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A Review – Microencapsulation of Bio-Pesticides using Natural Oils

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ABSTRACT

Microencapsulation is a process of building a functional barrier between the core and wall material to avoid chemical and physical reactions and to maintain the biological, functional, and physicochemical properties of core materials. Microencapsulation of marine, vegetable, and essential oils has been conducted and commercialized by employing different methods including emulsification, spray-drying, coaxial electrospray system, freeze-drying, coacervation, in situ polymerization, melt-extrusion, supercritical fluid technology, and fluidized-bed-coating. Spray-drying and coacervation are the most commonly used techniques for the microencapsulation of oils. The choice of an appropriate microencapsulation technique and wall material depends upon the end use of the product and the processing conditions involved. Microencapsulation has the ability to enhance the oxidative stability, thermostability, shelf-life, and biological activity of oils. In addition, it can also be helpful in controlling the volatility and release properties of essential oils. Microencapsulated marine, vegetable, and essential oils have found broad applications in various fields. This review describes the recognized benefits and functional properties of various oils, microencapsulation techniques, and application of encapsulated oils in various food, pharmaceutical, and even textile products. Moreover, this review may provide information to researchers working in the field of food, pharmacy, agronomy, engineering, and nutrition who are interested in microencapsulation of oils.

1. Introduction

Microencapsulation is a technique for entrapping liquid or solid molecules in polymeric shell material [1]. This has now been commonly applied in various fields like pharmaceuticals, foods, cosmetics, fragrances, adhesives, perfumery, textiles, self-healing paints, coatings, and pesticides [2-8]. Pesticides are important labor-saving agrochemicals useful for the improvement of the quality and quantity of agricultural products. However, extreme use and misuse of pesticides has resulted in environmental pollution, adverse effects on the ecosystem, and loss of biodiversity. In recent years, microencapsulation of pesticides has been demonstrated to be a promising remedial technique for resolving and addressing such issues [8, 9]. It has resulted in important advantages, such as the protection of the active ingredient (a.i.) from early degradation, evaporation and leaching, safety to the applicator, and prolonging the effect of pesticides against different pests due to the controlled release of a.i. [10-14]. In our research work, neem seed oil, as a biopesticide, was used as the core material Neem oil (*Azadirachta indica* A. Juss) extracted from the neem seed kernel is an excellent insect-controlling agent. Neem oil contains Azadirachtin, a major ingredient responsible for the insect-controlling effect. The pest-control potential of neem, which does not kill pests like a neurotoxin but instead affects their behavior and physiology, has been recognized for the past decade. Though subtle, neem's effects, such as repellency, feeding and oviposition deterrence, growth inhibition, mating disruption, chemo-sterilization, etc., are now considered far more desirable than a quick knock-down in integrated pest management programs, as they reduce the risk of exposing the pest's natural enemies to poisoned food or starvation [15]. Neem oil enters the system of insects and blocks the real hormones from working properly and hence impairs their activity. The population eventually plummets, and gradually disappears. Thus, neem oil can control at least 200 species of agricultural and storage insect pests belonging to different orders. The purpose of encapsulation of neem oil was to prevent its rapid degradation in the environment and, thus, sustained release and improved stability in the environment, which is necessary to improve its effectiveness [16]. The microencapsulation of neem oil was designed by forming a continuous polymeric film of phenol formaldehyde (PF) by in-situ polymerization.

Nanoformulations have the ability of improving biological activity of lipophilic compounds by increasing the surface area per unit of mass [17-19]. Moreover, high kinetic stability, low viscosity and optical transparency make them very attractive systems for many industrial applications [20, 21]. Karanj oil and castor oil nanoemulsion finds applications in fields like agriculture and pharmaceuticals. Karanj oil and Neem oil are the two effective botanicals commonly used to control insect pests and mosquito larves [22]. The nanoformulations of single and mixture of non-edible oils with artificial surfactants and natural surfactants are effective for pesticidal activity [23]. Oil extracts from fruits and seeds of Neem (*Azadirachta indica*) and Castor (*Ricinus Communis*), Karanj (*Pongamia glabra*) are explored for their larvicidal activity against vector of filaria, *Cx. quinquefasciatus* and *Aedes agypti* mosquitos [19, 24]. The use of encapsulation of active agents for control release applications is a promising alternative to solve the major problem of food or agro products [25]. The process of entraping active agents within a carrier material called as encapsulation is the useful tool to improve the delivery of bioactive molecules into pesticides. Controlled release formulations have the potential to reduce the environmental problems associated with the application of pesticides [25]. Microspheres prepared by microencapsulation techniques are the most frequently employed in delivery platforms. Alginates are polysaccharides derived from brown sea weed that are made up of linear chains of a-L-guluronic acid (G) and b-D-mannuronic acid. Alginates are anionic compounds with the ability to produce hydrogels in the presence of divalent cations like Ca^{2+}, which is one of their most important properties [26-28]. Alginate hydrogels are biocompatible polymers having mucoadhesive abilities that have been proven to be useful in a variety of pharmaceutical and biotechnological systems [29, 30]. They have been extensively used in the controlled release of pests and drug molecules [31].

