International Journal of Ecotoxicology and Ecobiology
2020; 5(2): 13-22
http://www.sciencepublishinggroup.com/j/ijee
doi: 10.11648/j.ijee.20200502.11
ISSN: 2575-1727 (Print); ISSN: 2575-1735 (Online)

Review Article

Review: Essential Oils A Viable Pest Control Alternative

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To cite this article:
Julio Garay, Thomas Brennan, Dori Bon. Review: Essential Oils A Viable Pest Control Alternative. *International Journal of Ecotoxicology and Ecobiology.* Vol. 5, No. 2, 2020, pp. 13-22. doi: 10.11648/j.ijee.20200502.11

Received: October 31, 2019; **Accepted**: November 20, 2019; **Published**: June 9, 2020

Abstract: Indiscriminate use of pesticides is troublesome in our environment, creating toxic soils, groundwater, ponds and lakes, and oceans. Application of chemical pest control results in the death of many insects. These toxic chemicals interrupt entire ecosystems, causing havoc on pollinators such as bees and other beneficial insects, birds and animals as well as humans. It has been estimated that about 2.5 million tons of pesticides are used on crops each year, and that the worldwide damage caused by pesticides reaches $100 billion annually. This paper summarizes the results found in the scientific literature and highlights the fact that secondary metabolites of plants are involved in the interaction with other species, primarily in the defense response of plants against pests. These secondary metabolites sometimes called botanicals represent a huge reservoir of chemical structures with pesticidal activity largely underutilized in modern times compared to the industrial scale seen with chemical pesticides. There are several advantages of botanical pesticides including fast degradation by sunlight and moisture or by detoxifying enzymes. The target-specific nature and lower phytotoxicity of these botanicals have prompted researchers to investigate more in depth the mechanisms of action and structure-activity relationship of these botanicals in order to evaluate their potential as a viable pest management system. Higher plants produce a diverse array of secondary metabolites, which include phenols, terpenes, alkaloids, lignans and their glycosides. This variety of active compounds plays a significant role in the defense mechanisms of plants, and potentially offers a more sustainable platform to develop structural prototypes in order to identify lead molecules/products that can eventually serve as new environmentally friendly pest control agents. Alternative green methods of pest control are found in essential oils as single or multi component preparations. The positive results in repellency and killing of predatory insects proved to be both safe and biodegradable and have a broad spectrum of applications with no re-entry time. Essential oil pest controls are widely used in organic pest management practices globally, and the emerging market reflects steady growth in agriculture, home and garden, equine, livestock, turf, pets and more. Moreover, new fields of business, research and development for understanding the complexities of plant-based oils and their benefits can be created.

Keywords: Essential Oils, Antibiotic, Insecticide, Agriculture, Food, Crops, Sustainability, Fertilizers, Botanicals, Pesticides, Secondary Metabolites, Terpenes

1. Introduction

The agricultural crop losses due to insects range from 10% to 30% of the total harvest worldwide. Synthetic pest control continues to become less effective due in large part to insects building more immunity to conventional chemical pest control, leaving farmers to seek alternatives to improve best management practices [1].

When looking retrospectively in the history of essential oils utilized as pest control alternatives, Egypt can be used as a prime example. Essential oil pest control was used in ancient Egypt as early as 2600 BCE for mummification, in tombs to preserve bodies, and to repel insects and animals as a normal practice of preservation and pest control.

Throughout history over 2,000 species of plants have provided biologicals with insecticidal properties. These plants have developed defense mechanisms against insects since the beginning of life on earth, billions of years ago [2]. Today, as in ancient times, the main essential oils come from Egypt, Iran, Greece, Italy and the Orient. Distillation of extracts of plant flowers, barks, roots and seeds were created for easier transport into European markets.

Mosquitos and biting flies have created health hazards to humans and animals throughout time transmitting illnesses that have plagued humankind throughout history. These include malaria, dengue, West Nile virus, chikungunya, yellow fever, filariasis, tularemia, dirofilariasis, Japanese encephalitis, Saint Louis encephalitis, Western equine encephalitis, Eastern equine encephalitis, Venezuelan equine encephalitis, Ross River fever, and Barmah Forest fever [3]. Flies also carry additional horrific diseases such as typhoid, cholera and dysentery. Additional diseases carried by normal houseflies include tuberculosis, salmonella, and anthrax. There are many other diseases carried by insects, and essential oils not only kill these vectors but deter them from flying and crawling into sprayed barrier areas.

