IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.53
Volume 4, Issue 7, March 2024

Utilization and Application of Essential Oils for Managing Stored Grain Insect Pests

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Abstract: *Essential oils are natural phytochemicals produced as secondary metabolites in aromatic plants. These complex mixtures of volatile compounds typically consist of 20 to 60 different molecules in varying concentrations. Due to their lipophilic nature and lower density compared to water, essential oils can interfere with key metabolic, biochemical, physiological, and behavioral processes in insects. Many essential oils and their components have demonstrated repellant, antifeedant, ovicidal, oviposition-inhibitory, and developmental-inhibitory effects on insects. These effects are believed to result from disruptions to the respiratory and nervous systems of the insects.*
As a source of bioactive molecules, essential oils offer an eco-friendly alternative to traditional insect control agents. They are largely selective in their action and have minimal or no adverse effects on the environment or non-target organisms, including humans. Consequently, essential oil-based formulations hold promise as sustainable methods for insect management, particularly in the context of protecting stored grains.

Keywords: Essential oils, repellant, antifeedant, bioactive molecules stored grain insects

I. INTRODUCTION

Plant-derived essential oils, often referred to as volatile or ethereal oils, are intricate mixtures of fragrant and volatile compounds. These naturally occurring secondary metabolites are distinguished by their strong aroma and typically exhibit a density lower than that of water. Approximately 10% of plant species are known to produce essential oils. Among higher plants, there are an estimated 17,500 aromatic species, with around 3,000 essential oils identified. Of these, 300 are extensively used in the pharmaceutical, cosmetic, perfume, and pesticidal industries. Essential oil-producing genera are predominantly limited to specific families, such as Apiaceae, Asteraceae, Compositae, Cupressaceae, Labiatae, Lauraceae, Myrtaceae, Piperaceae, Poaceae, Rutaceae, and Zingiberaceae. These oils are derived from various plant parts, including leaves, flowers, peels, seeds, wood, berries, resins, rhizomes, and roots.

Due to their cytotoxic nature, essential oils are synthesized and stored within specialized structures. These structures include oil cells, oil glands, ducts, and trichomes, which are distributed across various parts of the plant, from flowers to roots. Research by Gottlieb and Salatino emphasizes that the synthesis of essential oils is closely associated with the development of these secretory structure. For example, oil globules in the secretory cells of Zingiber officinale rhizomes, peltate glands on the leaves of Lippiascaberrima, and secretory cavities in Citrus peels play pivotal roles in the production and storage of essential oils.

Both endogenous and exogenous factors influence the production of essential oils. Endogenous factors include the developmental stage of the plant and its specialized organs, while exogenous influences encompass biotic and abiotic factors. Sangwan et al. identified variables such as ontogeny, photosynthetic rate, photoperiod, light quality, climatic and seasonal variations, nutrition, humidity, salinity, temperature, soil properties, storage conditions, and growth regulators as critical determinants of the quantity and quality of essential oils produced.

The overall essential oil content in plants is typically low, rarely exceeding 1%. Exceptions include plants such as clove (*Syzygium aromaticum*) and nutmeg (*Myristica fragrans*), where essential oil content can reach up to 10%. The molecular structures of essential oil components, characterized by double bonds and functional groups like hydroxyl, aldehyde, and ester, make them highly susceptible to oxidation when exposed to light, heat, or air. The oils are stored as

DOI: 10.48175/IJARSCT-15701G
ISSN 2581-9429 IJARSCT

microdroplets in specialized glands within the plants. These droplets eventually diffuse out of the glands, spreading across the plant surface before evaporating and dispersing into the air.

The tropics, with their high solar energy levels, host many of the most aromatic plants. Seasonal variations significantly influence the oil content and composition of aromatic plants, with microclimatic factors such as temperature, rainfall distribution, and geographical features—especially altitude—affecting the chemotypes of essential oil-bearing plants. The composition and concentration of essential oil constituents are critical for their biological activities. For example, Vekiari et al. reported seasonal variations in the levels of neryl acetate, geranyl acetate, and citronellal in the leaves and peels of certain lemon varieties, with maximum levels observed during the spring compared to winter.

