.31%) and p-cymene-8-ol (2.66%). | 25 |
| *Eucalyptus curtisii* | α-Pinene (17%), *E*-β-ocimene (11%) and globulol (9%). | 101 |
| *Eucalyptus dalrympleana* | 1,8-Cineole (80.3%), p-Cymene (5.6%) and α-Pinene (207%). | 31 |
| *Eucalyptus dives* | α-Phellandrene (20%) and piperitone (53%). | 102 |
| *Eucalyptus dunnii* | α-Pinene (7%), 1,8-cineole (32%) and aromadendrene (16%). | 103 |
| *Eucalyptus elata* | α-Phellandrene (35.2%), *p*-cymene (18.6) and piperitone (8.4%). | 104 |
| *Eucalyptus fastigata* | P-Cymene (37.7%), 1, 8-Cineole (14.7%) and α-Pinene (0.68%). | 31 |
| *Eucalyptus fraxinoides* | 1,8-Cineole (58.3%), α-pinene (8.7%) and α-terpineol (3.1%). | 30 |
| *Eucalyptus intertexta* | α-Pinene (18%), limonene (4%) and 1,8-cineole (68%). | 105 |
| *Eucalyptus globulus* | 1,8-Cineole (31%), trans-3-Caren-2-ol (10%) and 3,7-dimethyl-2-Octen-1-ol (9%). | 21 |
| *Eucalyptus grandis* | α-Pinene (44.7%) and β-pinene (30.5%). | 106 |
| *Eucalyptus gunnii* | 1,8-Cineole (38%), α-pinene (16%) and *p*-cymene (7%). | 107 |
| *Eucalyptus lehmanii* | Camphene (21.14), 1,8 cineole (18.42) and α-terpineole (15.14). | 29 |
| *Eucalyptus leucoxylon* | 1,8-Cineole (14.09), g-gurjunene (12.16) and α-terpineol (6.65). | 29 |
| *Eucalyptus maidenii* | 1,8-Cineole (57.8%), *p*-Cymene (7.4%) and α-Pinene (7.3%). | 108 |
| *Eucalyptus mannifera* | α-Pinene (6%), aromadendrene (17%) and globulol (30%). | 109 |
| *Eucalyptus moorei* | 1,8-Cineole (26%), α-, β-, γ-eudesmol (40% total). | 109 |
| *Eucalyptus nicholii* | 1,8-Cineole (82.19%). | 25 |
| *Eucalyptus nitens* | α-Pinene (13.2%) and 1,8-cineole (34.5%). | 106 |
| *Eucalyptus nobilis* | 1,8-Cineole (30.4%), p-cymene (18.2%) and α-pinene (12.9%). | 31 |
| *Eucalyptus nortonii* | α-Pinene (29.0%), 1,8-Cineole (18.0%) and p-cymene (17.2%) | 110 |
| *Eucalyptus obliqua* | Piperitone (15%), bicyclogermacrene (20%) and spathulenol (7%). | 111 |
| *Eucalyptus ovata* | α-Pinene (12%), 1,8-cineole (23%) and linalool (13%). | 107 |
| *Eucalyptus polybractea* | 1,8-Cineole (85.0%), p-cymene (4.1% ) and α-Pinene (0.2% ). | 31 |
| *Eucalyptus radiata* | 1,8-Cineole (68.7% ), α-pinene (2.8% ) and p-cymene (0.7% ). | 31 |
| *Eucalyptus resinifera* | 1,8-Cineole (52%), α-terpineol acetate (9%) and trans-nerolidol (9%). | 112 |
| *Eucalyptus robertsonii* | 1,8-Cineole (62.0% ), p-cymene (2.8.7% ) and α-Pinene (1.6% ). | 31 |
| *Eucalyptus robusta* | α-Pinene (41.7%), p-cymene (8.5%) and 1,8-cineole (0.64% ). | 31 |
| *Eucalyptus rubida* | α-Pinene (11%), 1,8-cineole (45%) and α-terpineol (6%). | 107 |
| *Eucalyptus rudis* | O-Cymene (16.35), Trans-caryophyllene (10.1) and terpinen-4-ol (7.87). | 29 |
| *Eucalyptus saligna* | 1,8-Cineole (93.2%), γ-terpinene (1%) and *p*-cymene (1%). | 45 |
| *Eucalyptus sargentii* | 1,8-Cineole (55.48%), α-pinene (20.95%), trans-pinocarveol | 113 |