Plants create complex volatile odors and secondary metabolites, which are capable of warding off bacteria, fungus, and a host of predatory, and plant eating (phytophagous) insects, as well as beckoning in pollinators - all as survival mechanisms and creating biological control [4].

Biologicals

Terpenes are the most volatile and dominant constituents of essential oils. The properties of these chemicals fall into several categories including repellents, feeding deterrents, toxins, and growth regulators. Most can be grouped into five major chemical categories: (1) nitrogen compounds (primarily alkaloids), (2) terpenoids, (3) phenolics, (4) proteinase inhibitors, and (5) growth regulators [5].

Different methods of preparation and extraction of essential oils have been used such as tinctures, extractions from bark, tissue, seeds from plants; and different methods of application have been implemented using injector systems, backpack sprayers, hand sprayers, misting systems, and airplane applications. The effects of applying most essential oils are safe when applied around humans and animals. Their application will stop the ability of the receptors of insects to detect food and mates, and to reproduce. When their normal food sources and breeding partners are eliminated, insects are known to relocate. Insect displacement interrupts the “egg laying cycle”, eliminating new generations. Insects breathe through their bodies, and the scent of essential oil volatiles is absorbed directly into the body affecting the insect’s neurological/biological systems, causing paralysis, confusion, and death [6]. The application of plant extracts for pest control can accomplish many positive results. These volatile biologicals can:

1. Promote pest free zones.
2. Control insects and act as natural deterrents.
3. Exhibit low toxicity together with very low persistence.
4. Prevent insects outside the spray zone from crossing the essential oil barrier.
5. Are oil soluble, non-ionic liquids that effectively drive off insects and prevent infestation.
6. Repel flying insects, crawlers, hoppers, ants, pests, grubs, digging insects, mosquitoes, biting flies, and midges.
7. Are not harmful to people, pets or crops.
8. Have no minimum re-entry time.
9. Exhibit low environmental impact during and after use.
10. Are biodegradable.

2. Brief History of Essential Oils

The use of plants for curative purposes can be traced back to the very origin of humankind. Over the centuries, we have learned how to identify, isolate and synthesize some of the active principles found originally in nature, and to manipulate their reactivity by introducing or modifying existing functional groups for specific purposes. One group of natural occurring substances are the essential oils that have been used throughout history for perfumes, food additives, cosmetics, therapeutic agents, religious ceremonies, pet control and much more. In fact, human vanity has been a prime motor to drive individuals to stand out amongst their peers as in the royal and upper class citizens in ancient cultures such as China, Egypt, Greece, India, and Persia exemplified. They used perfumes and scented oils as a sign of distinction and refinement. This, in turn, motivated them to gain a deep understanding of the many properties and applications of essential oils [7, 8]. Even religious books frequently refer to oils as a paradigm of sanctification, and their odors as external manifestations of spirituality. In some of its passages, the Old Testament references the usage of these types of substances. One example is in Ezekiel passage: “Dan also and Javan going to and fro occupied in thy fairs: bright iron, cassia, and calamus, were in thy market.” Ezekiel [27, 19]. Another example is “He poured some of the anointing oil on Aaron’s head and anointed him to consecrate him.” Leviticus [8, 12]. The Quran in Surah 16 An-Nahl [verse 11] reads “He causes to grow for you thereby the crops, olives, palm trees, grapevines, and from all the fruits. Indeed in that is a sign for a people who give thought.” For most of the ancient cultures, fine spices used to hold the same value as gold itself. Many of the initial rudimentary methods to extract essential oils came from ancient eastern civilizations. However, it was in the Western World where systematic methods were developed to obtain these products. Greek historians such as Pliny, Herodotus and others wrote about the production of turpentine oil, which is possibly the first historically recorded essential oil extracted, although no details about the method used were provided.

