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REVIEW ARTICLE

Essential Oils as Green Pesticides: For Sustainable Agriculture

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ABSTRACT

The environmental problems caused by overuse of pesticides have been the matter of concern for both scientists and public in recent years. It has been estimated that about 2.5 million tons of pesticides are used on crops each year and the worldwide damage caused by pesticides reaches $100 billion annually. Natural products are an excellent alternative to synthetic pesticides as a means to reduce negative impacts to human health and the environment. The move towards green chemistry processes and the continuing need for developing new crop protection tools with novel modes of action makes discovery and commercialization of natural products as green pesticides are good alternatives to chemical pesticides. Green pesticides are eco-friendly, economic, target-specific and biodegradable. Many plant essential oils show a broad spectrum of activity against pest insects and plant pathogenic fungi ranging from insecticidal, antifeedant, repellent, oviposition deterrent, growth regulatory and antivector activities. This special regulatory status combined with the wide availability of essential oils from the flavor and fragrance industries, has made it possible to fast track commercialization of essential oil-based pesticides. Though well received by consumers for use against home and garden pests, these "green pesticides" can also prove effective in agricultural situations, particularly for organic food production. Further, while resistance development continues to be an issue for many synthetic pesticides, it is likely that resistance will develop more slowly to essential oil based pesticides owing to the complex mixtures of constituents that characterize pesticides based on plant essential oils or their constituents have demonstrated efficacy against a range of stored product pests, domestic pests, blood feeding pests etc. These features indicate that pesticides based on plant essential oils could be used in a variety of ways to control a large number of pests. Some essential oil constituents, for example, limonene, pulegone, citronellal and 1,8-cineole are active ingredients of commercially available flea shampoos, mosquito repellents and different agrochemicals.

Keywords: Essential oils, Green pesticides, Natural products.

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INTRODUCTION

Agriculture in a tropical country like India, owing to its climatic conditions and its particular environment, suffers severe losses due to pests. The Indian farmers are in need of effective tools to fight against pests. The environmental problems caused by overuse of pesticides have been the matter of concern for both scientists and public in recent years. It has been estimated that about 2.5 million tons of pesticides are used on crops every year and the worldwide damage caused by pesticides reaches $100 billion annually. The overuse of chemical pesticides is the cause of some environmental problems due high toxicity and non-biodegradable properties of these pesticides and the residues in soil, water resources and crops that affect public health. After severe setback arising from the use of chemical pesticides on living systems and the environment, the use of eco-friendly biopesticides is gaining momentum. However, the small farmers in India are not yet fully aware of the concept, use or advantages of ecofriendly pest management. Though India has a rich source of plants that could be harnessed as botanical pesticides, accentuated research on the preparation of biopesticides has not gained ground [1, 2].

Natural products or eco-friendly pesticides are an excellent alternative to synthetic pesticides as a means to reduce negative impacts to human health and the environment. The move toward green chemistry processes and the continuing need for developing new crop protection tools with novel modes of action makes discovery and commercialization of natural products as green pesticides, an attractive and profitable pursuit that is commanding attention. The concept of “Green Pesticides” refers to all types of nature-oriented and beneficial pest control materials that can contribute to reduce the pest population and increase food production. Green pesticides are safe, eco-friendly and are more compatible with the environmental components than synthetic pesticides [3]. Thus in the present concept of green pesticides, some rational attempts have been made to include substances such as plant extracts, hormones, pheromones and toxins from organic origin and also encompass many aspects of pest control such as microbial, entomophagous nematodes, plant derived pesticides, secondary metabolites from microorganisms, pheromones and genes used to transform crops to express resistance to pests. More recently, the encouragement of use of products from natural resources and even the extremely biodegradable synthetic and semi synthetic products in pest management has been considered to constitute the umbrella of green pesticides [4-6]. However, it will be beyond the scope of any article to discuss all of them at one place. Here, we shall like to emphasize on some recent developments where essential oils have been projected as safe and commercially viable green pesticides with some recent commercial developments along with their potential and constraints. Essential oils are defined as any volatile oil(s) that have strong aromatic components and that give distinctive odour, flavour or scent to a plant. These are the by-products of plant metabolism and are commonly referred to as volatile plant secondary metabolites. Essential oils are found in glandular hairs or secretory cavities of plant-cell wall and are present as droplets of fluid in the leaves, stems, bark, flowers, roots and fruits in different plants. The aromatic characteristics of essential oils provide various functions for the plants including (i) attracting or repelling insects, (ii) protecting themselves from heat or cold; and (iii) utilizing chemical constituents in the oil as defence materials. Many of the