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| Plant species | Major constituents | References |
|---|---|---|
| | (5.92%). | |
| *Eucalyptus sideroxylon* | 1,8-cineole (69.2%), α-pinene (6.9%), α-terpineol (5.4%). | 108 |
| *Eucalyptus smithii* | 1,8-Cineole (78.5% ) and α-pinene (4.6% ). | 31 |
| *Eucalyptus staigerana* | (+) Limonene (28.82%), Z-citral (10.77%) and E-citral (14.16%). | 50 |
| *Eucalyptus stellulata* | 1,8-Cineole (41%), α-terpineol (10%), β-, γ-eudesmol (20% total). | 109 |
| *Eucalyptus tereticornis* | 1,8-Cineole (37.5%), *p*-cymene (22.0%) and γ-terpinene (10.8%). | 45 |
| *Eucalyptus urophylla* | 1,8-Cineol (58.3%), α-terpenyl acetate (14.8%) and α-pinene (6.2%). | 41 |
| *Eucalyptus viminalis* | 1,8-Cineole (46.2%), γ-terpinene (23.2%) and *p*-cymene (17.4%). | 45 |
| *Eugenia melanadenia* | 1,8-Cineole (45.3%), terpinen-4-ol (10.6%) and p-cymene (8.2%). | 114 |
| *Leptospermum polygalifolium* | α-Pinene (20%), 1,8-cineole (9%) and caryophyllene Z (8%). | 115 |
| *Melaleuca alternifolia* | Terpinen-4-ol (41.6%), *γ*-terpinene (21.5%) and *α*-terpinene (10.0%). | 116 |
| *Melaleuca armillaris* | 1,8-Cineole (42.8%), terpinen-4-ol (16%) and α-terpinene (8.9%). | 25 |
| *Melaleuca cajuputi* | p-Menth-l-en-4-01 (6.1%), γ-terpinene (5.0%) and caryophyllene (4.0%). | 77 |
| *Melaleuca dissitiflora* | Terpinen-4-ol (48.2%) and p-cymene (22.6%). | 94 |
| *Melaleuca ericifolia* | Linalool (60%) and 1,8-cineole (16%). | 118 |
| *Melaleuca fulgens* | 1,8-cineole (77.5%). | 25 |
| *Melaleuca linariifolia* | Methyl eugenol (86.8%), limonene (1.8%) and o-cymene (1.0%). | 99 |
| *Melaleuca quinquenervia* | 1,8-Cineole (34.9%), *E*-nerolidol (24.1%) and linalool (15.1%). | 119 |
| *Melaleuca thymifolia* | Terpinen-4-ol (47.2%), ρ-cymene (27.7%) and 1,8-cineole (7.7%). | 99 |
| *Myrcianthes cisplatensis* | 1,8-Cineole (45.7%), limonene (27.1%) and α-terpineol (7.7%). | 45 |
| *Myrtus communis* | 1,8-Cineole (24.0%), α-pinene (22.1%) and limonene (17.6%). | 120 |
| *Pimenta dioica* | Methyl eugenol (62.7%), eugenol (8.3%) and 1,8-cineol (4.1%). | 121 |
| *Pimenta racemosa* | Eugenol (45.6%), myrcene (24.9%) and Estragole (9.3%). | 122 |
| *Psidium guajava* | Caryophylene oxide (22%), caryophyllene (12%) and 1,8-cineole (5%). | 75 |
| *Psidium rotundatum* | α-Pinene (18.3%) and 1,8-cineole (28.0%). | 123 |
| *Syzygium aromaticum* | Eugenol (86.5), trans-caryophyllene (10.9) and α-caryophyllene (1.5). | 59 |

The major terpenoids contained in EOs are monoterpenoids (citronellal, linalool, menthol, pinene, mentona, carvona and limonene), sesquiterpenoids (nerolidol) and phenylpropanoids (eugenol), among other compounds [124]. The great majority of the literature on the effects of terpenoids on insects has reported (Table 3). For example, 1,8-Cineole were tested against *T. castaneum* for contact and fumigant toxicity, and antifeedant activity [125]. The adults of *T. castaneum* were more susceptible than larvae to both contact and fumigant toxicity of 1,8-cineole. The compound 1,8-cineole reduced the hatching of *T. castaneum* eggs. Feeding deterrence of 81.9% was achieved in adults by using a concentration of 121.9 mg/g food. Palacios et al. [126] evaluated the fumigation toxicity of some oils and monoterpenes against housefly adults and found 1,8-cineole to be most effective, achieving $LC_{50}$ at 3.3 mg/l. Eugenol, isoeugenol and methyleugenol were toxic to Coleoptera *Sitophilus zeamais* and *Tribolium castaneum*. For *S. zeamais* all compounds were equally toxic with $LD_{50}$ values approximately 30 μg/mg insect. For *T. castaneum*, the order of potency of these chemicals was isoeugenol ($LD_{50}$=21.6 μg/mg insect) > eugenol ($LD_{50}$=30.7 μg/mg insect) > methyleugenol ($LD_{50}$=85.3 μg/mg insect) [127]. The relationship between chemical composition and feeding deterrent activity of essential oil from *Syzygium*

