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Review Article

Prospects for the Use of Essential Oils as Repellants and/or Insecticides

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ABSTRACT

Essential oils are produced by a large number of plant species. Plants from several families, which include Asteraceae (Compositae), Apiaceae (Umbelliferae), Geraniaceae, Labiatae (Lamiaceae), Lauraceae, Myrtaceae, Rosaceae, Rutaceae, Santalaceae, Zingiberaceae, etc. are being studied closely because they may be promising sources of essential oils with strong repellent and/or insecticidal properties. Botanical garden collections necessitate close attention to the condition of the grown plants as well as the health of those who visit the botanical gardens. The use of effective chemical insecticides in crowded places is prohibited. The use of solutions of various oils (fatty and essential), non-toxic for warm-blooded animals and humans, opens up the prospect of developing an environmentally friendly way to combat phytophages and plant diseases. A review of several publications demonstrating the insecticidal, repellent, and antimicrobial properties of essential oils is provided. New areas of research can be identified by analyzing published works on the search for essential oils with repellent and/or insecticidal properties. Many years of research in the protection of collection plants in the Peter the Great Botanical Garden using a mixture of natural oils has demonstrated its efficacy. Regular treatments (every 25-30 days) with an aqueous emulsion of neem oil (*Azadirachta indica*) containing essential oils from various families (Lamiaceae, Lauraceae, Myrtaceae, and so on) reduce the number of insect pests by 60-80%.

Keywords: Biological methods, Pest control, Phytophages, Plant protection, Secondary metabolites.

Introduction

The UN has declared 2020 as the International Year of Plant Health and Protection.[1] Plant pests and diseases affect up to 40% of food crops each year, according to FAO UN estimates,[2] thereby causing serious damage to agriculture. Protecting plants from pests and diseases is much more economical and effective than dealing with full-scale plant health disasters. Preventing the growth of pests and plant disease incidences, as well as developing ecologically friendly techniques to combat them, is an urgent task at the moment. An ecosystem-based plant health and protection approach combines different strategies and control methods to grow healthy plants with minimal pesticide use. Avoiding hazardous pesticides not only preserves the environment but also protects pollinators, natural pest enemies, beneficial organisms, and people, as well as animals that depend on plants.

To date, a large number of various drugs have been developed, and many new chemical compounds have been synthesized that can destroy various pests of crops in a short time. However, such preparations will have major consequences for human health, animal welfare, and soil health. From the end of the 20th century to the beginning of the 21st century, research and development of plant-based preparations (groups of compounds isolated from plants) have been going on in different countries of the world. Thus, it has already been shown that phytosterols can be successfully used against a large number of phytophages since they work as hormones of insect molting.[3]

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Pyrethrin (a group of natural insecticides found in the flowers of perennial herbs of the Asteraceae family from the genera *Pyrethrum*, *Chrysanthemum*, and *Tanacetum*, etc.) and pyrethroids (synthetic insecticides analogous to natural pyrethrins) have been widely used to control insect pests. They are neurotoxic poisons for insects, as they impair the transmission of nerve impulses, causing paralysis and death. Some pyrethroids are also effective against ticks. Due to their high lipophilicity, they quickly penetrate the integument of the insect, which provides an almost instantaneous defense against various phytophagous insects.[4] Some fatty and essential oils, on the other hand, are even more environmentally friendly as insect repellents and pesticides. Even in the wide outdoors, essential oils can be used to repel bugs. Many essential oils are known to have insecticidal or insect repellant characteristics, which means they can kill or repel insects. Table 1 displays some essential oils that have been shown to repel bugs. Many essential oils are not expensive in comparison with several insecticidal compounds. They are relatively cheap to obtain, which distinguishes them favorably from phytosteroids. Most importantly, these compounds are not toxic to warm-blooded animals or humans. The search for insecticidal agents among species belonging to various families and groupings of secondary metabolites is still relevant.[15-17] Identifying the biological activity of essential oils is the first step in analyzing their mode of action. The presence of chemical substances such as limonene, linalool, menthol, menthone, terpinolene, geraniol, apiol, p-cymene, terpinene, terpinene, myrcene, and thujene in essential oils show that they possess antimicrobial, antifungal, and antiviral activities. In addition, their insecticidal and repellant properties were mentioned in several published papers.[18-24]

Species of the genus *Monarda* (contains about 22-31 species), as a source of essential oil containing basic substances with repellent and insecticidal properties, are of great interest for detailed and in-depth research. Thus, it was shown that about 60 components have been identified in *Monarda* essential oil. The primary components of the essential oil in most of the samples investigated are thymol and carvacrol (oxygenated monoterpenes), which account for 41- 85% of the total.