Currently, all polymeric shell materials used for encapsulation by in situ polymerization are based on petroleum feed stock. However, there are reports regarding renewable sources based on cores, including neem and karanja oils. This is the first report regarding efficient encapsulation of a biobased core (karanja oil) by biobased shell-wall material (cardanol based) via in situ polymerization. In addition, our investigation has focused on designing shell components and the release of core substances,

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wherein both are based on renewable sources. The continuous application of synthetic organic pesticides in the agricultural field for controlling pests affects bio-diversity, leading to environmental damage affecting living organisms and human health.[32] Hence as an alternative green approach, agriculturists are now interested in the application of formulated bio-pesticides, which have attracted the attention and interest of those concerned with integrated crop management (ICM) as an efficient method of pest management by developing formulations that are safer and environmentally friendly [33].

2. Bio Pesticides in Agriculture

Chemical pesticides can have detrimental implications on individuals and society, as well as toxic effects to non-target creatures, which has an adverse effect on ecosystems [34]. Several risks connected mostly with mishandling and excess use of chemical pesticides had prompted the development of alternate solution for pest management.

Biopesticides have no toxic effect in the managing of plant pathogens, these are as secure and efficient solutions for both the applicator and the user. These are environmentally safe, easily biodegradable, target specialized and do not develop resistance among pests. Whereas biopesticides offer benefits such as a secure ecosystem and good produce for public intake, there are still some barriers that obstruct its use as pest and disease management tools. At field conditions higher dosages of such component substances are required for better activity [35]. The habitat wherein crops develop represents the frequency of bioactive component in biopesticides. The range of crops and its cultivars also affect the component active ingredients resulting in variations of disease reactions. The process of production utilized has an impact on the efficacy of plant extract. It might be difficult to achieve the proper quantities of functional and inert components throughout the formulation process. In addition, there are still no standardized processing techniques or recommendations besides efficiency evaluation, especially in the field conditions.

Whereas most in vitro studies give great outcomes, variations are usually present in the field condition due to low storage period or occasionally bad quality of sources or processes of production.

3. Essential Oils as Pesticides

An important difference between the production of botanical insecticides (complex mixtures of several, often closely related secondary metabolites) and synthetic pesticides (generally based on a single active ingredient) is the standardization of the active ingredient(s), that is, there can be great variability in the quality and composition of botanical pesticides. The source of variability might be natural or might occur as a result of different harvest or extraction methods [36]. By creating standard criteria for botanical product composition, extraction methods, blending, or fortification, it might be possible to achieve greater uniformity. Compared with synthetic pesticides, botanical insecticides are relatively unstable and breakdown faster when exposed to light, temperature, and air. Essential oils are found in special secretory structures either on the surface of the plant or within the plant tissues. Once plant chemicals have been removed from their plant compartments, their constituents become prone to oxidative damage, chemical transformations, or polymerization reactions as a result of destructive extraction methods. As plant extracts age, their quality declines further. The compositional diversity of the botanical extracts and the instability of their constituents can make botanical insecticides unsuitable for applications where residual effects over long periods of time are desirable. Novel technologies that consider the behavior and control level of individual constituents of botanical insecticides smooth the path for a new generation of essential-oil insecticides that are applied in a manner closer to the natural defense methods used by plants. Additionally, botanical insecticides have been successfully used in combination or rotation with synthetic pesticides. Considering the relatively higher cost of botanical insecticides and their limitations, the integrated use of botanical insecticides with other control measures could be a more practicable option [37].