II. CHEMICAL COMPOSITION OF ESSENTIAL OILS

Essential oils are intricate mixtures of volatile compounds, typically comprising 20 to 60 individual components at varying concentrations. Each essential oil is defined by two or three dominant components, which are present in relatively high concentrations (20–70%) and primarily determine the oil's biological properties. For instance, carvacrol (30%) and thymol (27%) dominate *Origanum compactum* oil, linalool (68%) is the primary component of *Coriandrum sativum* oil, and 1,8-cineole (50%) is abundant in *Cinnamomum camphora* oil. Similarly, phellandrene (36%) and limonene (31%) characterize the essential oil of *Anethum graveolens* leaves, while carvone (58%) and limonene (37%) dominate the oil from its seeds. Menthol (59%) and menthone (19%) are major constituents of *Mentha piperita* oil.

The chemical composition and fragrance of essential oils vary significantly based on factors such as geo-climatic location, soil type, altitude, climate, water availability, season (e.g., before or after flowering), harvesting time, and plant genetics. These variables influence the biochemical synthesis of essential oils, leading to variations in the chemical profile of the same plant species, which may result in differing biological activities.

Essential oil components are classified into two main groups:

(a) Volatile Fractions

Volatile fractions make up 90–95% of the oil and include**Terpenes (monoterpenes and sesquiterpenes) and their oxygenated derivatives,Aliphatic aldehydes, alcohols, and esters.**Common volatile constituents include hydrocarbons (e.g., pinene, limonene, bisabolene), alcohols (e.g., linalool, santalol), acids (e.g., benzoic acid), aldehydes (e.g., citral, cuminal), ketones (e.g., camphor), lactones (e.g., bergaptene), phenols (e.g., eugenol), and oxides (e.g., 1,8-cineole).

(b) Nonvolatile Residues

Nonvolatile residues account for 1–10% of the oil and include**Hydrocarbons,Fatty acids,Sterols,Carotenoids**, **Waxes**, and **Flavonoids**

Chemical Groups in Essential Oils

Terpenes

Terpenes are the primary constituents of essential oils and are composed of hydrogen and carbon atoms arranged in isoprene units (C5). These are further classified based on the number of isoprene units:

Hemiterpenes (C5)

Monoterpenes (C10) – Formed by coupling two isoprene units, constituting about 90% of essential oils. Examples: limonene, myrcene, phellandrene.

Sesquiterpenes (C15)

Diterpenes (C20), triterpenes (C30), tetraterpenes (C40) – Larger terpenes with varied structures.

Esters

Esters are sweet-smelling compounds formed by the reaction of an alcohol with an acid. They contribute significantly to the pleasant aroma of essential oils. Examples include linalyl acetate, geranyl acetate, and citronellyl acetate.

Oxides

Oxides, or cyclic ethers, are potent odorants, with 1,8-cineole being the most common. Other examples include bisabolone oxide and caryophyllene oxide.

Lactones

Lactones are relatively high molecular weight compounds. Examples include nepetalactone, bergaptene, and citroptene.

Alcohols

Alcohols are significant aromatic components that contribute to fragrance. Examples: menthol, borneol, citronellol, and linalool.

Phenols

Phenols, which are highly reactive oxygen-containing molecules, are responsible for the strong aroma of oils. Examples: thymol, eugenol, and carvacrol.

Aldehydes

Aldehydes are characterized by the -CHO group and are highly reactive but unstable. Examples: citral, citronellal, and cinnamaldehyde.

Ketones

Ketones are less common and are characterized by the –C=O group. Examples: menthone, camphor, and jasmone.

Essential oil components, whether terpenes or oxygenated compounds (e.g., esters, alcohols, ketones), contribute collectively to the oil's aroma and biological activity, making them valuable across industries.

