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Plant oils as sustainable biopesticides: natural alternatives for pest control

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ABSTRACT

Plant oils from various parts of plants have been used for centuries in alternative medicine, aromatherapy and pest control. Among these, essential oils and oils from other plants such as neem, pongamia, castor and *Annona squamosa* have shown great potential as biopesticides. These contain bioactive compounds such as terpenes, phenols and alkaloids that contribute to their insecticidal properties. With growing concerns about the environmental impacts and health risks associated with synthetic pesticides, Plant oils offer a safer and biodegradable alternative. The effectiveness of certain plant oils against pests such as termites, whiteflies and mites has been proven. Despite challenges such as low solubility and high production costs, innovations such as microencapsulation have improved stability and effectiveness. The growing demand for environmentally friendly pest control solutions highlights the potential of Plant oils as sustainable alternatives in integrated pest management (IPM) strategies.

Keywords: Plant oils, Biopesticides, Neem oil, Integrated pest management, Essential oils

INTRODUCTION

Plant oils are mixtures of natural substances that are obtained from different parts of plants such as flowers, fruits and forests. There are three main types of plant oils, which differ in both the extraction method of the plant parts and the properties of the resulting oil. These are *Plant* oils that were previously obtained by putting pressure on plant parts to extract the oil. This oil is obtained by adding herbal ingredients to the base oil and macerating it. Also called infusion or carrier oils, these can be used as solvents to extract the therapeutic effects of certain plants (Dekebo, 2019). Essential oils consist of volatile aromatic compounds obtained from plants through distillation. These oils are found in the glandular hairs and secretory cavities of plant cell walls and are present as liquid droplets in various parts of different plants (Crang et al., 2018). For centuries, plant oils or plant extracts have been used in alternative medicine, aromatherapy, food flavorings, perfumes, preservatives and

biological agents. They are responsible for the characteristic smell and taste of the plants obtained from them. These oils can be used as insecticides to repel or kill certain animals and insects. Essential oils of plant origin offer a promising alternative to synthetic pesticides in pest control (Koul et al., 2008). These oils contain a variety of secondary metabolites with insecticidal properties, such as phenols, terpenes and alkaloids (Garay et al., 2020).

The increasing use of plant oils in pest control is due to concerns about the harmful effects of chemical pesticides. The excessive use of these chemicals has resulted in significant environmental pollution, with global pesticide consumption estimated to reach 4.2 million MT and 74.8% of global agricultural land at risk of contamination (Tang et al., 2021). In addition, pesticide residues can accumulate in organisms and cause long-term health risks. Every year, 385 million agricultural workers suffer from acute pesticide poisoning, with 256 million cases occurring in Asia alone (Bödeker & By., 2022). Because of these issues, low-toxicity plant oils are considered an effective environmentally friendly alternative to synthetic pesticides, offering a safer approach to human health and the environment.

Chemistry behind

Plant oils are a mixture of triacylglycerides and certain fatty acids. Glycerol is the base and is the same for all oils. The differences between the oils are due to the composition of the fatty acids that bind to three sites on glycerol. Oils are defined chemically and physically by their fatty acid structure. The most common fatty acids found in plant oils include palmitic acid ($C_{16}H_{32}O_2$), stearic acid ($C_{18}H_{36}O_2$), linoleic acid ($C_{18}H_{32}O_2$) and oleic acid ($C_{18}H_{34}O_2$) (Sams & Deyton, 2002). Essential oils generally consist of a complex mixture of monoterpenes, biogenetically related phenols and sesquiterpenes (Pavela & Benelli, 2016). Monoterpene compounds contain 10 carbon atoms, often arranged in a cyclic or acyclic manner, and sesquiterpenes are hydrocarbons with 15 carbon atoms. Example: 1,8 cineole, from rosemary and eucalyptus, eugenol from clove oil, thymol from garden thyme, menthol from various types of mint, asarones of Calamus and Carvacrol and linolol from many plant species (Koul et al., 2008).

