Materials and methods for the microencapsulation of substances of food and agricultural interest

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ABSTRACT

Microencapsulation involves trapping solid, liquid, or gas particles within an inert cover to protect them from the environment. This technique has numerous biotechnological applications in the food, agricultural, pharmaceutical, and other industries. Microcapsules are relevant for obtaining viable products and optimizing their efficacy, stability, safety, and ease of application. There is a wide range of coating materials and techniques used to microencapsulate various substances of interest. This article presents a review of encapsulating materials and microencapsulation methods used in the food and agricultural industries.

Keywords: Biotechnology, Cover, Microcapsule, Polymers, Protection.

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INTRODUCTION

Microencapsulation is a method or technique that involves trapping solid particles, liquid droplets, or gases within an inert cover. Its aim is to protect substances from surrounding environments that inactivate them (Jyothi *et al.*, 2010; Nazzaro *et al.*, 2012; Solanki *et al.*, 2013). Microencapsulation originated in the late 1930s and has since had numerous applications in the food, agricultural, and pharmaceutical industries (Agnihotri *et al.*, 2012; Teixeira *et al.*, 2014). The microencapsulated substance can be called core material, substance of interest, active agent, or internal phase, while the substance that surrounds or covers it can be called coating, membrane, envelope, carrier material, wall material, external phase, or matrix. This coating forms a microcapsule (Figure 1), defined as a spherical particle with a size ranging from 1 to 1,000 μm (Singh *et al.*, 2010; Zuidam and Shimoni, 2010). Numerous materials have been reported as potential encapsulants. Overall, these materials maintain the integrity of the core, *i.e.*, they must form a barrier between the internal phase and its environment and be biodegradable. Polysaccharides are among the most used materials for food microencapsulation.

However, proteins and lipids are also appropriate for this application (Nedovic *et al.*, 2011; Ocampo-Salinas *et al.*, 2020). Aside from materials, different microencapsulation methods have been developed, *e.g.*, coacervation, solvent evaporation, thermal gelation, polymerization, spray drying, cold drying (lyophilization), extrusion, emulsification, and others. To decide which method is most appropriate, one must search for the most suitable formulation depending on the active ingredients (Jyothi *et al.*, 2010; Vemmer and Patel, 2013). Nevertheless, the efficiency of encapsulation —*i.e.*, the generation of microcapsules— will depend on many factors, such as the concentration of the wall material and the substance of interest, the rate of solvent removal, or the affinity between the internal phase and the coating (Jyothi *et al.*, 2010). Therefore, it is necessary to conduct research focused on studying the interaction and optimization of cover materials and substances of interest, as well as encapsulation methods, for their potentially better application in various industrial activities.

MATERIALS AND METHODS

Terms of interest were identified in the literature relevant to the topic. The terms were subsequently combined, and a search was conducted, both in English and Spanish, in the following scientific databases: Google Scholar, ScienceDirect, SciELO, Dialnet, MDPI, and ResearchGate. The keywords used were: "materials", "methods", "encapsulation", "agriculture", "food", and "application". After reviewing and analyzing summaries and keywords in the papers found, we were able to select the most significant ones to evaluate them. A selection of papers by section was conducted to determine the materials and methods used in the microencapsulation of substances of food and agricultural interest.

RESULTS AND DISCUSSION

The literature search suggests that a wide range of coating materials have been used to microencapsulate active ingredients in both the agricultural and food sectors. Most of these coating materials are biocompatible and have been approved as safe for humans (Escobar-Avello *et al.*, 2021). The selection of coating materials determines the physicochemical and functional properties of microcapsules. Among the most used materials we find a wide array of natural and synthetic polymers, including carbohydrates (starch, modified starches, dextrins, sucrose, cellulose, and chitosan); gums (gum arabic, alginate, xanthan, and carrageenan); lipids (wax, paraffin, monoglycerides and diglycerides, hydrogenated oils and fats); inorganic materials (calcium sulfate and silicates); and proteins (gluten, casein, gelatin, and albumin). These can be used alone or combined for microencapsulation (Agnihotri *et al.*, 2012; Dias *et al.*, 2017; Teixeira *et al.*, 2014). Coating materials must form a cohesive film or coating for the core material, be compatible and non-reactive with it, and provide the desired coating properties, such as strength, flexibility, impermeability, optical properties, and stability, to ensure the quality of the product (Bansode *et al.*, 2010; Ocampo-Salinas *et al.*, 2020).