Until late medieval times the method of choice for extraction involved the suspension of the plant specimen (flowers, seeds, bark, leaves) in oil for a certain period of time until the raw oil turned into a scented one with a new fragrance and with a much higher commercial value. In the twelfth century, the Benedictine Abbess Hildegard of Bingen (1098-1179) was authorized by the Church to publish her visions on medicine in her book Causae et Curae. The book describes methods used to figuring out possible causes as well as suitable remedies for illnesses suffered by people of her time [9]. When the plague invaded Europe, aromatic plants were used by doctors to protect the physician from infected patients and in some cases even to cure the victims. Later on Paracelsus observed the relationship between structure and activity, isolating some substances from plant extracts incorporating them in his medical practice. He established the foundation of the liniment by mixing soap in alcohol, to which camphor and sometimes a number of herbal essences, most notably wormwood, were added [10]. The New Gross (Destillirbuch fol 175-189) described "the correct method of preparing by distillation according to the rules of art, several precious oils" [11] that were introduced by the mid-1800s [11]. J. J. Houton (1818) proposed for the first time to focus the attention on the importance of the carbon/hydrogen ratio, but it was not until 1887 when O. Wallach, considered to be "the Messiah of terpenes", proposed a systematic classification of the essential oils. Ever since, the research on this subject has been focused on the separation and identification of these substances [12].

3. Chemistry of Essential Oils

The US Pharmacopeia Guideline for Assigning Titles to USP Dietary Supplement Monographs [13], defines an essential oil as natural aromatic complex mixtures of compounds mainly involving two chemical categories: Terpenoids and Phenylpropanoids. 1) Terpenoids are hydrocarbons containing diverse functional groups that contribute to the smell and the makeup of the plant. There are different kind of terpenoids such as: a) monoterpenoid ketones, alcohols, hydrocarbons, and esters such as carvone, menthol, α-pinene, and thymol acetate; b) sesquiterpenoids such as α-bisabolol and caryophyllene; and c) diterpenoids such as phyllocladene and (+)-kaurene). 2) Phenylpropanoids such as anethole, cinnamaldehyde, coniferyl alcohol. However, there may also be other volatile compounds such as phenols (e.g., methyl salicylate or vanillin), non-terpene alcohols, non-terpene alkanes, alkenes, alkynes, spiro-ethers, coumarin, sulfur-containing compounds such as allyl isothiocyanate in mustard oil, or aldehydes such as benzaldehyde in bitter almond essential oil [14].

Essential oils are liquids at room temperature; they do not mix with water but show a very good solubility in alcohol and other organic solvents. The "essential" connotation comes from the fact that their fragrance represents the "essence" of the plant itself. Because essential oils evaporate when exposed to the air at room temperature, they are also called volatile oils or ethereal oils. They may be present in the leaf, seed, bark, stem, root, flower, and other plant parts, and they may be obtained by steam distillation, extraction using various solvents, or several other techniques. Many of the essential oil components such as eugenol, limonene, carvacrol, thymol, phenethyl alcohol, α-terpinol, and safrol have been extracted and synthesized, and been made commercially available. Many antibacterial and antimicrobial activity studies have been conducted against different kinds of microorganisms [15, 16], with promising results for application in human health, food preservation and antimicrobial activity.

One more important group of compounds considered part of the essential oils family are Terpenes, which are hydrocarbons produced from combination of several isoprene units (C_5H_8).

Terpenes are synthesized in the cytoplasm of plant cells, and the synthesis proceeds via the mevalonic acid pathway starting from acetyl-CoA [17]. Comparative studies have been conducted to determine whether terpenes and terpenoids have similar antimicrobial activities. In fact, it was found that in most cases that terpenes have very low activity compared to their terpenoids counterpart [17]. This may be attributed to the presence of certain functional groups in the terpenoids' molecular structure that confer such an antimicrobial activity boost.

4. Toxicology of Essential Oils

Essential oils have been used for a long time for different purposes, such as functional foods and nutritional supplements, as additives to enhance the flavor and preservation of foods, and in pharmaceutical, therapeutic and cosmetic products. This long history of usage of essential oils is due to their free radical, antioxidant, anti-inflammatory and antimicrobial properties that make them suitable for alleviating different human illnesses and maladies among other desirable benefits. There is great interest in isolating, characterizing, synthesizing and testing for the biological activity of many of the natural products that are found in herbs, vegetables and fruits. Many of these natural products such as polyphenols are capable of preventing lipid oxidation and protecting foods from damage. Countless studies have been conducted with many essential oils to determine cytotoxic effects by manipulating concentrations of the essential oils as well as changing the cell line type to determine best inhibition conditions; at the same time, in order to diminish cell damage to the lowest possible levels without significantly sacrificing effectiveness. Fabian et al described the effect of essential oil dose variation on entero-invasive *E. coli.* He found that a 0.05% concentration of the extract completely inhibited the growth, showing significantly high cytotoxicity to intestinal-like cells cultured in vitro. In contrast, a 0.01% concentration of the same extract caused only a partial antimicrobial activity along with a less damaging effect to the Caco-2 cells utilized in these experiments [18]. Eugenol did not cause any kind of damage at lower concentrations, while carvatrol increased the apoptotic cell death slightly. However its inhibition properties also increased even at low concentrations. These experiments were conducted using single compounds and mixtures of essential oils to find out the relationship between the apoptotic and necrotic damage to cells versus the concentration of the extracts.