Efficacy of Specific Plant Oils

Neem oil

Neem (*Azadirachta indica*) has emerged as a promising ecological alternative to synthetic insecticides in pest control. Neem-derived products act as systemic and contact toxins and have anti-feeding, toxicological, repellent and growth-inhibiting effects on pests. Neem oil contains at least 100 biologically active compounds. Among them, the main components are triterpenes called limonoids, the most important of which is azadirachtin, which is believed to be responsible for 90% of its effectiveness against most pests. Other ingredients include nimbinin, meliantriol, nimbin, nimbidin, nimbolide and fatty acids (oleic acid, stearic acid). and palmitic acid) and salanin. The active ingredient azadirachtin impairs the feeding, molting and reproduction of insects and is therefore an effective natural growth regulator for insects (Perveen, 2024). Studies have shown that neem formulations are just as effective as synthetic insecticides in controlling pests such as the brown plant hopper (Wahjono et al., 2024). Neem oil has also been shown to inhibit the growth of termite colonies more effectively than other oils. One study found that neem seed oil extract has

particularly strong insecticidal properties, quickly killing termites and weevils. (Achio, 2012). It is also non-toxic to mammals and birds, making it ideal for controlling parasites. However, challenges need to be addressed, including potentially lower efficiency and higher production costs compared to chemical pesticides. Despite these challenges, neem has numerous benefits such as soil improvement and erosion control, making it a valuable resource for sustainable pest control.

Pongamia oil

Pongamia oil obtained from the seeds of *Pongamia pinnata* has great potential as an effective biopesticide for agricultural pest control. Research has proven its effectiveness against a variety of sucking pests, crop pests and household pests (Gadge et al., 2021). This oil contains more than 19 biologically active ingredients, including karanjin, which contributes to its insecticidal and larvicidal properties (Purkait et al., 2021). Pongamia oil provides excellent pest control when combined with other plant oils such as neem and lemongrass. To overcome challenges such as low water solubility and high light sensitivity, microencapsulation techniques have been developed to improve oil stability and controlled release. In addition, Pongamia cake, a by-product of oil extraction, acts as an excellent organic fertilizer, rich in nutrients and beneficial for soil fertility (Kv et al., 2019).

Castor oil

Castor oil has shown promising results as an effective biopesticide for pest control in various crops. It has repellent, ovicidal and larvicidal properties against several harmful insects. Studies have demonstrated its effectiveness against pests such as the red coffee mite, a major pest of coffee crops, and *Leucinodes orbitalis* Guenee L., an eggplant pest (*Solanum melongena*) (Dutra et al., 2022; Mariame et al., 2023). Castor oil exhibits broad spectrum insecticidal activity against insects and arthropods when used as a solid oil, emulsifying concentrate or spray liquid. Their mode of action is to suffocate most pests. It has been shown to inhibit larval hatching and cause high mortality in nymphs and adults of the target pests (Umar, 2013).

***Annona squamosa* seed oil**

Annona squamosa seed oil has shown promising results as an effective and environmentally friendly pest control solution. Sugar apple seed oil (*Anona squamosa*) effectively controlled whitefly on tomato plants under greenhouse conditions and complied with recommended insecticides without being toxic to plants. Under the microscope, it was found that the oil causes whitefly larvae to shrink and detach from the leaves. There was also a success in controlling cotton aphids on melon leaves and Kanzawa spider mites on soybean leaves (Lin et al., 2009). *A. squamosa* seed extract has also been shown to be effective against aphids, thrips, whiteflies and mealybugs on various horticultural crops. When combined with *Annona muricata* seed extract, it shows high mortality against mealworms and crickets (Irwan et al., 2021). The insecticidal properties of *A. squamosa* are attributed to acetogenins, which kill target organisms through ATP deficiency (Mondal, 2018). These results suggest that the oil and seed extracts of *A. squamosa* represent a broad-spectrum and environmentally friendly alternative to conventional pesticides for sustainable pest control in agriculture.

Essential oils

Essential oils appear to be an effective and ecological alternative to chemical pesticides in pest control. These plant-based compounds have many advantages, including biodegradability, species specificity, and minimal side effects on human and environmental health. Essential oils have insecticidal and repellent properties and have a wide range of uses in agriculture, household use and animal care. They are broken down quickly and have targeted properties, which is why they are preferred by beneficial insects. The global market for essential oils is large, with an estimated production of 45,000 tons and US $700 million (Tripathi et al., 2009). Research is currently underway to understand the mechanisms of action and structure-activity relationships of these plants with the aim of developing more sustainable antiparasitic active ingredients. With the growing demand for biological pest control, essential oils represent a promising solution to reduce the environmental and health risks associated with traditional pesticides.

