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A Brief Overview On The Essential Oils' Encapsulation With Biodegradable Polymers

G.G. Lenetha*

Department of Life Sciences, Central University of Technology, Free State, Bloemfontein, South Africa

ABSTRACT
It is known that the chief benefit of natural products such as essential oils is that they do not increase antibiotic resistance compared to the long-term use of synthetic antibiotics. Essential oils demonstrate many applications in various sectors for medicinal, agriculture, food, and health purposes due to their antibacterial, antiviral, antifungal, anticarcinogenic, antimutagenic, anti-inflammatory and antioxidant properties. Although essential oils have many useful properties, their chances of success and scale up at industrial level becomes a challenge because they possess some limiting factors in their use such as hydrophobic property (which needs to be encapsulated before use), high volatility, and high risk of deterioration upon direct exposure to heat, humidity, light, or oxygen. Therefore, encapsulation of essential oils with polymers would be the ideal method for the preservation of essential oils. This is because it offers benefits such as improved stability and water solubility, effective protection against degradation, prevention of volatile components evaporation and enhance antimicrobial activity against food-borne pathogens. It is clear from this review that using essential oils (EOs) encapsulation in biopolymer-based materials could be one of the strategies and promising antimicrobial agents for bacterial pathogens. However, further studies need to be done to research the properties of many other biopolymers encapsulated essential oils due to their promising contribution in reducing environmental solid waste caused by conventional plastics.

Keywords: Essential oils, encapsulation, biodegradable polymers

INTRODUCTION

Among the natural compounds with antimicrobial activity such as marine, vegetable, and essential oils; essential oils received the most attention because they do not increase antibiotic resistance compared to the long-term use of synthetic antibiotics [1,2]. According to Kavanaugh and Ribbeck (2012) [3], plant-derived essential oils have been used for hundreds of years as natural medicines to contest a wide range of pathogens, including bacteria, fungi, and viruses. Furthermore, in recent years there has been an increased interest in the use of essential oils because of their antifungal, antibacterial and antioxidant properties [4,5]. Moreover, apart from their antibacterial properties, essential oils have been described to show antiviral, antimycotic, antioxygenic, antiparasitic and insecticidal properties [6].

Medicinal plants that contain essential oils have been used in developing countries as complementary treatments for health problems [7,8]. There is thus an escalating interest in what is termed 'green consumerism' that has led to the use of plant-derived natural products. These products are used as preservatives and essential oils and their compounds are acknowledged to possess inherent antimicrobial properties [9,10]. Essential oils are also used in different industries. For instance, they are used in perfumes and lotions, in foodstuff as preservatives and for additives and in pharmaceutical products for therapeutic action [10]. There has thus been an increasing inclination towards the use of organic and natural products among health-conscious consumers. For instance, the global essential oils market was reported to be 226.8 kilotons in 2018 and it is expected to increase to a compound annual growth rate (CAGR) of 8.6% from 2019 to 2025 [11]. The rise in the demand for essential oils globally is the result of its antimicrobial benefits [11]. Unlike synthetic antibiotics which lose their potency against diseases causing organisms, it is not yet reported that bacterial have developed resistance against essential oils.

Although essential oils have many useful properties, their chances of success and scale up at industrial level becomes a challenge because they possess some limiting factors in their use such as hydrophobic property (which needs to be encapsulated before use), high volatility, and high risk of deterioration upon direct exposure to heat, humidity, light, or oxygen [12-16]. There is thus a need to research their properties in biopolymer-based materials because of the promising alternatives of biodegradable polymers as compared to conventional plastics that contribute to the rise in the municipal solid waste. This contribution focuses on the essential oils' encapsulation with polymeric materials, bacterial biopolymer, and its role in pathogenesis to effective biomaterials, mode of action of essential oils against bacteria and antibiotic resistance.

Essential oil (EO) encapsulation with polymeric materials

Essential oils (EOs) are a complex liquid mixture of volatile, fragrant, and lipophilic compounds bio-synthesized by living organisms. They have demonstrated many applications in various sectors for medicinal, agriculture, food, and health purposes due to their antibacterial, antiviral, antifungal, anticarcinogenic, antimutagenic, anti-inflammatory and antioxidant properties [17-22]. Although essential oils have many useful properties and applications, their use is limited because of their water insolubility, high volatility, rapid oxidation, and degradation [16,23]. Various techniques have been utilized to provide physical stability and water solubility to essential oils such as emulsification, aerosol spray, fumigation, and encapsulation [16,23].