essential oils have other uses as food additives, flavourings, and components of cosmetics, soaps, perfumes, plastics and as resins. Typically these oils are liquid at room temperature and get easily transformed from a liquid to a gaseous state at room or slightly higher temperature without undergoing decomposition. The amount of essential oil found in most of the plants is 1 to 2%, but can contain amounts ranging from 0.01 to 10%. For example, orange tree produce different composition of oils in their blossoms, citrus fruits, and/or leaves. In certain plants, one main essential oil constituent may predominate while in others it is a cocktail of various terpenes. In *Ocimum basilicum* (basil) methyl chavicol makes up 75% of the oil, β-asarone amounts to 70-80% in *Acorus calamus* (Bach) rhizomes, linalool, in the range of 50-60%, occurs in coriander seed and leaf oils procured from different locations at different time intervals and is by far the most predominant constituent followed by *p*-cymene, terpinene, camphor and limonene. Interestingly 2-decenol and decanal were the other most predominant constituents in leaf oil [7]. However, in other species there is no single component which predominates. Most essential oils comprise of monoterpene compounds that contain 10 carbon atoms often arranged in a ring or in acyclic form, as well as sesquiterpenes which are hydrocarbons comprising of 15 carbon atoms. Higher terpenes may also be present as minor constituents. The most predominant groups are cyclic compounds with saturated or unsaturated hexacyclic or an aromatic system. Bicyclic (1, 8-cineole) and acyclic (linalool, citronellal) examples also make the components of essential oils. However, intraspecific variability in chemical composition does exist, which is relative to ecotype variations and chemotype races or populations.

ESSENTIAL OILS AS GREEN PESTICIDES

Naturally green concept suggests the avoidance of use of any pesticide via public education and awareness-raising program, and also to inform public about the potential risk of pesticide use and alternatives that are available. In fact, such programs support the policy of "prudent avoidance". Use of essential oils or their components add to this natural concept owing to their volatility, limited persistence under field conditions and several of them having exemption under regulatory protocols. Essential oils are usually obtained via steam-distillation of aromatic plants, specifically those used as fragrances and flavourings in the perfume and food industries, respectively, and more recently for aromatherapy and as herbal medicines. Plant essential oils are produced commercially from several botanical sources, many of which are members of the mint family (Lamiaceae). The oils are generally composed of complex mixtures of monoterpenes, biogenetically related phenols, and sesquiterpenes. Examples include 1,8-cineole, the major constituent of oils from rosemary and eucalyptus; eugenol from clove oil; thymol from garden thyme; menthol from various species of mint; asarones from bach; and carvacrol and linalool from many plant species. A number of source plants have been traditionally used for protection of stored commodities, especially in the Mediterranean region and in Southern Asia, but interest in the oils was renewed with emerging demonstration of their fumigant and contact insecticidal activities to a wide range of pests in the 1990s [3]. The rapid action against some pests is indicative of a neurotoxic mode of action, and there is evidence for interference with the neuromodulator octopamine by some oils [8]. Several examples of essential oils like rose (*Rosa damascena*), patchouli (*Pogostemon patchouli*),

sandalwood (*Santalum album)*, lavender (*Lavendula officinalis*), geranium (*Pelargonium graveolens*) etc. are well known in perfumery and fragrance industries. Other essential oils such as lemon grass (*Cymbopogon flexuosus*), eulcalyptus (*Eulcalyptus globules*), rosemary (*Rosmarinus officinalis*), vetiver (*Vetiveria zizanioides*), clove (*Eugenia caryophyllus*) and thyme (*Thymus vulgaris*) are known for their pest control properties. While peppermint (*Mentha piperita*) repels ants, flies, lice and moths. Spearmint (*Mentha spicata*) and basil (*Ocimum basilicum*) are also effective in warding off flies. Similarly, essential oil bearing plants like *Artemesia vulgaris*, *Melaleuca leucodendron*, *Pelargonium roseum*, *Lavandula angustifolia*, *Mentha piperita* and *Juniperus virginiana* are also effective against various insects and fungal pathogens [9].