Table 1. Essential oils against targeted pests

Plant species	**Family**	**Part of a plant**	**active ingredient**	**Biological test**	**Target Insect**	**References**
Z. officinale	Zingiberaceae	rhizome	β-Zingiberene	Antifeedant, IGR	*Tribolium castaneum*	(Brito et al., 2020)
Melaleuca cajuputi	Myrtaceae	leaves	Terpine-4-ol, Terpiniolene	Contact, Fumigant	*Tribolium castaneum, S. oryzae, E. kuehniella, R. dominica*	(Jayakumar et al., 2021)
Artemisia annua	Asteraceae	Leaves	1,8-cineole	Fumigant	*Tribolium castaneum*	(Deb & Kumar, 2020)
Cupressus lusitanica	Cupressaceae	leaves	Umbellulone and a-pinene	Contact, fumigant	*Tribolium castaneum, A. obtectus, S. cerealla, S. zeamais*	(Bett et al., 2016)
Eucalyptus saligna	Myrtaceae	leaves	P-cymene	Contact, fumigant	*T.castaneum, S. oryzae*	(Bett et al., 2016)
Tagetes filifolia	Asteraceae	Aerial parts	(E)-anethole, estragole	Fumigant	*Tribolium castaneum*	(Olmedo et al., 2015)
A.Polystachya	Verbenaceae	leaves	Carvone, limonene	repellent	*Tribolium castaneum, Tribolium confusum*	(Benzi et al., 2014)
Carum carvi	Apiaceae	leaves	Carvone Limonene, (E)-Anethole	Contact	*R. Dominica, S. Oryzae, S. zeamais*	(Fang et al., 2010)
Nardostachys jatamansi	Caprifoliaceae	roots	Aristolone	Contact, Fumigant	*Tribolium castaneum, S. oryzae*	(Liu et al., 2014)

Juniperus foestidissima	Cupressaceae	Juveline branches	Citronellol	fumigant	*T. granarium*	(Tayoub et al., 2012)

Table 2. Some commercial formulation from plant oils

Commercial products (Company)	Active Compounds
ANOSOM (Agri Life, India)	Debitterized annona oil
Molt-X (BioWorks,Inc.,U.S.A)	Azadirachtin
DERISOM (Agri Life, India)	Debitterized karanjin oil
Insect Repellent (EcoSMART, U.S.A)	Rosemary (0.5%), cinnamon leaf (0.5%), lemongrass (0.5%), geraniol (1%)
Mosquito Fogger (EcoSMART, U.S.A)	Geraniol (3.0%), rosemary (2.0%), peppermint (0.4%)
Requiem EC (Bayer AG, Germany)	*Chenopodium ambrosioides* (16.75%)
EcoVia WD (Rockwell Labs Ltd., U.S.A)	Thyme (10%)
Trilogy (Certis, U.S.A)	Neem oil
Triact (OHP, Inc.)	Neem oil
70% Neem oil **(**Monterrey)	Neem oil

Advantages of Plant Oils

Plant oils are environmentally friendly due to their volatility and pose a lower risk compared to synthetic pesticides. Essential oil pesticides are well suited for integrated pest management (IPM) because they have minimal residual effects and less on beneficial insects such as predators, parasitoids and pollinators are harmful. For example, azadirachtin, the main component of neem oil, has a half-life of only 3 to 44 days in soil and 1 to 1.2 days in plant leaves. Essential oil-based insecticides contain complex ingredients, so insects are less likely to develop resistance.

Disadvantages of Plant Oils

The effects of combining the various active components of essential oils are not precisely known. There are a limited number of commercially available products for agricultural use. Plant oils require higher application rates and must be reapplied frequently.

CONCLUSION

Plant oils, especially essential oils, represent a promising and sustainable alternative to synthetic pesticides in agricultural pest control. Due to their biodegradability, species-specific effects and minimal toxicity for non-target organisms, they are suitable for integrated crop protection. Although challenges such as high application rates and cost issues remain, advances in formulation technologies such as microencapsulation could alleviate these issues. The effectiveness of oils such as neem, pongamia, castor and *Annona squamosa* against a variety of pests highlights their potential. To maximize the benefits of plant oils and achieve more environmentally friendly pest control

solutions that ensure agricultural productivity and ecosystem health, further research into mechanisms of action and improved commercialization are required.

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