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Table 1: Some essential oils that are commonly used to control insect pests

Essential oil	Source plant	Characteristics	Ref.
Clove	*Syzygium aromaticum* (L.) Merr. & L.M.Perry (Myrtaceae)	The main component of essential oil is eugenol (up to 90%), it also contains 3% acetyleusgenol and caryophyllene	5-7, 9-12
Cedarwood	From various types of conifers (*Cedrus*, *Juniperus*, etc), most in the Pinaceae or Cupressaceae families	In the essential oil: (+)-cedrol (20-40%), cedren, cedrenol, thujopsen	5-7, 9-12
Cinnamon	*Cinnamomum cassia* (L.) J. Presl, *Cinnamomum aromaticum* Nees, *Cinnamomum tamala* (Buch.-Ham.) T. Nees & Eberm., *Cinnamomum culilawan* Blume (Lauraceae)	The bark contains 1-2% essential oil, consisting mainly of cinnamic acid aldehyde (about 90%)	5-7, 9-12
Citronella	*Cymbopogon nardus* L.; *Cymbopogon winterianus* Jowitt (Cardiopteridaceae)	Ceylon chemotypes (obtained from *Cymbopogon nardus* L.), the main composition is geraniol (18–20%), limonene (9–11%), methyleugenol (7–11%), citronellol (6–8%), citronellal (5–15 %). %). Java chemotypes (obtained from *Cymbopogon winterianus* Jowitt), the main composition is citronellal (32-45%), geraniol (11-13%), geranyl acetate (3-8%), limonene (1-4%).	5-7, 9-12
Eucalyptus	*Eucalyptus citriodora* Hook. is a synonym of *Corymbia citriodora* (Hook.) K. D. Hill & L.A.S. Johnson (Myrtaceae)	In the essential oil: *α*-pinene 2.3%, β-pinene 1.6%, *α*-thuyene 0.3%, sabinene 1.9%, myrcene 0.4%, citronellol 5.0%, neo-isopulegol 4.6%, isopulegol 2.6%, citronellal 72.0%, 1.8-cineole 0.8%, citronellyl acetate 1.1%	5-7, 9-12
Fennel	*Foeniculum vulgare* Mill. (Apiaceae = Umbelliferae)	The fruits contain up to 6.5%, and the leaves - up to 0.5% essential oil. It contains: anethole, fenchon, methylchavicol, *α*-pinene, *α*-phellandrene, cineole, limonene, terpinolene, citral, bornyl acetate, camphor	5-7, 9-12
Geranium	*Geranium sanguineum* L. and some species from the genus *Pelargonium* (Geraniaceae)	In the essential oil: cittrophenellol, geraniol	5-7, 9-12
Lemongrass	*Cymbopogon citratus* (DC.) Stapf (Poaceae)	The plants contain essential oil, the main part of which is citral. In addition, limonene, isopulgenol, citronelic and geranic acids, and *α*-camphonene were found.	5-7, 9-12
Manuka	*Leptospermum scoparium* J.R.Forst. & G.Forst. (Myrtaceae)	In the essential oil: *α*-pinene; myrcene; caryophyllene and humulene; geranyl acetate; γ-ylangene + *α*-copaene; trans-methyl cinnamate; linalol; elemene and selinene.	13
Niaouli	*Melaleuca viridiflora* Sol. ex Gaertn. (Myrtaceae)	In the essential oil: *α*-pinene, limonene, β-pinene, paracymene, γ-terpinene, myrcene, *α*-terpineol, terpinen-4-ol, linalool, 1,8-cineol (50-60%), beta-caryophyllene, *α*-selinene, viridiflorol, nerolidol, *α*-terpenyl acetate	5-7, 9-12, 14
Patchouli	*Pogostemon cablin* (Blanco) Benth. (Labiatae = Lamiaceae)	In the essential oil, the most important components are patchulol (30%) and *α*-patchoulene (6%)	5-7, 9-12
Peppermint	*Mentha* × *piperita* L. (Labiatae + Lamiaceae)	In the essential oil: *α*-pinene, β-pinene, limonene (2-3%), terpinene, phellandrene, menthol, menthon.	8
Tea Tree	*Melaleuca alternifolia* (Maiden & Betche) Cheel (Myrtaceae)	In the essential oil: *α*-pinene 2.5%, phellandrene, *α*-terpinene 9.1%, para-cymene - 3.9%, γ-terpinene 24.6%, terpinolene 4%, 4-ol 42.1%, *α*-terpineol 2.3%, 1.8-cineole 4.3%., viridiflorene (up to 1%), β-terpineol (0.24%), L-terpineol (traces) and allihexanoate (traces)	5-7, 9-12