Studies conducted on the effects of volatile oil constituents of *Mentha* species are highly effective against *Callosobruchus maculatus* and *Tribolium castanum*, the common stored grain pests [10]. Essential oils derived from eucalyptus and lemongrass have also been found effective as animal repellents, antifeedants, insecticides, miticides and antimicrobial products; thus finding use as disinfectants, sanitizers, bacteriostats, microbiocides, fungicides and some have made impact in protecting household belongings. Essential oil from *Cinnamomum zeylanicum*, *Cymbopogon citratus*, *Lavandula angustifolia* syn. *L. officinalis*, *Tanacetum vulgare*, *Rabdosia melissoides, Acorus calamus*, *Eugenia caryophyllata*, *Ocimum* spp., *Gaultheria procumbens*, *Cuminum cymium*, *Bunium persicum*, *Trachyspermum ammi*, *Foeniculum vulgare*, *Abelmoschus moschatus*, *Cedrus* spp. and *Piper* spp. are also known for their varied pest control properties. Citronella (*Cymbopogon winterianus*) essential oil has been used for over fifty years both as an insect repellent and an animal repellent. Combining few drops each of citronella, lemon (*Citrus limon*), rose (*Rosa damascena*), lavender and basil essential oils with one litre of distilled water is effective to ward off indoor insect pests. The larvicidal activity of citronella oil has been mainly attributed to its major monoterpenic constituent citronellal [11]. Vetiver (*Vetiveria zizanioides*) essential oil obtained by steam distillation of aromatic roots contains a large number of oxygenated sesquiterpenes. This oil is known to protect clothes and other valuable materials from insect attack when placed in closets, drawers, and chests. Catnip (*Nepeta cateria*) essential oil is highly effective for repelling mosquitoes, bees and other flying insects. The most active constituent in catnip has been identified as nepetalactone. It repels mosquitoes ten times more than DEET. It is particularly effective against *Aedes aegypti* mosquito, a vector for yellow fever virus. Oil of *Trachyspermum* sp. is also larvicidal against *A. aegypti* and southern house mosquito, *Culex quinquefasciatus*.

COMMERCIAL PRODUCTS AND USES

In spite of considerable research effort in many laboratories throughout the world and an ever-increasing volume of scientific literature on the pesticidal properties of essential oils and their constituents, surprisingly few pest control products based on plant essential oils have appeared in the market place. This may be a consequence of regulatory barriers to commercialization (i.e. cost of toxicological and environmental evaluations) or the fact that efficacy of essential oils toward pests and diseases is not as apparent or obvious as that seen with currently available products. In the United States, commercial development of insecticides

based on plant essential oils has been greatly facilitated by exemption from registration for certain oils commonly used in processed foods and beverages [12]. This opportunity has spurred the development of essential oil-based insecticides, fungicides and herbicides for agricultural and industrial applications and for the consumer market, using rosemary oil, clove oil and thyme oil as active ingredients. Interest in these products has been considerable, particularly for control of greenhouse pests and diseases and for control of domestic and veterinary pests. Nonetheless, some U.S. companies have introduced essential oil-based pesticides in recent years. Mycotech Corporation produced an aphidicide /miticide /fungicide for greenhouse and horticultural use and for bush and tree fruits based on cinnamon oil with cinnamaldehyde as the active ingredient, however, this product is no longer being sold. EcoSMART Technologies has introduced insecticides containing eugenol and 2-phenethyl propionate aimed at controlling crawling and flying insects, under the brand name EcoPCO® for pest control professionals. An insecticide /miticide containing rosemary oil as the active ingredient has recently been introduced for use on horticultural crops under the name EcoTrolTM. Another product based on rosemary oil is a fungicide sold under the name SporanTM, while a formulation of clove oil (major constituent: eugenol), sold as MatranTM, is used for weed control. All of these products have been approved for use in organic food production. The primary active ingredients in EcoSMART products are exempt from Environmental Protection Agency registration and are approved as direct food additives or classifies as GRAS (generally recognized as safe) by the Food and Drug Administration. Several smaller companies in the U.S. and the U.K. have developed garlic oil-based pest control products and in the U.S. there are consumer insecticides for home and garden use containing mint oil as the active ingredient. Menthol has been approved for use in North America for control of tracheal mites in beehives, and a product produced in Italy (Apilife VARTM) containing thymol and lesser amounts of cineole, menthol and camphor is used to control Varroa mites in honeybees [13]. *Tagetes patula*, the French marigold species most common to gardens, has the ability to destroy attackers under the soil. Israel startup Botanocap, founded on oil encapsulation knowledge created at the Ben Gurion University of the Negev, is developing a slow release technology for essential etheric oils, to make relatively environmentally friendly pesticides. The company has developed a patented technology for the gradual release of essential oils and natural components. It possesses patents on capturing essential oils in capsules, to achieve the delayed release effect. Etheric oils can be produced from some 3000 plants. Controlled slow release with protecting the active components until release are the main point of Botanocap [14]. In terms of green pesticide technology using oil-in-water micro emulsions as a nano-pesticide delivery system to replace the traditional emulsifiable concentrates (oil), in order to reduce the use of organic solvent and increase the dispersity, wettability and penetration properties of the droplets is being developed. The advantages of using pesticide oil-in-water micro emulsions for improving the biological efficacy and reducing the dosage of pesticides would be a useful strategy in green pesticide technology.