Among these techniques, encapsulation is the most preferred method for the preservation of essential oils. This is because it offers benefits such as improved stability and water solubility, effective protection against degradation, prevention of volatile components evaporation and enhance antimicrobial activity against food-borne pathogens [7,9,12,13,20] [13,14,22,24,25]. Four types of encapsulation can be listed: (i) particles generated by a matrix where essential oils are dispersed; (ii) capsules with a membrane surrounding a core where the EOs reside; (iii) complexes, where EOs are stabilized in cavities by chemical interactions; and (iv) droplets created by a simple emulsion in surfactants [19]. Encapsulation can be divided into three sizes: macro-, micro-, and nano-. Microencapsulation involves filling a hollow, usually cylindrical, perm-selective membrane with cells, generally suspended in a matrix, and then sealing the ends to form a capsule. Polymers used for microencapsulation are bio durable, with a thicker wall than that found in microencapsulation. Although thicker wall and larger implant diameters can enhance long-term implant stability, these features may also impair diffusion, compromise the viability of the tissue, and slow the release kinetics of desired factors. Microencapsulation is a process in which tiny particles are surrounded by coating wall to form a small capsule. The core material is gradually released through the capsule wall, thus offering a controlled release property under the desired conditions. This technology can be used to deliver bioactive substances to the desired site at specific time and rate. It is normally applied in cosmetics [23,14,26]. Nanoencapsulation provide a larger surface area per unit volume and potential enhancement of essential oils concentration in area of the food where microorganisms are potentially located. They are potential candidates for application in food preservation [25]. Among the three encapsulation sizes, nanoencapsulation is more effective than macro and/or microencapsulation due to the smaller nano systems that are more compatible and stable with the matrix [12].

Recently, polymeric materials have been used to encapsulate essential oils shielding them with good stability, controlled delivery, enhanced bioavailability, and improved efficacy. Also, many studies have been developed on the application of essential oils into polymeric matrices to evaluate their properties into matrices, as well as the potential effects of the biobased and biodegradable materials as promising alternatives to conventional plastics due their availability, non-toxicity, and biodegradability [13,16]. Biodegradable polymers are mainly synthesized from renewable natural resources and they degrade over of time through enzymolysis of micro-organisms when exposed to a natural environment. The biodegradable polymer matrices that have been utilized to encapsulate essential oils include alginate, chitosan, cyclodextrin, poly(lactide-co-glycolide), polycaprolactone, and poly(lactic acid) [13,17,19,26]. Their selection depends on various parameters such as safety, cost, applicability, availability, and biocompatibility [16]. Several authors encapsulated essential oils such as eugenol with polycaprolactone and reported an improvement in the stability against light oxidation. Furthermore, the heat resistance of Jasminum officinale essential oil was increased after encapsulation in gelatin and Arabic gum nanoparticles. Some studies used nanoencapsulation to encapsulate essential oils of thyme and dill with copper nanoparticles and reported an improvement in antifungal activity. Moreover, the essential oil from Zanthoxylum rhoifolium leaves encapsulated in polycaprolactone against B tabaci showed that nanoencapsulation is an effective protector of the active ingredients [15].

Bacterial Biopolymer and its Role in Pathogenesis to Effective Biomaterials

Bacteria are considered as the major cell factories, which can effectively convert nitrogen and carbon sources to a wide variety of extracellular and intracellular biopolymers like polyamides, polysaccharides, polyphosphates, polyesters, proteinaceous compounds, and extracellular DNA [27]. Extracellular biopolymers, which are produced by pathogenic bacteria, act as significant virulence factors. Thus, inhibiting their biosynthetic pathways using essential oils [9,10,28] could be one of the strategies and promising antimicrobial agents to treat infections caused by bacterial pathogens. Due to the increased degree of antimicrobial resistivity, newer strategies must be developed to combat bacterial infections [27]. Further studies on biopolymer synthesis, production, and regulation should be carried out to find improvised and suitable drug developing strategies such as weakening of the bacterial immune system against antimicrobial treatment or host immunity. Such drug developing strategies include using essential oils (EOs) encapsulation in polymer-based materials.

Mode of Action of Essential Oils against Bacteria

Bacteria have a cell membrane that serves as a blockade between the cytoplasm and the external environment. Gram-positive bacteria consist of a tough and rigid mesh cell wall, whereas Gramnegative bacteria have a thin cell wall surrounded by an outer membrane that is an additional protective layer [29]. The cell membrane remains important for the existence of bacteria, whereas the cytoplasm exists to prevent ions from flowing into and out of the cells of bacteria. When bacteria are treated with antimicrobial agents such as essential oils, these oils degrade the cell membrane which is detrimental to the cytoplasmic membrane. This causes cytoplasmic coagulation, thus damaging the membrane proteins and increasing penetrability, which leads to the leaking of cell substances and its subsequent destruction [28,30].