Phenols account for 68-79% of the total (with a high concentration of monoterpene hydrocarbons, including p-cymene, γ-terpinene, *α*-terpinene, β-myrcene, and *α*-thujene). Within the species, there are many forms with different physical traits and, more importantly, different oil compositions (chemotypes or chemises). In some chemotypes, menthol or limonene (or linalool) predominate in the essential oil composition, determining the main direction of the smell.[25-31] Table 2 displays some active components from essential oils. The main idea of this work is the analysis of publications on the insecticidal and repellent effects of essential oils, with the aim of a practical assessment of the prospects for using a mixture of fatty and essential oils to protect plants from insect pests.

Over the past 20 years, numerous techniques for controlling diseases and pests detected on collected plants, both in outdoor and indoor environments (areas under glass, in greenhouses, or conservatories), have been researched and developed by the Peter the Great Botanical Garden.[33-35] It has been demonstrated that it is promising for use for plant protection against phytophages.[37,38] The use of chemical compounds in closed rooms is prohibited by various laws. Therefore, the use of secondary plant metabolites (including essential oils) is safe for humans and animals. This is the basis for experimental research on the use of essential oils of different species from different families against insect pests to protect botanical garden collection plants from insect pests. Botanical gardens where living plants are collected require protection from insect pests and various pathogens. Outdoor (greenhouses and hothouses) use of highly effective chemical insecticides is prohibited by law. This is especially true for botanical gardens, which attract families with children and school groups on field trips. Therefore, the use of natural substances that have insecticidal and repellant properties is relevant and important for the environment. It permits experimentation in botanical gardens, on collection plants, and is based on substantial published data on the use of essential oils of various plant species as repellents and insecticidal preparations. Botanical gardens are unique in that, unlike commercial greenhouses, where monocultures are commonly grown, botanical gardens can include anywhere from one hundred to two hundred distinct kinds of plants, representing several families, growing in a single greenhouse. This makes the selection of mixtures for disease and insect pest treatments more complex.

Neem (*Azadirachta indica* A. Juss; Meliaceae) oil is beneficial against a variety of insect pests and plant diseases on numerous occasions. At the same time, it has been demonstrated that when essential oils of several types (mostly *Lamiaceae* species) are combined, insecticidal and repellant effects are enhanced.[38,39] The effectiveness of essential oils of thyme (species of the genus *Thymus*) and oregano (species of the genus *Origanum*) is shown by the example of protecting museum exhibits from pests and pathogenic fungi. Essential oils have been determined to have no harmful effects on human health and do not pollute the environment when used to protect and preserve works of art. Essential oils can be utilized as non-toxic biocides for warm-blooded animals.[40]

In several publications, [39-46] it has been shown that the main components of oregano (*Origanum tyttanthum* Gontsch., a synonym of *Origanum vulgare* subsp. *gracile* [K.Koch] Ietsw.) essential oil are thymol and carvacrol. Linalool, thujone, pinene, cineole, camphor, nerolidol, and sclareol are all present in the essential oil of clary sage (*Salvia sclarea* L.). Octyl acetate and a variety of terpenes are found in the essential oils of the Hogweed (*Heracleum* L.) species. These oils have an antibacterial action. Their antibacterial and antiviral properties have been demonstrated.[39-46]

Table 2: Characteristics of active components from some essential oils

Plant	Active component	Activity	Target organism	Ref.
Haplopappus foliosus DC. (Compositae = Asteraceae)	limonene, epi-bicyclosesquiphellandrene, bornyl acetate, 4-terpineol, p-cymene, agarospirol, -muurolene, -cadinene, and caryophyllene	Insecticidal effect	*Musca domestica*	30
Mentha pulegium L. (Lamiaceae)	pulegone, isomenthone, and limonene	Insecticidal, repelling, antimicrobial, antifungal, antibacterial, and antiviral	*Rhyzopertha dominica* (Fabricius, 1792) (Coleoptera: Bostrichidae).	23
Lavandula stoechas L. (Lamiaceae),	camphor, 1,8-cineole and camphene	Insecticidal, repelling, antimicrobial, antifungal		
Ruta chalepensis L. (Rutaceae)	undecanone, 2-nonanone and 2-decanone	Insecticidal, antimicrobial, antifungal		