The scientific literature contains hundreds of publications on the subject of effectiveness and suitability of essential oils for agricultural applications to prevent infestation of crops at different stages of the plant development and post-harvest. Some of the most recent studies address the problem from different perspectives. Pavela et al pointed out the need to develop more efficacious stabilization processes such as microencapsulation; simplification of the complex and costly bio-pesticide authorization requirements; and optimization of plant growing conditions and extraction processes leading to more homogeneous and stable chemical compositions suitable for commercialization. Other researchers have been more focused on testing essential oils from different natural sources against multiple microorganisms or plagues to determine their biological activities. Pandey et al tested the nematicidal activities of several essential oils at concentrations as low as 250-500 ppm with high toxicity [19]. Hussain et al [20] measured the effect of seasons on the concentration and composition of the aerial part of basil oil and its antimicrobial activity on *S. aureus*, *E. coli, B. subtilis*, *P. multocida* and pathogenic fungi *Aspergillus niger*, *Mucor mucedo*, *Fusarium solani*, *Botryodiplodia theobromae*, *Rhizopus solani* using disc diffusion method and minimum inhibitory concentration measurements. They found a variation in the response less than 0.05% depending on the season. Nevertheless, in all cases, toxicity was always present regardless of the variation in composition influenced by the change of season [20]. In a study of insecticidal activities of *Ruta graveolens*, *Mentha pulegium* and *Ocimum basilicum* leaves, essential oils from south of Tunisia, Chaaban et al found that the lethal concentration (LC_{50}) values of *O. basilicum, M. pulegium* and *R. graveolens* were, respectively, 0.96, 0.3 and 1.02 µL/L air on *E. kuehniella,* and were 1.23, 0.31 and 1.97 µL/L air on *E. ceratoniae. M. pulegium* essential oil was more toxic to the two stored date pests *E. kuehniella* and *E. ceratoniae* at all tested concentrations [21]. Pavela et al reported the potential of the boldo *folium* (*Peumus boldus*) as an insecticide as their main active components, 1,8-cineole (20.7%), p-cymene (18.5%), limonene (9.1%), ascaridole (9.1%) and β-phellandrene (6.4%) were toxic to larvae of the *filariasis* vector *Culex quinquefasciatus* and adults of the housefly *Musca domestica*, showing LC_{50}/LD_{50} values of 67.9 mg·L−1 and 98.5 µg·adult−1, respectively, among other species tested during their studies with promising insecticidal activity despite the fact that the mode of action is still unclear [22]. Behiry et al reported that the essential oil from *Eriocephalus africanus* leaves when tested against some phytopathogenic bacteria including *Agrobacterium tumifaciens*, *Dickeya solani, Erwinia amylovora, Pseudomonas cichorii* and *Serratia pulmithica*, using the disc diffusion method and minimum inhibitory concentration (MIC) evaluation, proved effective in most cases, although. The concentration of the oil was found to be a determining factor in the size of the growth inhibition disc [23].

From these few examples of the hundreds of publications found in the literature, it is clear that the need to continue exploring more alternatives to create a sustainable model of biopesticides production to satisfy the current needs of the worldwide market, and to anticipate the growth of the future demands as the population continues raising and the need for more food produced under eco-friendly conditions becomes more urgent.

5. Pharmacology of Essential Oils

The mechanisms of the toxic action of terpenoids are still poorly understood. It is accepted that microorganisms can be classified into five major groups: viruses, bacteria, algae, fungi and protozoa [24]. From the clinical point of view, bacteria can be further classified taxonomically base on genera and species, for example, *Mycobacterium* which has mycolic acids within its cell wall), or classified base on requirement of strict anaerobic conditions for growth (in this category *Fusobacterium sp.* is an example), or according to which region of the body that they inhabit as part of normal flora; or whether they are frequently isolated or cause disease (for example, *Clostridium difficile* causes disease only when they have a special opportunity to gain entrance into the body.) Prokaryotic cells are also characterized according to their morphology; they exist in a variety of shapes or morphologies. The three basic shapes are *cocci* (roughly spherical), *bacilli* (rod-shape) and *spirals* [25]. Bacteria can typically be differentiated based on gram stain appearance under the light microscope. For instance, the *cocci* group has round shape and stain either red or blue. The *bacilli* have rod-like shape and stain either red or blue as well. These characteristics account for general features in how both virulence factors and antigenic determinants are expressed, and for general distinctions in susceptibility to antibiotic drugs. Thus, the gram stain is considered an important characteristic of bacteria. However, the gram stain itself is not used for the identification of organisms.