The cytoplasmic membrane of a bacterium cell has a pump function that takes antimicrobial agents out of the cell, which is referred to as the efflux pump mechanism. However, essential oils degrade the entire cell, thus making it difficult for bacteria to fight against them [28,30,31]. It is known that essential oils and their components act upon a variety of targets, such as the cell membrane and cytoplasm. In some cases, they totally change the structure of the bacterial cells [28,32]. However, the chemical components of plants' essential oils are different, and these differences are linked to the nature of their antimicrobial activities against diverse pathogenic microorganisms [32,33]. Commonly, these essential oils have a hydrophobic nature, which is what allows them to penetrate microbial cells. It also causes a change in the structure and function of Gram-positive bacteria [30]. Essential oils are regarded as rich in phenolics that enable them to penetrate the phospholipids bilayer of the bacteria cell wall and to bind with proteins. This prevents bacteria cells from executing their normal functions [28,30].

Antibiotic Resistance

The growing resistance of microorganisms to conventional chemicals and drugs is continuing to be a global problem that has driven research into finding new biocides with far-reaching action [28,34]. One of the main causes associated with antibacterial drug resistance is the misuse and overconsumption of these drugs that are found in human medicine and in agricultural products [35]. The food chain is also considered a main route of transmission of antibiotic resistant bacteria among animal and human populations. Because the antibiotics that are used in agriculture often have the same or similar compounds used clinically for the treatment of various infections, this overuse can contribute to drug resistance [36]. The World Health Organization (2016) states that antibiotics are largely used to combat bacteria that can cause illnesses, diseases, and infections, but antibiotic resistance remains a public health problem. In the earlier years of antibiotic use, they had a major impact on extended human health as many diseases that had once caused death were effectively treated with antibiotics. However, some bacteria such as Staphylococcus aureus have become resistant to commonly used methicillin, amoxicillin and metronidazole antibiotics and Escherichia coli have become resistant to ciprofloxacin [37].

Antibiotics can commonly get rid of most bacteria in a colony, but a different strain of bacteria that has mutated genetically can result in resistance [36]. Antibiotics also fail to inhibit bacterial growth because bacteria change or limit the number of openings in the cell wall. Antibiotic drug molecules normally gain access to the cell by diffusion through the porins found in the outer membrane of Gram-positive bacteria, which means that a reduction in the number of porin channels leads to a decrease in the entry of antibiotics into the cell [28,29]. The cytoplasmic membrane of bacteria has pumps that take antibiotics out of the cell and these 'pumps' are known as efflux mechanism pumps. For example, Tetracyclines, Macrolides, Lincosamides, Streptogramins, Oxazolidinones, Phenicols, Cationic peptides, Lipopeptides, Quinolones, Pyrimidines, Rifamycins and the Sulfonamides groups of antibiotics are pumped out in this manner [36]. The pumps function at the same speed as the speed at which antibiotics gain access to the cells and they thus pump the antibiotic out before it reaches the target. The outer membrane of a Gram-positive bacterium thus keeps the antibiotic from gaining entrance into the cell [28,29].

It is for this reason that microorganisms are becoming more antibiotic resistant as they can survive and increase in the presence of antibiotics. They tend to prevent the antimicrobial from meeting its target by limiting its ability to enter the cell. Essential oils, on the other hand, have shown great potential in the biomedicine field as they can efficiently destroy several fungal and viral pathogens. Essential oils inhibit the growth of pathogens by targeting the membrane and cytoplasm and, in some cases, totally alter the structure of the cells [30,38]. For this reason, it is therefore believed that replacing antibiotics with EOs during the encapsulation with polymer-based materials will be highly beneficial in medicinal industries.

CONCLUSION

Essential oils have been widely studied for applications in food preservation due to their antimicrobial properties that are against many resistant bacteria. However, the synergistic effect of essential oils with biopolymers bring about many more improved properties such as antioxidation that leads to an increase in the shelf life of the food. Based on the reported literature, nano-encapsulation of essential oils with polymers have shown to be more effective than macro- and microencapsulation. However, there is still a need to research the properties of many other biopolymers encapsulated essential oils due to their promising contribution in reducing environmental solid waste caused by conventional plastics.

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CONFLICTS OF INTEREST

The author does not have conflicts of interest to declare.

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