Methods

The greenhouse whitefly, *Trialeurodes vaporariorum* Westwood, 1856 (Hemiptera: Aleyrodidae), is distributed in greenhouses all year round. Also, it can be found in the summer in the outdoor collections of the Peter the Great Botanical Garden of the Komarov Botanical Institute (BIN RAS). Numerous species make up the fodder base. One of the major priorities is to reduce the number of this phytophage. Hydroalcoholic (in 40% ethanol) extracts of chili pepper (*Capsicum annuum* L. syn. *Capsicum* frutescens L.), garlic (*Allium sativum* L.), and sugar (as a "glue" agent, splitting the shell of insect eggs) were previously employed for plant protection. The use of an aqueous emulsion of neem oil (*Azadirachta indica*) (50 ml of oil and 15 ml of Tween 80 per 10 liters) has been investigated in recent years. To enhance the insecticidal and repellent effects, 10 ml of commercial essential oil was added. *Cinnamomum aromaticum* Nees or *Cinnamomum cassia* (L.) J. Presl; *Litsea cubeba* (Lour.) Pers., *Thymus vulgaris* L.; *Lavandula angustifolia* Mill.; *Origanum vulgare* L., *Mentha* x *Piperita* L., etc. were used.[47-49] The treated plants were sprayed with the produced mixture in a knapsack sprayer. Every 25-30 days (in the winter and spring), collection plants were processed in the greenhouses in the park of Peter the Great Botanical Garden.

Results and Discussion

The problem with plant protection in greenhouses is that in one greenhouse, there are up to 100-150 different plant species, representatives of different families. In this study, the phytotoxicity of the solutions employed on the test plants was not recorded. A toxic effect was observed on the greenhouse whitefly, which was determined by the presence of dead whiteflies. A repelling effect was observed with the solutions utilized. The efficiency values on each of the plants did not indicate significant variations between the experimental variants on the 14th day after spraying, and the average value was 77±18.7%. When fresh larvae hatch from eggs after 20-25 days, the number of insect pests increases. Regular plant treatments, once every three to four weeks in early spring (before insect activity begins) lower pest numbers by 60-80%. Fungal and bacterial plant diseases were not recorded.

According to data from published studies, the use of essential oils as insecticidal agents or repellents has potential. It is important to recognize plant species whose essential oils contain a considerable number of biologically active chemicals. Thymol, carvacrol, linalool, linalyl acetate, menthol, menthone, pulegone, apiol, pinene, 1,8-cineole, and a variety of other compounds are examples. Species from different genera, such as the Lamiaceae family including *Agastache* Gronov., *Hyptis* Jacquin, *Lavandula* L., *Lepechinia* Willdenow, *Lophanthus* Adans., *Lycopus* L., *Mentha* L., *Melissa* L., *Ocimum* L., *Origanum* L., *Perilla* L., *Perovskia* Kar., *Phlomis* L., *Rosmarinus* L., *Plectranthus* L'Hér., *Salvia* L., *Satureja* L., *Teucrium* L., *Thymus* L., *Vitex* L. *Zataria* Boissier, *Zhumeria* Rech., and *Ziziphora* L., should be studied as prospective producers of essential oils with a pronounced insecticidal and repellent effect.

Conclusion

Analysis of published works on the search for essential oils with a repellent and/or insecticidal effect allows new areas of research to be determined. In addition, the well-known neem oil (*Azadirachta indica*), which has an insecticidal effect, in combination with essential oils, also exhibits a repellent effect. Regular treatments (every 25-30 days) with an aqueous emulsion of neem oil containing essential oils from various families (Lamiaceae, Lauraceae, Myrtaceae, etc.) reduce the number of insect pests by 60-80%. Expanding the search for essential oils with pronounced antimicrobial effects is vital to produce innovative, non-toxic, ecologically acceptable insecticidal treatments that also have repelling properties.

Conflict of Interest

The authors declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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