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Review

Recent advances in microencapsulation of natural sources of antimicrobial compounds used in food - A review

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ABSTRACT

Food safety and microbiological quality are major priorities in the food industry. In recent years, there has been an increasing interest in the use of natural antimicrobials in food products. An ongoing challenge with natural antimicrobials is their degradation during food storage and/or processing, which reduces their antimicrobial activity. This creates the necessity for treatments that maintain their stability and/or activity when applied to food. Microencapsulation of natural antimicrobial compounds is a promising alternative once this technique consists of producing microparticles, which protect the encapsulated active substances. In other words, the material to be protected is embedded inside another material or system known as wall material. There are few reports in the literature about microencapsulation of antimicrobial compounds. These published articles report evidence of increased antimicrobial stability and activity when the antimicrobials are microencapsulated when compared to unprotected ones during storage. This review focuses mainly on natural sources of antimicrobial compounds and the methodological approach for encapsulating these natural compounds. Current data on the microencapsulation of antimicrobial compounds and their incorporation into food suggests that 1) encapsulation increases compound stability during storage and 2) encapsulation of antimicrobial compounds reduces their interaction with food components, preventing their inactivation.

1. Introduction

Food borne diseases remain a significant cause of morbidity and mortality worldwide despite the progress in understanding the infectious process of pathogenic microorganisms, improved control measures and a strict control of commercial food production processes. Food decomposition due to microbial action also generates financial losses. Preserving food is a challenge for the food industry and common food preservatives such as nitrites, benzoates and sodium metabisulfite have a long history of safe usage (Gould & Russell, 2003). However, occasional allergic reactions in sensitive individuals and the potential formation of toxic by-products from some preservatives, some of them carcinogenic (*e.g.*, nitrosamines from nitrites), are good reasons for concern among consumers due to the possible negative effects to health. This has generated an increasing consumer demand for foods free of chemical preservatives, the use of limited risk preservatives, and/or lower limits on preservative concentrations (Leite, Montenegro, & De Oliveira, 2006). Natural antimicrobial compounds are widely applied as food preservatives to improve microbiological safety and quality and to extend the shelf life of food products (Tiwari et al., 2009). A great number of natural compounds are attracting increasing interest from researchers and the food industry because of their potential role as antimicrobial agents against spoilage and pathogenic microorganisms (Maresca et al., 2016). The use of natural antimicrobial compounds is a promising alternative to ensure food safety and quality. Antimicrobial compounds are classified into six categories based on the following criteria: 1) biosynthesis; these compounds are ribosomally synthesized, or are primary or secondary metabolites; 2) biological source; produced by bacteria, animals (vertebrates and invertebrates) or plants; 3) biological functions; such as antibacterial, antifungal, antiparasitic and/or insecticide; 4) molecular properties; based on charge, hydrophobicity and size; 5) structure and composition; the chemical agents or biomolecules with different topology and 6) molecular objectives; either extracellular or intracellular (Singh, Sarkar, Janaswamy, Yao, & Kumar,

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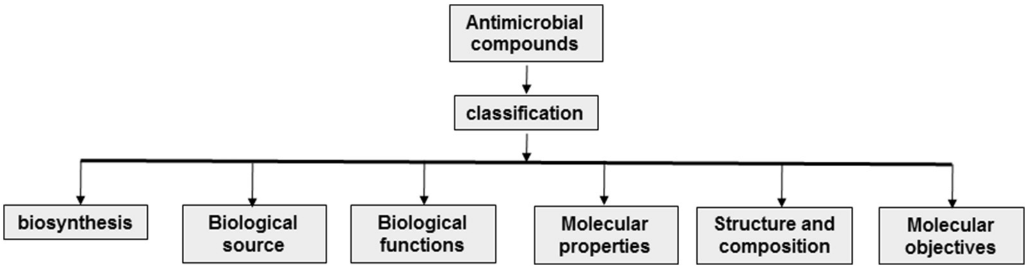

Fig. 1. Antimicrobial compounds classification according to Singh et al., 2014.

2014) (Fig. 1). Different antimicrobial compounds produced by bacteria and plants have been used as biopreservatives in food products because they extend the foods' shelf life. For example, bacteria produce antimicrobial compounds that inhibit other bacteria, making them useful in controlling bacterial decomposition of food and against pathogenic microorganisms. The antimicrobials are mainly produced by gram-positive bacteria, including lactic acid bacteria (LAB) (Davidson, Critzer, & Taylor, 2013; Tiwari et al., 2009). Nisin is the most commonly used bacteriocin in commercial applications, although pediocin also has potential applications in food systems. Nisin has been used to inhibit microbial growth in beef (Eckner, 1992), sausages (Hugas, Garriga, Aymerich, & Monfort, 1995), liquid whole eggs (Henning, Metz, & Hammus, 1968), ground beef (Zhang & Mustapha, 1999), and poultry (Delves-Broughton, Williams, & Wilkinson, 1992). Unfortunately, some factors lead to a reduction in its antimicrobial activity in food matrices (Maresca et al., 2016). Various factors can impact the antimicrobial efficacy of bacteriocins. These include the emergence of bacteriocin-resistant bacteria, conditions that destabilize the biological activity of proteins such as the presence of proteases or oxidation processes, binding to food components such as fat particles or protein surfaces, inactivation by other additives, poor solubility, and uneven distribution in the food matrix (this means, when the antimicrobial is added to the food matrix in a non-homogenous form, leaving some areas exposed, which are susceptible to the development of microorganisms) and/or pH effects on bacteriocin stability and activity (Daeschel, 1989). Therefore, it is necessary to develop an adequate distribution or delivery system to reduce these interactions and maximize the bioprotective potential of these compounds (Gálvez, Abriouel, Lucas, & Omar, 2007; Khaksar et al., 2014).