Essential oils interfere with basic metabolic, biochemical, physiological, and behavioral functions of insects (Table 1). Genera with such effects are distributed in a limited number of families, such as Myrtaceae, Lauraceae, Rutaceae, Lamiaceae, Asteraceae, Apiacecae, Cupressaceae, Poaceae, Zingberaceae, and Piperaceae. The point of entry of essential oils is important for their toxic (pesticidal) effect. Essential oils can be inhaled, ingested, or skin absorbed by insects. Plants of families Myrtaceae, Lamiaceae, Asteraceae, Apiaceae, and Rutaceae are considered to show antiinsect activities against specific insect orders like Lepidoptera, Coleoptera, Diptera, Isoptera, and Hemiptera. The physiological actions of essential oils on insects have not been studied enough, but symptoms after treatments suggest a neurotoxic mode of action [38].

Table 1 Pests and corresponding essential oils with pesticidal activity

Pest	Essential Oil
Ants	Peppermint, Spearmint
Aphids	Cedarwood, Hyssop, Peppermint, Spearmint
Beetles	Peppermint, Thyme
Caterpillars	Peppermint, Spearmint
Chiggers	Lavender, Lemongrass, Sage, Thyme
Fleas	Peppermint, Lemongrass, Spearmint, Lavender
Flies	Lavender, Peppermint, Rosemary, Sage
Gnats	Patchouli, Spearmint
Lice	Cedarwood, Peppermint, Spearmint
Mosquitoes	Lavender, Lemongrass
Moths	Cedarwood, Hyssop, Lavender, Peppermint, Spearmint
Plant lice	Peppermint, Spearmint
Slugs	Cedarwood, Hyssop, Pine
Snails	Cedarwood, Pine, Patchouli
Spiders	Peppermint, Spearmint
Ticks	Lavender, Lemongrass, Sage, Thyme
Weevils	Cedarwood, Patchouli, Sandalwood

Footnote: *Essential oil used at home as alternative pest management products*

4. Encapsulation Techniques for Biopesticide Production

Encapsulation refers to a process, where an active ingredient, such as chemicals, drugs, and even tissues is caged inside an encapsulating or gelling agent to form a stable complex. Encapsulation is a widely-used, technique in pharmaceuticals and food industries. In agriculture, development and use of biopesticides often encounter with problems, like human exposure related issues, chemical residual issues, and environmental contamination issues.

However, encapsulation of the developed biopesticides can help in minimizing all these issue in practice. The method of encapsulation can vary depending on the active ingredient of the biopesticide. In addition, the encapsulating chemical can also be of many choices, ranging from solids to liquids, at times even gases. Similarly, shape of the encapsulation can be different, including spherical, bead-structural, capsules, and multi-core/shell. Thus, to finalize an encapsulation method, various factors, such as biopesticide particle size, physical and chemical nature, biocompatibility, release mechanism, and encapsulating material play vital roles [39].

A number of encapsulation techniques are there which are employed in the agricultural sector on the basis of their physical or chemical natures. For instance, some of the most widely used physical encapsulation processes are gelation, fluidize coating, and spray drying. Similarly, some of the popular chemical processes include polymerization, melt-dispersion, and coacervation. At many occasions, the choice of encapsulation technique can actually alter the efficacy of the biopesticide. For example, the antimicrobial activity essential oils from oregano and thyme were amplified by the use of encapsulated carvacrol. Likewise, the toxic effects of carvacrol on the nontarget organisms were evaluated [40].

5. Conclusion

Presently, the use of biopesticides is gaining recognition and farmers are showing interests to adopt it as an alternative to the chemical pesticides. As the biopesticides cost a fraction of the cost of the chemical pesticides, use of the biopesticides seems to be a pocket-friendly option. Their advantages and less toxicity natures are gaining the biopesticides a good marketplace in India. On the other hand, various encapsulation techniques are improving the biopesticide stability, bioavailability, and release mechanism. These collectively reflect on the success of various encapsulated biopesticide formulations. Having said that, advances in the encapsulation techniques are essential to achieve even more stability and effectiveness of the bio pesticides. Microencapsulation using natural oils for agricultural purposes offers valuable insights into a promising technological approach to enhance agricultural sustainability. The integration of natural oils via microencapsulation not only improves efficiency but also promotes environmental stewardship in farming practices. Further research and development are needed to address scalability and economic feasibility, but the potential benefits for both farmers and the environment make this an exciting area of exploration in modern agriculture.

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This review highlights the importance of continued research in this field to optimize formulations, expand applications, and ensure widespread adoption of microencapsulated natural oils in global agriculture.

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