The cell wall structure has a significant effect on how easily drug molecules may enter a fully formed bacterial cell. It is known that many membrane processes, such as transport or signal transduction, depend on the fluidity of the membrane lipids, which in turn depends on the properties of the fatty acid chains. Fatty acids in membrane bilayers can exist in an ordered, rigid state or in a relatively disordered, fluid state. The transition from the rigid conformation into the fluid one and vice versa depends on temperature. This transition temperature depends on the length of the fatty acid chains and its degree of unsaturation. Bacteria regulate the fluidity of their membranes by varying the number of the double bonds and the length of their fatty acid chains [26].

Several examples of studies using essential oils to control fungi can be found in the literature. (Freitas-Souza et al, 2018) reported the use of *Melaleuca alternifolia* essential oil to control aflatoxins that can be a potential contaminant present in vegetable protein used to feed catfish. The catfish were fed with aflatoxin-contaminated protein tested in triplicate, and analyzed at periods of 5 days and 10 days of dietary intake. The results showed a reduced antioxidant enzyme activity together with increased lipid peroxidation (LOOH) and protein carbonyl (PC) content in the plasma and in the liver, with 16.6% mortality. With the addition of the essential oil a protective effect was observed; inhibition of increase levels of ROS, LOOH, and PC in plasma and in the liver, together with significant reduction of liver damage as well as an increase in antioxidant protection effects [27].

6. Applications of Essential Oils in Agriculture

Extracts of essential oils can be considered as sources of raw materials whether used singularly as pure products or blended for their combined properties to stave off pests in agriculture. Because of their stability and effectiveness, it is preferred to blend them with a carrier to prevent plant damage as pure essential oils may cause physical harm to the foliage. Multi-component blends are broadly used in many cases to protect crops. For example, applications to nightshades of red thyme oil along with clove, garlic and lemongrass will decimate chewing caterpillars, and prevent infestations of trips, grubs, and brown russet mites. There are several recent examples of essential oil applications tested as potential pest control agents such as the study done by Chaaban et al in which they evaluated the insecticidal activities of *Ruta graveolens, Mentha pulegium* and *Ocimum basilicum* leaves essential oils from south of Tunisia. This study evaluated the fumigant toxicities of these essential oils toward the most important and destructive insects that attack dates in storage. The most active components of *Ruta graveolens* oil identified by GC-MS were linalool (29.23%), methyl cinnamate (18.97%) and eugenol (5.84%), followed by 1,8-cineole (5.74%), α-cadinol (5.69%), estragol (4.72%) and α-bergamotene (4.24%); whereas *M. pulegium* essential oil had 1,8-cineole (14.60%), p-menthan-3-one (14.9%), piperitenone (11.4%), carene (10.19%), menthol (8.76%), trans-caryophyllene (6.64%) and menthyl alcohol (6.14%) as major components [21]. Chaubey studied the insecticidal properties of *Zingiber officinale* and *Piper cubeda* against *Tibolim castaneum* which is a wheat flour insect pest, finding activity at concentrations as low as 0.003215% and with LC_{50} values against this insect's larvae of 2.29, 1.23 and 0.97 $\mu l/cm^3$ respectively. This opens the possibility for these oils to become a potentially effective and environmentally friendly insecticides [28]. Bigdoli et al reported that the Rosmarinus officinalis essential oil may influence metabolic pathways in such a way that it can limit the interactions between plant and beneficial bacteria, producing an ineffective performance in plant growth promotion and disease management [29]. Ibanez and Blazquez found out that the active components of essential oils of ginger (α-zingiberene (24.9±0.8%), β-sesquiphelladrene (11.7±0.3%), ar-curcumene (10.7±0.2%), and β-bisabolene (10.5±0.3%)), and the active components of turmeric oil (ar-turmerone (38.7±0.8%), β-turmerone (18.6±0.6%), and α-turmerone (14.2±0.9%)) caused weed decay without producing phytotoxic effects in the crops [30]. While the majority of these studies target the germination stage of weeds [31], it is important to note that the effects of the application of essential oils goes far beyond the herbicidal effects into the preservation of the normal beneficial soil microbial activity, especially desirable for organic agricultural production.