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*aromaticum* was evaluated against the cabbage looper, *Trichoplusia ni* Hubner. At the initial testing dose of 50 µg/cm, geraniol, eugenol, camphene, isoeugenol, cinnamaldehyde, γ-terpinene-4-ol, d-limonene, l-carvone, α-pinene and α-terpineol were the most active compounds (LSD, $P < 0.05$). Comparison of the deterrent activity of 'full mixtures' with respective artificial blends missing individual constituents demonstrated that, for most oils, minor constituents in a mixture can be as important as major constituents with respect to the overall feeding deterrent effect [96].

The structural characteristics of terpenoids can influence their insecticidal properties. Their shape, degree of saturation and type of functional group can influence penetration into the insect cuticle, affect the ability of the compound to move to and interact with the active site, and influence their degradation [128]. It had been found that the monoterpenes possess varying insecticidal activities on various insect species and, in general, some oxygenated monoterpenes such as fenchone, linalool, citronella and menthone were found to be more toxic [129,130,54]. In the study of Papachristos et al. [54], the insecticidal action of *Eucalyptus globulus* Labill and of its main constituents on *Acanthoscelides obtectus* (Say) adults was evaluated. Tested essential oil exhibited strong activity, with varying $LC_{50}$ values depending on insect sex and the structure of the monoterpenoid. A correlation between total oxygenated monoterpenoid content and activity was observed, with oxygenated compounds exhibiting higher activity than hydrocarbons. Among the main constituents, only linalyl and terpinyl acetate were not active, while all the others exhibited insecticidal activity against both male and female adults, with $LC_{50}$ values ranging from 0.8 to 47.1 mg/l air. The most active for both sexes were terpinen-4-ol, camphor, 1,8-cineole and verbenone, followed by linalool ($LC_{50}$ 0.8–7.1mg/l air). The remaining monoterpenoids tested (*β*-pinene, *p*-cymene, *S*(−)limonene, *R(+)*limonene, *γ*-terpinene, *α*-terpineol, *α*-pinene, myrcene and borneol) were 7 to 48 times less active than the most active ones. Ketones were generally more active than alcohols and both were more active than hydrocarbons. They found that the insecticidal activity of the studied essential oil was not linearly dependent upon the content of their main constituents. The $LC_{50}$ of the crude oils were always lower than those calculated for each main constituent. Explanations could be that either the untested fractions of the oils possess a high toxic potency and are thus responsible for the higher final activity, or that synergistic phenomena enhance the oil' insecticidal activity when their main constituents are mixed. Lee et al [131] reported a similar result with oxygenated monoterpenes such as 1,8-cineole, menthone, eugenol, linalool, isosafrol and terpinen-4-ol, which were toxic to *Sitophilus oryzae*. Also, they reported that mono- and bicyclic monoterpenes are more toxic than acylic monoterpenes with the exception of linalool. However, Choi et al. [71] showed bicyclic monoterpenes such as α- and β-pinene possessed strong fumigant toxicity to the sciarid insects. The bioactivities of a series of monoterpenes as well as of some sesquiterpenes are also reported on *Tribolium castaneum* [132]. *α*-terpineol had a dual action, produced high levels of toxicity and also had the highest repellent activity on *T. castaneum* adults. The pure compounds that produced acute toxic activity were *β*-pinene, pulegone and *α*-terpineol. However, the reduced derivatives of the monoterpenes, and sesquiterpenes evaluated were more repellent that the carbonyl homologue. In addition, unsaturated carbon–carbon bonds in the germacrane skeleton enhance responses in the binary choice test. Larvicidal activities of carvacrol, γ-terpinene, terpinen-4-ol and thymol, studied against fourth/fifth-instar larvae of *T. wilkinsoni* [133]. Carvacrol proved to be more effective than others, and caused 90.0% mortality at the highest dose and exposure time. Among other components, thymol was relatively effective and achieved 65.0% larval mortality. The components included in this investigation are classified into three groups depending on their chemical nature: alcohols: terpinen-4-ol, hydrocarbons: γ-terpinene and phenols: carvacrol and thymol. When their larvicidal activity is compared, it can be concluded that phenol forms of components were more toxic than alcohol and hydrocarbon forms. Developmental inhibitory activities of α-pinene and β-caryophyllene alone or in binary combination were determined against 4th

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instars larvae of *Tribolium castaneum*. The percentage of larvae transformed into the pupae and percentage of pupae transformed into adult were decreased when fumigated with two sublethal concentrations of α-pinene and β-caryophyllene alone or in binary combination. Results indicated that α-pinene and β-caryophyllene in binary combination showed synergism and reduced pupation and adult emergence in *T. castaneum* [134].