III. BIOLOGICAL ACTIVITIES OF ESSENTIAL OILS

The excessive use of synthetic insecticides during the 20th and 21st centuries has raised significant concerns about their long-term effects on human health, non-target organisms, and the environment. Consequently, there is an increasing demand for alternatives that are eco-friendly, biodegradable, and safe for humans and other non-target species. Essential oils, as natural plant products, have gained attention for their potential to replace synthetic pesticides due to their diverse biological activities. These oils are volatile, lipophilic, and composed of numerous bioactive compounds, which enable them to function as toxins, repellents, antifeedants, oviposition inhibitors, and fumigants against various insect pests.

3.1. As Attractants

Volatile components of essential oils play a defensive role in plants, attracting pollinators and natural predators of herbivores while also deterring harmful insects. Examples include *Cinnamaldehyde* and *cinnamyl alcohol* attracting *Diabrotica* species (corn rootworm beetles), *Geraniol* and *eugenol* effectively luring *Popillia japonica* (Japanese beetle), *1,8-Cineole* attracting *Lobesiabotrana* (grape berry moth).These properties make essential oils useful in biological pest control programs, where they can be employed as baits to monitor or manage pest populations.

3.2. As Repellents

Essential oils and their components are effective insect repellents, targeting species such as *Sitophilus oryzae*, *Bruchus chinensis*, and *Triboliumcastaneum*. Examples includes *Ocimum suave* oil repelling *S. zeamais*, *Juniperus communis* berry oil as a mosquito repellent.*Turmeric* oil, rich in turmerone and dehydroturmerone, protecting wheat grains from *T. castaneum*.Major active compounds responsible for repellency include eugenol, thymol, α-pinene, and limonene.

3.3. As Antifeedants

Antifeedants inhibit insect feeding behavior and disrupt their nutritional processes. For instance*Curcuma longa* and *Zingiber officinale* oils deter feeding in *T. castaneum* and *S. oryzae*, *Schinus molle* oil alters nutritional indices and feeding patterns in *S. oryzae*, *Piper aduncum* oil reduces foliar consumption in beetles.Synergistic effects between essential oil constituents often enhance antifeedant activity, providing opportunities for developing integrated pest management solutions.

3.4. As Ovicidals and Oviposition Deterrents

Essential oils can reduce egg-laying and inhibit hatching. Examples include*Citrus* peel oil reducing oviposition in *Callosobruchus maculatus*, *Acorus calamus* oil inhibiting reproduction in *C. maculatus*, *Carvone* completely suppressing egg hatching in *T. castaneum*.These oils are particularly effective due to their volatility and rapid degradation, which prevents egg survival.

3.5. As Toxicants

Essential oils exhibit fumigant and contact toxicity against a variety of insect pests. Prominent examples include*Eucalyptus* oil causing mortality in *S. oryzae* and *C. chinensis*, *Mentha citrata* oil showing significant fumigant toxicity to rice weevils, *Artemisia judaica* oil exhibiting neurotoxicity in *C. maculatus*.Toxicity mechanisms often involve interference with neurochemical pathways, such as octopaminergic signaling or acetylcholinesterase inhibition. Constituents like thymol, cineole, and carvone are notable for their neurotoxic effects.

Mechanism of Action

Essential oils primarily act on the nervous systems of insects through:
Interaction with octopaminergic pathways, causing neurotoxicity.
Inhibition of acetylcholinesterase, disrupting nerve impulses.

Environmental Safety

Essential oils are rapidly biodegradable, non-persistent, and safe for humans and non-target organisms. Their natural origin and selective action make them ideal candidates for integrated pest management programs, reducing reliance on synthetic pesticides.

3.6. As Growth Inhibitors

Essential oils and their constituents have demonstrated significant egg-laying, growth-inhibitory, and progeny production-inhibitory effects against a variety of insect pests. These properties make essential oils a valuable tool in integrated pest management strategies.