In addition to the application of essential oils directly to the farm-lands as anti-fungicidal, herbicidal, and insecticidal with remarkable results as have been already noted by many researchers, much attention has been extended to the post-harvest stage as shown in the study done by Saleh et at [32]. They applied Arabic Gum, Jojoba oil and Moringa oil at 10% w/v each at the 100% rate alone to Le Conte fruits for preservation. These oils resulted in a reduction in fruit weight loss and decay percentages, while improving fruit quality and extending storage fruit life and fruit shelf life.

Another important factor is the stability of the essential oil preparations due to their volatility and lack of solubility in aqueous media. Kfoury et al studied the effect of encapsulation using cyclodextrins as the molecular structure of the carrier favors increased solubility (up to 16-fold) as well as protection of the essential oils from photodegradation (up to 44-fold), conferring a slow release property, therefore making them more lasting and effective over time [33]. The oil emulsions can be used as herbicide formulations. For commercialization, investigation of mixed emulsions of oils and field trials may lead to the introduction of a tailored-made herbicide for sustainable weed management [32].

Essential oil pest control, which can be applied singularly using one essential oil with carriers or multiple components of essential oils with added carriers, is considered safe, and farmers do not need to dress in specialized protective gear when applying products that are formulated with essential oil blends. There is no re-entry time when spraying products considered safe for humans, animals, wildlife and the environment.

7. Essential Oils in Human Health

There are many examples of the use of essential oils throughout history. In particular, the recorded history about Chinese and Indian medicine between 3000 and 2000BC has listed more than 700 substances including cinnamon, ginger, myrrh, and sandalwood as being effective for healing [34]. Hippocrates, considered as the "father of medicine", used aromatic fumigations to eradicate the plague in Athens. In addition, the aromatic baths and massages were used to strengthen the Roman soldiers. However, the most interesting aromatic traditions belong to the ancient Egyptians. Doctors from around the world used to go to Egypt to learn and master the use of essential oils [35]. Historical records of essential oils indicate Thieves oil use date back to the ancient Chinese and Egyptians. While the specific year that the

Egyptians started using aromatic herbs and aromatherapy is not known, evidence traces it back to around 3500 BC. Over three thousand years later, the ancient Greeks also took advantage of the benefits that essential oils offer. Hippocrates used them in the treatment of his patients. The temple of Isis located on the island of Philae had a sacred room for a cleansing ritual involving use of essential oils. The Book of Exodus has a recipe for a holy anointing oil, and in the New Testament, three wise men gifted the Christ child with myrrh and frankincense [36]. Essential oils create a barrier for predatory insects while not harming pollinators. Farmers and beekeepers seek safer approaches for workers and the environment. Many farmers and technicians when applying chemical pest control agents are required to wear OCA regulated suits that are considered hazmat suits. After application of these toxic sprays, it may take a day or more before humans can reenter applied areas of pest control [37]. With essential oils, farmers and technicians in regular clothing can apply biologicals nearby grazing cattle and there is no indicated re-entry time [38]. Applications of essential oils in organic classification can be allowed under 25B Exemptions, meaning that they are classified as minimum risk pesticides. Essential oil pest control can be used in an integrated crop management program as normal protocol for farms globally, decreasing exposures to groundwater pollution in comparison to the synthetic alternative [39].

8. Market Size for Essential Oils

Essential oil pest controls are increasing at a fast rate due to global demand for safe pest control for humans, animals and the environment. The U.S. essential oil market size was valued at USD 3.36 billion in 2015 and is expected to witness an estimated growth rate of 9.0% from 2016 to 2024 [40]. In a recent review paper on neem and other botanical insecticides, three barriers to the commercialization of new products of this type were identified: (i) the scarcity of the natural resource; (ii) the need for chemical standardization and quality control; and (iii) difficulties in registration [41]. As the essential oils and their purified constituents have a long history of global use by the food and fragrance industries, and most recently in the field of aromatherapy, many of the oils and/or constituents that are pesticidal are readily available in diverse quantities at low to moderate cost [42]. A number of essential oil constituents are available commercially in reasonable purity (95%), and essential oil producers and suppliers can often provide chemical specifications for even the most complex oils. Of great importance, some of these materials are exempt from the usual data requirements for registration [43] if not exempt from registration altogether, at least in the USA. Some American companies have recently taken advantage of this situation and have been able to bring essential-oil-based pesticides to the marketplace in a far shorter period than would normally be required for conventional pesticides. Thoron Environmental Services is a good example in the area of pest control for agricultural crop protection. This company has developed in the past eleven years biological pesticide products sold in the market under label names such as ICT Mosquito Cure, ICT Essential One, GGO's Mosquito Mist, and Repel. Such products are concentrated multiple component essential oil pest control blends that can be used monthly as an alternative pest control method for all sorts of insects and can be used globally in agriculture as well as in greenhouses and open-field farming [44].