As mentioned above, we can say that terpenoid potency varies considerably, and that minor structural variations can elicit major differences in activity. The use of terpenoids as pest-management agents may be easier since their activity is more predictable than that of the complex essential oil mix. Consequently, previous studies have shown that the toxicity of essential oils obtained from Myrtaceae family against insect pests (Table 1) is related to the oil's main components (Table 2). On the other hand, the constituents of EOs such as 1,8-cineole, caryophyllene, chavicol, citral, p-cymene, limonene, linalool, myrcene, α-pinene, γ-terpinene, terpinen-4-ol and α-terpineol (Table 2) can be considered as main reseans of insecticidal activities of EOs from Myrtaceae family (Table 1) for their insecticidal bio-efficiency on insect pests (Table 3).

**Table 3. Insecticidal effects of essential oil's constituents that have been declared in Myrtaceae family.**

| Major constituents | Insecticidal activity and target insect | References |
|---|---|---|
| Borneol | Repellent activity against *Pediculus humanus capitis*. | 45 |
| | Feeding deterrent activity against larvae of *Trichoplusia ni*. | 96 |
| Camphene | Fumigant toxicity on *Sitophilus oryzae* and *Tribolium castaneum* adults. | 135 |
| | Repellency against adults of *Phthorimaea operculella*. | 28 |
| | Contact and fumigant toxicity against *Tribolium castaneum* adults. | 136 |
| | Fumigant toxicity against adults of *Sitophilus zeamais*, *Tribolium castaneum*, *Anisopteromalus calandrae* and *Trichogramma deion* larvae. | 137 |
| Camphor | Feeding deterrent activity against larvae of *Trichoplusia ni*. | 96 |
| | Fumigant toxicity against *Tribolium castaneum* adults. | 69 |
| | Fumigant toxicity on *Sitophilus oryzae* and *Tribolium castaneum* adults. | 135 |
| | Contact toxicity against larvae and adults of *Leptinotarsa decemlineata* | 97 |
| | Fumigant toxicity against adults of *Sitophilus zeamais*, *Tribolium castaneum*, *Anisopteromalus calandrae* and *Trichogramma deion* larvae. | 137 |
| | Feeding deterrent activity against larvae of *Trichoplusia ni*. | 96 |
| 3-Carene | Repellent and insecticidal activities against *Tribolium castaneum* and *Sitophilus zeamais*. | 138 |
| Carveol | Fumigant toxicity to *Oryzaephilus surinamensis*, *Musca domestica*, and *Blattella germanica* adults. | 139 |
| | Contact toxicityand acetylcholine esterase inhibition activity against in adult male and female *Blattella germanica*. | 140 |
| Carvone | Fumigant toxicity against *Tribolium castaneum* adults. | 69 |
| | Fumigant toxicity on *Sitophilus oryzae* and *Tribolium castaneum* adults. | 135 |
| | Contact toxicity against larvae and adults of *Leptinotarsa decemlineata*. | 97 |
| | Feeding deterrent activity against larvae of *Trichoplusia ni*. | 96 |
| Caryophyllene | Repellency against adults of *Phthorimaea operculella*. | 28 |
| Caryophyllene oxide | Ovicidal and Adulticidal Effects on *Pediculus capitis* | 90 |
| | Contact and fumigant toxicity against *Tribolium castaneum* adults. | 136 |
| *β*-Caryophyllene | Ovicidal and Adulticidal Effects on *Pediculus capitis* | 90 |
| | Toxicity and acetylcholinesterase inhibitory activity against *Sitophilus oryzae* adults. | 131 |
| 1,8-Cineole | Antifeedant activity and contact and fumigant toxicity against adults of *Tribolium castaneum.* | 125 |
| | Fumigant toxicity against *Tribolium castaneum* adults. | 69 |