On the other hand, recently, Calo, Crandall, O'Bryan, and Ricke (2015), in their review on essential oil antimicrobials in food systems, discussed mechanisms of antimicrobial action, and the antimicrobial properties of plant essential oils and their uses in food. Functional group structure and composition in these antimicrobials play a vital role in the function of their antimicrobial activity. Phenolic compounds such as simple phenols, quinones, tannins, cumarins, flavones and alkaloids exhibit antimicrobial activity. *In vitro* studies with essential oils have demonstrated antibacterial activity against *Listeria monocytogenes*, *Salmonella typhimurium*, *Escherichia coli* O157:H7, *Shigella dysenteriae*, *Bacillus cereus* and *Staphylococcus aureus*. A number of essential oil components have been identified as effective antibacterials, *e.g.*, carvacrol, thymol, eugenol, perillaldehyde, cinnamaldehyde and cinnamic acid. Studies with fresh meat, meat products, fish, milk, dairy products, vegetables, fruit and cooked rice have shown that the concentration needed to achieve a significant antibacterial effect is approximately 0.5–20 μL/mL in food and approximately 0.1–10 μL/mL in solutions for washing fruits and vegetables (Burt, 2004; Edris, 2007). The active compounds in essential oils tend to interact with food components such as proteins, fats, sugars and salts. As a result, only a portion of the total dosage of an essential oil added to food remains available to perform its antimicrobial activity (Gutierrez, Barry-Ryan, & Bourke, 2008). Other extrinsic factors such as temperature can also limit their antimicrobial action (Davidson, 1997). Efficacy can also be affected by the spatial distribution of the phases (solid/liquid) and water homogeneity in food, as bacterial growth is more robust in liquids than in already formed colonies on or within a solid matrix (Wilson et al., 2002). The antimicrobial effect of essential oils applied to different food matrices such as meat and meat products has been reported by some authors, but the concentrations required to cause an effect were extremely high compared to those in *in vitro* studies (Sánchez et al., 2014). These high concentrations can modify the food's organoleptic characteristics. Factors present in complex food matrices such as fat content, proteins, water activity, pH and enzymes can potentially diminish the efficacy of essential oils (Burt, 2004; Gutierrez et al., 2008).

Classic preservation technologies such as thermal treatment have been increasingly complemented with emerging technologies such as natural origin antimicrobial compounds. A challenge to extending the use of these compounds is that they are often affected by food treatment or processing, or the interaction with compounds in food may reduce the antimicrobial effect. The level of natural preservatives required for sufficient efficacy in food products in comparison with laboratory media may be considerably higher, which may negatively affect the organoleptic properties of food (Tiwari et al., 2009). As an alternative, encapsulation of these preservatives can help protect their activity and keep them stable when added to food systems (Martins, Barreiro, Coelho, & Rodrigues, 2014; Xiao, Liu, Zhu, Zhou, & Niu, 2014).

Microencapsulation is a promising method in which various food ingredients are protected from the environment; this process can also be used as a means to control their release to target specific sites or to improve their flow and organoleptic properties (Fang & Bhandari, 2010; Gouin, 2004).

The development of encapsulation delivery systems ("wall" materials) that carry, protect, and deliver functional food ingredients ("core" materials) to their specific site of action is one of the current challenges in food engineering (Beirão da Costa et al., 2012). When a fast delivery of the core material is required, it can be released by solubilization, disintegration or disorganization of the micropaticles wall or gradually released through the wall. These specific stimuli are known as release triggers which include mechanical rupture of the wall or changing the medium where the microparticles are placed as in temperature, pH, enzymatic activity or changing the solvent used (Reineccius, 1989). When the microparticle matrix is inert to the environment in which is inserted, the core can still be released by diffusion, with or without swelling (Shahidi & Han, 1993). The way the core material is distributed inside the microparticles also affects the release (mononucleated, multinucleated, matrix type or reservoir type) (Thies, 1995). Considering the encapsulation process used, the microparticles will present various shapes such as films, spheres or irregular particles, porous or compact structure, amorphous or crystalline dehydrated solids, rubbery or glass matrix, that will influence the core diffusion or external substances such as oxygen or solvent migration (Madene, Scher, & Desobry, 2006). The structure of core-wall microparticles can be classified into capsules with a core that is surrounded by a shell of a matrix material (reservoir system) or a core that is entrapped within a continuous network of the matrix material (matrix system). Variations of these structures include multiple cores or multi-layered microcapsules (Augustin & Hemar, 2009). When the release of an active agent occurs by diffusion and the system is a reservoir, the principal steps in