Application of essential oils as pest control systems used in homes, gardens and commercial gardens is another area experiencing a very dynamic growth in the United States [45]. Massive insect decline calls for a responsible approach to pest management, and essential oils can meet the markets demand for alternative pest control strategies, by controlling insects without harming humans and the ecosystem [46]. A quick web search will show numerous businesses throughout the United States taking on a holistic approach to pest control along with organic certified farms using all essential oils to help ward off predatory insects and to keep fungus levels low during heavy rainy seasons [47].

Botrytis is a serious disease due to a grey mold fungus that can attack a wide range of plants. It is known for pre- and post-harvest losses of grapes, strawberries, and blueberries. The benefits of the antifungal essential oils - Holy Basil Tulsi, Tulasi, *Madura-tala., O. sanctum*, *P. persica* and *Z. officinale* – are strongly indicated by their lower Minimum Inhibitory Concentration (MIC) as compared to other fungitoxic oils. The selected oils were subsequently standardized through physico-chemical and fungitoxic properties [48].

Control of fungus and foodborne bacteria using essential oils in post-harvest stage is also an emerging area, as the small fruits sector has become in a multi-billion dollar industry in the US, and it is an economically important sector in many other countries [49]. However, they are perishable and susceptible to physiological disorders and biological damage. Food safety and fruit quality are the major concerns of the food chain from farm to consumer, especially with increasing regulations in recent years. At present, the industry depends on pesticides and fungicides to control food spoilage organisms. However, due to consumer concerns and increasing demand for safer produce, efforts are being made to identify eco-friendly compounds that can extend the shelf life of small fruits [50]. Most volatiles and essential oils produced by plants are safe for humans and the environment, and lots of research has been conducted to test the *in vitro* efficacy of single-compound volatiles or multi-compound essential oils on various microorganisms. Use of thyme and savory essential oil vapor treatments control brown rot and improve the storage quality of peaches and nectarines. However, exposure to grey molds is concerning, and the use of chitinase products in combination with essential oils is a powerful combination to control food spoilage [51].

Turf management using essential oils has become economically significant in the marketplace. In fact, essential oils such as cedar wood, garlic and lemongrass are used to control grubs, ants, ticks, fleas and a host of predatory insects. They are used in commercial turf care and golf courses throughout the United States and Europe [52].

Safe Mosquito and tick control -25b FIFRA Exemption-cedar wood oil is safe and effective against disease carrying mosquitoes and ticks. Fortune 500 companies are selling essential oils to high-end accounts in Florida, Maryland, Virginia, and Rhode Island to keep their customers with re-entry times in minutes instead of hours. The focus of cedar oil is for larval stage insects in the soil like white grubs. Exposure to the cedarwood oil formulation immediately triggers the erosion of the exoskeleton of insect eggs and larvae, which results in their dehydration, subsequently rendering their pre-life status DBH (dead before hatch) [53].

Cedarwood oil has many modes of action and has shown that insects do not build up a resistance to it. Cedarwood oil will slow down to and stop the ability of the insects' receptors to detect food, mates, and to reproduce. When comfort levels are destroyed, insects become confused and relocate [54]. Insect displacement interrupts the "egg laying cycle" and eliminates a new generation of arthropod. All insects breathe through their bodies. therefore, the scent is absorbed directly into the body affecting the insect's neurological/biological systems, causing paralysis, confusion, death or flight. Cedarwood oil consistently and persistently will create a barrier of re-entry and increase the desired results [55].