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| Major constituents | Insecticidal activity and target insect | References |
|---|---|---|
| | Fumigant toxicity to *Sitophilus oryzae*, *Tribolium castaneum, Oryzaephilus surinamensis*, *Musca domestica*, and *Blattella germanica* adults. | 139 |
| | Fumigant toxicity against *Lycoriella mali* adults. | 71 |
| | Fumigant and repellent activities against *Pediculus humanus capitis*. | 45 |
| | Effects on mortality and reproductive performance of *Tribolium castaneum*. | 141 |
| | Fumigant toxicity against different stages of *Tribolium confusum*. | 142 |
| | Inhibition acetylcholine esterase on adults of *Sitophilus oryzae*. | 135 |
| | Repellent and insecticidal activities against *Tribolium castaneum* and *Sitophilus zeamais*. | 138 |
| | Larvicidal and nymphicidal on *Blattella germanica*. | 44 |
| | Fumigant toxicity to adults of *Tenebrio molitor*. | 143 |
| | Fumigant toxicity against adults of *Sitophilus zeamais*, *Tribolium castaneum*, *Anisopteromalus calandrae* and *Trichogramma deion* larvae. | 137 |
| | Feeding deterrent activity against larvae of *Trichoplusia ni*. | 96 |
| | Contact and fumigant toxicities and acetylcholine esterase inhibition activity against in adult male and female *Blattella germanica*. | 140 |
| Citral | Fumigant toxicity to *Sitophilus oryzae*, *Oryzaephilus surinamensis*, and *Musca domestica* adults. | 139 |
| | Larvicidal against *Anisakis simplex*. | 144 |
| Citronellol | Fumigant toxicity to *Oryzaephilus surinamensis* and *Musca domestica* adults. | 139 |
| | Larvicidal against *Anisakis simplex*. | 144 |
| | Repellent activity against *Pediculus humanus capitis*. | 45 |
| | Fumigant toxicity to *Oryzaephilus surinamensis*, and *Musca domestica* adults. | 139 |
| Citronellal | Repellency against adults of *Phthorimaea operculella*. | 28 |
| | Fumigant toxicity against *Blattella germanica* adults. | 145 |
| | Larvicidal and oviposition deterrent activities against *Aedes aegypti*. | 146 |
| | Feeding deterrent activity against larvae of *Trichoplusia ni*. | 96 |
| | Toxicity and acetylcholinesterase inhibitory activity against *Sitophilus oryzae* adults. | 131 |
| | Fumigant toxicity against *Tribolium castaneum* adults. | 69 |
| | Contact toxicity and repellency against *Sitophilus zeamais* and *Tribolium confusum*. | 2 |
| *p*-Cymene (cymol) | Oviposition deterrent activity against *Aedes aegypti*. | 146 |
| | Contact and fumigant toxicity against *Tribolium castaneum* adults. | 136 |
| | Larvicidal and nymphicidal on *Blattella germanica*. | 44 |
| | Feeding deterrent activity against larvae of *Trichoplusia ni*. | 96 |
| | Larvicidal activity against *Aedes aegypti*. | 61 |
| | Contact and fumigant toxicities and acetylcholine esterase inhibition activity against in adult male and female *Blattella germanica*. | 140 |
| Estragole | Contact and fumigant activities against *Sitophilus oryzae*, *Callosobruchus chinensis* and *Lasioderma serricorne*. | 129 |
| | Toxicity and acetylcholinesterase inhibitory activity against *Sitophilus oryzae* adults. | 131 |
| | Fumigant toxicity against *Tribolium castaneum* adults. | 69 |
| | Ovicidal and Adulticidal Effects on *Pediculus capitis* | 90 |
| | Repellent activity against *Pediculus humanus capitis*. | 45 |
| Eugenol | Effect on the reproduction and egg hatchability and repellency against *Phthorimaea operculella*. | 28 |
| | Fumigant toxicity against *Blattella germanica* adults. | 145 |
| | Larvicidal and oviposition deterrent activities against *Aedes aegypti*. | 146 |
| | Contact toxicity against Bovicola *ocellatus* adults. | 62 |
| | Feeding deterrent activity against larvae of *Trichoplusia ni*. | 96 |