3.6.1. As Progeny Production Inhibitors

Several studies have established the role of essential oils in reducing progeny production by interfering with insect reproduction and development:
Cymbopogon flexuosus leaf essential oil exhibits fumigant toxicity, reducing progeny production in *Rhyzoperthadominica*, *Sitophilus oryzae*, and *Triboliumcastaneum*.
Essential oils from *Clausenaanisata* combined with clay powder reduce F1 progeny insect production.
Oils such as *Cymbopogon martini*, *Piper aduncum*, and *Lippiagracilis* reduce egg viability and adult emergence in *Callosobruchusmaculatus* .
Essential oils from *Nigella sativa*, *Anethum graveolens*, *Cuminum cyminum*, and *Piper nigrum* significantly inhibit egg hatching, pupation, and adult emergence at sublethal concentrations.
Zingiber officinale and *Piper cubeba* oils inhibit the development of larvae and pupae of *T. castaneum*, reducing reproductive potential.
Allium sativum essential oil inhibits oviposition and progeny production via both fumigant and contact methods.

3.6.2. As Development Inhibitors

Essential oils exhibit growth regulatory properties, often mimicking juvenile hormones or disrupting physiological processes:
1,8-Cineole from *Artemisia annua* inhibits growth, reduces food consumption, and disrupts food utilization in post-harvest pests.
Cymbopogon schoenanthus oil inhibits development at all stages of *C. maculatus*.
Essential oils from *Hyptisspicigera* and *Laurus nobilis* cause dose-dependent developmental delays and lethality in larvae and adults of pests like *T. confusum*.
Cuminum cyminum, *Foeniculum vulgare*, and *Nigella sativa* oils cause deformities during developmental stages of *T. castaneum*.

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Oils from *M. fragrans*, *P. nigrum*, and *T. ammi* interfere with growth and reproduction of *C. chinensis*.
Binary combinations of α-pinene and β-caryophyllene show synergistic effects in reducing pupation and adult emergence in *T. castaneum*.

3.7. Mode of Action of Essential Oils

The toxic effects of essential oils on insects are primarily due to their interactions with the nervous and respiratory systems. The mechanisms include:

Inhibition of Acetylcholinesterase (AChE):

Essential oil components such as thymol, cineole, and linalool inhibit AChE activity, leading to impaired neurotransmission and eventual mortality.Ryan and Byrne suggested competitive inhibition of AChE as the primary mode of action, where essential oil molecules bind to the enzyme's active site.

Octopaminergic System Disruption:

Octopamine, a neurotransmitter specific to insects, is disrupted by essential oils. This leads to breakdowns in nervous system coordination, resulting in paralysis and death.Essential oils act selectively on insects due to the absence of octopamine receptors in vertebrates, ensuring safety for humans and other non-target organisms.

Respiratory System Disruption:

Components like caryophyllene oxide inhibit the mitochondrial electron transport chain, reducing oxygen consumption and respiration rates in insects.

Disruption of Mating and Communication:

Essential oils interfere with antennal sensilla functions, disrupting mating behavior and reducing fecundity.
Essential oils and their active components are effective in reducing insect populations through multiple mechanisms, including growth inhibition, disruption of reproduction, and neurotoxicity. Their selectivity and rapid biodegradability make them promising alternatives to synthetic pesticides. Further research into their specific modes of action and potential synergistic effects will enhance their application in sustainable pest management strategies.

Future Prospects

- To optimize their use, further studies are needed to:
- Explore synergistic effects among essential oil constituents.
- Develop artificial blends targeting specific pest species.
- Evaluate impacts on non-target organisms and ecosystems.
- The versatility of essential oils offers a sustainable and eco-friendly approach to pest control, with significant potential for replacing conventional insecticides.

IV. CONCLUSION

In conclusion, essential oils and their constituents exhibit a wide range of biological activities, including repellent, antifeedant, ovicidal, oviposition inhibitory, and developmental inhibitory effects on insect pests. Their mechanisms of action involve interference with the respiratory and nervous systems of insects, leading to effective pest management outcomes. These natural products present a promising alternative to synthetic insecticides, offering selectivity in their action while posing minimal or no harm to the environment and non-target organisms, including humans. Consequently, essential oils hold significant potential for sustainable and eco-friendly insect management strategies.Essential oils and their active components are effective in reducing insect populations through multiple mechanisms, including growth inhibition, disruption of reproduction, and neurotoxicity. Their selectivity and rapid biodegradability make them promising alternatives to synthetic pesticides. Further research into their specific modes of action and potential synergistic effects will enhance their application in sustainable pest management strategies.

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