CONCLUSIONS AND CONSTRAINTS

Pesticides based on plant essential oils or their constituents have demonstrated efficacy against a range of stored product pests, domestic pests, blood feeding pests and certain soft-

bodied agricultural pests, as well as against some plant pathogenic fungi responsible for pre and post-harvest diseases. They may be applied as fumigants, granular formulations or direct sprays with a range of effects from lethal toxicity to repellence and/or oviposition deterrence in insects. These features indicate that pesticides based on plant essential oils could be used in a variety of ways to control a large number of pests. In terms of specific constraints, the efficacy of these materials falls short when compared to synthetic pesticides although there are specific pest contexts where control equivalent to that with conventional products has been observed. Essential oils also require somewhat greater application rates (as high as 1% active ingredient) and may require frequent reapplication when used out-of-doors. Additional challenges to the commercial application of plant essential oil-based pesticides include availability of sufficient quantities of plant material, standardization and refinement of pesticide products, protection of technology (patents) and regulatory approval. Although many essential oils may be abundant and available due to their use in the perfume, food and beverage industries, large-scale commercial application of essential oil-based pesticides could require greater production of certain oils. In addition, as the chemical profile of plant species can vary naturally depending on geographic, genetic, climatic, annual or seasonal factors, pesticide manufacturers must take additional steps to ensure that their products will perform consistently. All of this requires substantial cost and smaller companies may not be willing to invest the required funds unless there is a high probability of recovering the costs through some form of market exclusivity (e.g. patent protection). Finally, once all of these issues are addressed, regulatory approval is required. Although several plant essential oils are exempt from registration in the United States, many more oils are not, and few countries currently have such exemption lists. Accordingly, regulatory approval continues to be a barrier to commercialization and will likely continue to be a barrier until regulatory systems are adjusted to better accommodate these products [3]. In fact, pesticides derived from plant essential oils do have several important benefits. Due to their volatile nature, there is a much lower level of risk to the environment than with current synthetic pesticides. Predator, parasitoid and pollinator insect populations will be less impacted because of the minimal residual activity, making essential-oil-based pesticides compatible with integrated pest management programs. It is also obvious that resistance will develop more slowly to essential-oil based pesticides owing to the complex mixtures of constituents that characterize many of these oils. Ultimately, it is in developing countries where the source plants are endemic that these pesticides may ultimately have their greatest impact in integrated pest management strategy. It is expected that these pesticides will find their greatest commercial application in urban pest control, public health, veterinary health, vector control vis-a-vis human health and in protection of stored commodities. In agriculture, these pesticides will be most useful for protected crops (e.g. greenhouse crops), high-value row crops and within organic food production systems where few alternative pesticides are available. There are thus the opportunities like (i) changing consumer preferences towards the use of ‘natural’ over synthetic products; (ii) existence of and growth in niche markets, where quality is more important than price; (iii) strong growth in demand for essential oils and plant extracts; (iv) potential to extend the range of available products including new product development through biotechnology; (v) production of essential oils and plant extracts from low cost developing countries.

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