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| Major constituents | Insecticidal activity and target insect | References |
|---|---|---|
| | Larvicidal against *Anisakis simplex*. | 144 |
| | Fumigant toxicity against *Lycoriella mali* adults. | 71 |
| Geraniol | Fumigant toxicity against different stages of *Tribolium confusum*. | 142 |
| | Fumigant toxicity on *Sitophilus oryzae* and *Tribolium castaneum* adults. | 135 |
| | Feeding deterrent activity against larvae of *Trichoplusia ni*. | 96 |
| Isoeugenol | Ovicidal and Adulticidal Effects on *Pediculus capitis* | 90 |
| | Feeding deterrent activity against larvae of *Trichoplusia ni*. | 96 |
| Isopulegol | Fumigant toxicity to *Sitophilus oryzae*, *Tribolium castaneum, Oryzaephilus surinamensis* and *Musca domestica* adults. | 139 |
| | Fumigant toxicity against *Tribolium castaneum* adults. | 69 |
| | Fumigant toxicity to *Sitophilus oryzae*, *Tribolium castaneum, Oryzaephilus surinamensis*, *Musca domestica*, and *Blattella germanica* adults. | 139 |
| Limonene | Fumigant and repellent activities against *Pediculus humanus capitis*. | 45 |
| | Inhibition acetylcholine esterase on adults of *Sitophilus oryzae*. | 135 |
| | Repellent activity against *Blattella germanica*, *Periplaneta americana* and *Periplaneta fuliginosa*. | 58 |
| | Larvicidal activity against *Aedes aegypti*. | 61 |
| (R)-(+) limonene | Fumigant toxicity against different stages of *Tribolium confusum*. | 142 |
| | Fumigant toxicity against *Sitophilus oryzae* adults. | 131 |
| | Fumigant toxicity against *Tribolium castaneum* adults. | 69 |
| | Fumigant toxicity to *Oryzaephilus surinamensis*, *Musca domestica*, and *Blattella germanica* adults. | 139 |
| | Fumigant toxicity against *Lycoriella mali* adults. | 71 |
| | Fumigant activity against *Pediculus humanus capitis*. | 45 |
| Linalool | Effects on mortality and reproductive performance of *Tribolium castaneum*. | 141 |
| | Fumigant toxicity against different stages of *Tribolium confusum*. | 142 |
| | Fumigant toxicity on *Sitophilus oryzae* and *Tribolium castaneum* adults. | 135 |
| | Fumigant and repellent on first-instar nymphs of *Rhodnius prolixus*. | 147 |
| | Contact and fumigant toxicity against *Tribolium castaneum* adults. | 136 |
| | Contact toxicity against larvae and adults of *Leptinotarsa decemlineata*. | 97 |
| | Fumigant toxicity against *Lycoriella mali* adults. | 71 |
| | Repellency against adults of *Phthorimaea operculella*. | 28 |
| | Feeding deterrent activity against larvae of *Trichoplusia ni*. | 96 |
| D-Limonene | Repellent activity against *Pediculus humanus capitis*. | 45 |
| | Fumigant toxicity on *Sitophilus oryzae* and *Tribolium castaneum* adults. | 135 |
| | Contact toxicity against larvae and adults of *Leptinotarsa decemlineata*. | 97 |
| | Feeding deterrent activity against larvae of *Trichoplusia ni*. | 96 |
| Methyl eugenol | Fumigant toxicity and acetylcholinesterase inhibitory activity against *Sitophilus oryzae* adults. | 131 |
| | Ovicidal and Adulticidal Effects on *Pediculus capitis* | 90 |
| Myrcene | Fumigant toxicity on *Sitophilus oryzae* and *Tribolium castaneum* adults. | 135 |
| | Contact and fumigant toxicity against *Tribolium castaneum* adults. | 136 |
| (E)-Nerolidol | Larvicidal activity against *Aedes aegypti*. | 61 |
| Phellandrene | Repellency against adults of *Phthorimaea operculella*. | 28 |
| | Fumigant toxicity against *Tribolium castaneum* adults. | 69 |
| | Fumigant toxicity against *Lycoriella mali* adults. | 71 |
| | Fumigant and repellent activities against *Pediculus humanus capitis*. | 45 |
| | Repellency against adults of *Phthorimaea operculella*. | 28 |
| α-Pinene | Repellent activity against *Blattella germanica*, *Periplaneta americana* and *Periplaneta fuliginosa*. | 58 |
| | Repellent and insecticidal activities against *Tribolium castaneum* and *Sitophilus zeamais*. | 138 |
| | Contact and fumigant toxicity against *Tribolium castaneum* adults. | 136 |
| | Larvicidal and nymphicidal on *Blattella germanica*. | 44 |
| | Fumigant toxicity against adults of *Sitophilus zeamais*, *Tribolium* | 137 |