9. Essential Oils and Polymers

Antimicrobial and antifungal activities displayed by essential oils have been extensively documented in the literature [56-58]. Nevertheless, there are some limitations associated with their sensitivity to light and temperature, as well as their volatility and poor water solubility [59]. Many industries have turned their attention towards essential oils, as they are safe and regarded as non-toxic for human and animal consumption. The food industry for example, has benefited from the development of films containing essential oils to preserve products from environmental conditions, due to the presence of natural occurring antifungal and antimicrobial substances that will maintain the quality of the product while expanding their shelf-life [60]. Different biopolymers such as chitosan, hydroxypropyl methylcellulose, starch, carboxymethyl cellulose, and kefiran have been used to prepare nanoemulsions, composite films, and gels containing essential oils in order to lower or completely eliminate microorganisms that can spoil, damage or infect the final product. Essential oils can be used as both solvent and active material in light-responsive nano capsules synthesized via mini emulsion polycondensation [61]. Microencapsulation is also a common method used to prepare stable micro-gels loaded with the essential oil of choice. The coating provided by the polymer will surround the essential oil molecules, preventing them from being exposed to environmental conditions, extending their life and stabilizing these products for longer periods of time [62]. In a study, Khalili et al reported a nanogel preparation using chitosan and benzoic acid as a strategy to preserve thyme essential oil, which according to their findings, exhibits a considerable capacity to inhibit *aspergillus fulvous* growth [63]. Oliveira et al presented a study conducted against *Colletotrichom acutatum*, which is a pervasive pathogen for strawberry using carboxymethylcellulose to preserve the activity and integrity of the essential oils tested in their study [64]. Zanetti et al studied the effect of geranyl cinnamate on *Escherichia coli* and *Staphylococcus aureus* in a polycaprolactone matrix using the miniemulsfification/solvent evaporation method. The stability of the nanoparticles was monitored and only after 72 hours was the essential oil released [65]. Dusankova, M et al, reported the preparation of essential oil microspheres utilizing polylactic acid and poly (methyl methacrylate matrices with encapsulation efficiencies higher than 75% [66]. Kavetsou, E. et al published a study done using commercial Baker's yeast to encapsulate *Mentha pulegium* to test pesticide effectiveness against *Myzus persicae* reaching a loading capacity of 33% on average, Kavetsou [67]. Bai et al prepared silkworm pupae mircroparticles containing linolenic acid ethyl ester raising the antioxidant activity up to 85% [68]. Waterhouse et al reported the preparation of 3-D polymer composites to improve delivery and effectiveness of active molecules [69]. This method allows the polymeric matrix to be customized based on the conditions such as viscosity, solubility, charge, conductivity so it will be more specific for the intended application. The list of materials, methods of preparation, type of essential oils utilized, and applications go beyond the scope of this work, which indicates the versatility and application of polymers to enhance the essential oils shelf life and effectiveness.

10. Conclusions

Essential oils have a very long and rich history across time and cultures regardless of the location around the globe. Humankind has managed to recognize and utilize the benefits of the active ingredients present in plants; and has created the necessary resources and technologies to extract such products; and after thousands of years of experimentation has come to learn the best ways to apply them accordingly. It was not until synthetic pesticides made their breakthrough in the market, pedaled by the big corporations and media in the 1930s, that gatherers first and primitive farmers later on, managed to coexist harmoniously with their environment while benefiting from the abundance of harvesting under natural conditions. The massive and indiscriminate use of synthetic pesticides certainly have brought more abundant crops, but the cost of it has been very high to hundreds of species depleted because of the acute toxicity and deleterious effects on their natural habitat, soil, water, air; so wildlife and human communities have severally been affected by the poisonous effects caused by these products. In spite of the adverse effects and overuse of chemical pesticides, it is comforting nevertheless to contemplate the flood of examples in the scientific literature coming from all corners of the world corroborating what was already known to our ancestors, as they made it a routine practice. Billions of dollars are now invested in research and development of products centered on the use of naturally occurrence molecules in an effort to recover a healthier equilibrium with our environment. It is still a long way to travel, but people nowadays are more environmentally conscientious and in combination with practices like organic farming, it is expected that we will see a continuous increase of these type of products in the marketplace, as more and more people prefer consuming organic products in spite of the usual higher cost. As the culture changes, the habits also evolve and reencounter our true essence should be expected in future generations.

Conflict of Interest

The authors of this manuscript certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Acknowledgements

The authors want to express their gratitude to Dr. Neal Phillip, chairperson of the Department of Chemistry, Earth Sciences and Environmental Sciences at Bronx Community College for his support and valuable feedback.

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