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| Major constituents | Insecticidal activity and target insect | References |
|---|---|---|
| | *castaneum*, *Anisopteromalus calandrae* and *Trichogramma deion* larvae. | |
| | Feeding deterrent activity against larvae of *Trichoplusia ni*. | 96 |
| | Fumigant toxicity against *Tribolium castaneum* adults. | 69 |
| | Fumigant toxicity against *Lycoriella mali* adults. | 71 |
| | Fumigant and repellent activities against *Pediculus humanus capitis*. | 45 |
| | Toxicity and the highest repellency against *Tribolium castaneum* and *Sitophilus zeamais* adults. | 138 |
| β-Pinene | Repellent activity against *Blattella germanica*, *Periplaneta americana* and *Periplaneta fuliginosa*. | 58 |
| | Fumigant toxicity against adults of *Sitophilus zeamais*, *Tribolium castaneum*, *Anisopteromalus calandrae* and *Trichogramma deion* larvae. | 137 |
| | Feeding deterrent activity against larvae of *Trichoplusia ni*. | 96 |
| | Fumigant activity against *Pediculus humanus capitis*. | 45 |
| | Larvicidal and oviposition deterrent activities against *Aedes aegypti*. | 146 |
| Terpineol | Fumigant toxicity to *Oryzaephilus surinamensis* and *Musca domestica* adults. | 139 |
| | Effects on mortality and reproductive performance of *Tribolium castaneum*. | 140 |
| Terpinene | Repellent activity against *Pediculus humanus capitis*. | 45 |
| | Repellent and insecticidal activities against *Tribolium castaneum* and *Sitophilus zeamais*. | 138 |
| α-Terpinene | Fumigant toxicity and acetylcholinesterase inhibitory activity against *Sitophilus oryzae* adults. | 131 |
| | Larvicidal activity against *Aedes aegypti*. | 61 |
| α-Terpineol | Fumigant toxicity and acetylcholinesterase inhibitory activity against *Sitophilus oryzae* adults. | 131 |
| (−)-α-Terpineol | Feeding deterrent activity against larvae of *Trichoplusia ni*. | 96 |
| Terpinen-4-ol | Fumigant toxicity against *Sitophilus oryzae* adults. | 131 |
| | Larvicidal and adulticidal against *Leptinotarsa decemlineata*. | 148 |
| | Fumigant toxicity against different stages of *Tribolium confusum*. | 142 |
| | Insecticidal and synergistic activities towards *Spodoptera littoralis* and *Aphis fabae*. | 149 |
| | Fumigant toxicity against adults of *Sitophilus zeamais*, *Tribolium castaneum*, *Anisopteromalus calandrae* and *Trichogramma deion* larvae. | 137 |
| γ-Terpinene | Contact toxicity against Bovicola *ocellatus* adults. | 62 |
| | Larvicidal and adulticidal against *Leptinotarsa decemlineata*. | 148 |
| | Larvicidal activity against *Aedes aegypti* and *Aedes albopictus* | 150 |
| | Insecticidal and synergistic activities towards *Spodoptera littoralis* and *Aphis fabae*. | 149 |
| | Repellent activity against *Blattella germanica*, *Periplaneta americana* and *Periplaneta fuliginosa*. | 58 |
| | Contact and fumigant toxicity against *Tribolium castaneum* adults. | 136 |
| | Larvicidal and nymphicidal on *Blattella germanica*. | 44 |
| | Larvicidal activity against *Aedes aegypti*. | 61 |
| | Contact and fumigant toxicities and acetylcholine esterase inhibition activity against in adult male and female *Blattella germanica*. | 140 |
| γ-Terpinene-4-ol | Feeding deterrent activity against larvae of *Trichoplusia ni*. | 96 |
| Verbenone | Fumigant toxicity to *Sitophilus oryzae*, *Tribolium castaneum, Oryzaephilus surinamensis*, *Musca domestica*, and *Blattella germanica* adults. | 139 |
| | Effects on mortality and reproductive performance of *Tribolium castaneum*. | 141 |

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## 4. CONCLUSION

As a consequence of factors such as, strict environmental legislation, increased resistance of pest to synthetic pesticids, growing residue awareness among consumers, mounting industrial research and development cost of chemical insecticides, there has been shift towards the interest for the use of natural insecticides. The development of natural or biological insecticides will help to decrease the negative effects of synthetic chemicals. The secondary metabolites produced by plants against insects make them natural candidates in the control of species of insects, both vector of diseases and pests of agriculture. It is not logical to come to jump to the idea that they will completely replace the synthetic insecticides. Logical thinking is to have in them a complementary use to optimize and increase the sustainability of current integrated pest control strategies. Insecticide plants have the advantage of having other uses as medicinal, a rapid degradation which decreases the risk of residues in food and therefore can be more specific for pest insect and less aggressive with natural enemies. They also develop resistance more slowly in comparison with synthetic insecticides. By the other hand, the disadvantages include that they can be degraded more quickly by ultraviolet rays so its residual effect is low, however not all insecticides from plants are less toxic than synthetic and residual is not established. Given the rapid volatilization and low persistence of EOs in the environment, it is unlikely that they will be used in field crops. However, this property is conducive to using them to control stored product pests in a controlled condition [151]. There are many publications of lists of Myrtaceae plants with insecticidal properties. To use such plants, it is not enough to be regarded as promising or proven insecticidal properties. Analysis of risks to the environment and health should also be made. An ideal insecticide plant must be perennial, be widely distributed and in large amounts in nature or that can be cultivated, using renewable plant bodies such as leaves, flowers or fruits, not be destroyed every time you need to collect material to (avoid the use of roots and bark), agro-technitian minimum requirements and be eco-sustainability, have additional uses (such as medicines), not having a high economic value, be effective at low doses, possess potential scaling biotechnology. Results of many research demonstrated that some of EOs from Myrtaceae family such as Eucalyptus have had these features. Moreover, in the majority of the studies, it has been cited that different constituents of monoterpenes can be some of the best and safest alternatives to synthetic insecticides, for controlling pests [54,129,130].

Explanation of the mode of action of EOs and their constituents is of practical importance for insect control. According to Lee et al. [139], the monoterpenes can penetrate through breathing and quickly intervene in physiological functions of insect. These compounds can also act directly as neurotoxic compounds, affecting acetylcholinesterase activity or octopamine receptors [7]. Further studies on cultured cells of *Periplaneta americana* (L.) and brains of *Drosophila melanogaster* demonstrated that eugenol mimics the action of octopamine and increases intracellular calcium levels [152]. A comparative study has been conducted to assess acetylcholine esterase inhibitory of monoterpenes viz. camphene, camphor, carvone, 1,8-cineole, cuminal-dehyde, fenchone, geraniol, limonene, linalool, menthol and myrcene on *Sitophilus oryzae* and *Tribolium castaneum* [135]. In vitro inhibition studies of acetylcholinesterase from adults of *Sitophilus oryzae* show that cuminaldehyde inhibits enzyme activity most effectively followed by 1,8-cineole, limonene, and fenchone. 1,8-Cineole is the most potent inhibitor of acetylcholine esterase activity from *Tribolium castaneum* larvae followed by carvone and limonene. Rapid action of EOs or its constituents against insect pests is an indicative of neurotoxic actions. Kostyukovsky et al. [153] showed the activity of two purified essential oil constituents, ZP-51 and SEM-76 on several insect species. Both ZP-51 and SEM-76 showed an inhibitory action on acetylcholinesterase, but only at the high, pharmacological dose of 103 M. This indicated that acetylcholinesterase

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was not the main site of action for these essential oils. However, utilizing the octopamine antagonistic activity of phentolamine, they demonstrated that essential oils may affect octopamine receptors. Octopamine is a neurotransmitter, neurohormone, and circulating neurohormone-neuromodulator and its disruption results in total breakdown of nervous system in insects. The lack of octopamine receptors in vertebrates provides the mammalian selectivity of essential oils as insecticides. Consequently, octopaminergic system of insects represents a biorational target for insect control. Treatments the insects with natural compounds such as EOs or pure compounds may cause symptoms that indicate neurotoxic activity including hyperactivity, seizures, and tremors followed by knock down, which are very similar to those produced by the pyrethroid insecticides. However, some activity on the hormone and pheromone system and on the cytochrome P450 monooxygenase enzyme has also been seen [154,155]. These studies confirm that the insecticidal activity of monoterpenes is due to several mechanisms that affect multiple targets.

One of the most attractive features of EOs is that they are low-risk products. Their mammalian toxicity is low and they are relatively well-studied experimentally and clinically because of their use as medicinal products. Although most EOs are not particularly toxic, some need to be handled with caution. For example, EOs of Boldo (*Peumus boldus*), cedar, and Pennyroyal (a mixture of *Mentha pulegium* and *Hedeoma pulegiodes*) have $LD_{50}$ values of 130, 830, and 400 mg $kg^{-1}$ in rats, respectively. In addition, the EO of Boldo can cause convulsions at a dose of 70 mg $kg^{-1}$ [18]. Dermal applications of an insecticide containing 78.2% D-limonene to cats at doses exceeding 15 times the concentration recommended in the instructions for use, resulted in severe symptoms (hypersalivation, ataxia, hypothermia) [156].

In developed countries, several EOs are used in registered commercial formulations. Among these products, the most frequent are garlic, clove, cedar, peppermint, and rosemary oils. Several EOs are used in the United States in relatively closed spaces such as houses, as exemplified by the numerous formulations aimed at managing numerous arthropods, including flies, gnats, mosquitoes, moths, wasps, spiders, and centipedes [18]. If cost-effective commercial problems are solved, EOs obtained from plants can be used as part of integrated pest management strategies. Therefore, large quantities of plant material must be processed to obtain sufficient quantities of EOs for commercial-scale tests, situation which also requires breeding these plants in great quantities. Future research should be focused on residues on target commodity and the influence of any residues on product acceptability [157,158].

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