Main applications of microencapsulation

Food

Microencapsulation in the food industry can offer numerous benefits by changing or improving the properties of active materials (Jafari *et al.*, 2008a). In addition to protecting sensitive food components, microencapsulation prevents nutritional loss, allows the use of sensitive ingredients and the incorporation of release or unusual mechanisms in the formulation, masks or preserves flavors and aromas, and transforms liquid ingredients into easy-to-handle solids (Desai and Park, 2005). The application of this technique in the food industry is broad. It is mainly used on different active compounds, such as aromas, vitamins, and antioxidants, which, in turn, are used in various powdered food products (soups, instant drinks, and sauces) and food supplements (Turchiuli *et al.*, 2005). When applying microencapsulation to food, it is essential to select the appropriate coating material, for which several requirements must be met, such as good emulsifying properties, good drying properties, non-hygroscopic character, mild flavor, non-reactivity, and low cost, in addition to being hypoallergenic, generally recognized as safe (GRAS), and affordable (Ocampo-Salinas *et al.*, 2020). Table 1 presents some examples of microencapsulated foods.

Table 1. Microencapsulated food products.

Active material (Core)	Coating material	Method used	Author (year)
Orange oil	Lactose and sodium caseinate	Emulsification and spray drying	Edris and Bergnstahl (2001)
Food flavors	Dextrin	Spray drying	Reineccius *et al.*, (2002)
Food flavors	Arabic gum, maltodextrin, modified starch and water-soluble soy protein	Spray drying	Soottitantawat *et al.*, (2003)
Food flavors	Maltodextrin	Spray drying	Shiga *et al.*, (2004)
Vegetal oil	Maltodextrin and Arabic gum	Emulsification, spray drying and agglomeration	Turchiuli *et al.*, (2005)
Vegetal oil	Maltodextrin and Arabic gum	Spray drying	Fuchs *et al.*, (2006)
Fish oil	Maltodextrin, modified starch and whey protein	Spray drying	Jafari *et al.*, (2008)
Fish oil	Chitosan, maltodextrin and whey protein	Ultrasonic atomization, emulsification and cold spray	Klaypradit and Huang (2008)
Food flavors	Arabic gum, modified starch, sodium caseinate, and whey and milk proteins	Spray drying	Charve and Reineccius (2009)
Caffeine	Sodium alginate	Emulsification	Cangueiro (2011)
Flaxseed oil	Maltodextrin, gum Arabic and modified starch	Spray drying	Carneiro *et al.*, (2013)
Oregano oil	Chitosan	Emulsification and ionic gelation	Hosseini *et al.*, (2013)
Vitamins (α-tocopherol and ascorbic acid)	Native and modified soy protein	Spray drying	Nesterenko *et al.*, (2014)
Vitamin E	Whey protein and Arabic gum	Emulsification	Ozturk *et al.*, (2014)
Rice bran oil	Tapioca starch and soy protein	Spray drying	Murali *et al.*, (2016)
Sunflower oil	Sodium alginate and calcium chloride	Emulsification	Martins *et al.*, (2017)
Caramel flavoring	Maltodextrin and medium chain triglycerides	Emulsification and Spray drying	Kim *et al.*, (2019)
Vanilla extract	Rice starch	Spray drying	Ocampo-Salinas *et al.*, (2020)
Grape juice	Hydroxypropyl-beta-cyclodextrin (HP-~CD) and maltodextrin	Spray drying	Escobar-Avello *et al.*, (2021)

Agricultural products

Agrochemical markets differ depending on the regulations of each country. However, the sectors involved (governments, production companies, and environmental groups) have set out initiatives for the use of more environmentally friendly products in crops so that food grown in the countryside does not contain agrochemical residues (insecticides, fungicides, herbicides, nematicides, and other chemical products), which has also bolstered the use of agricultural bio-input agents (John *et al.*, 2011; Przyklenk *et al.*, 2017). Microencapsulation can improve or confer several properties in biofertilizers and biopesticides (bacteria, fungi, viruses, and nematodes). This method stands out for its easy handling and application, providing protection to microorganisms against climatic factors, allowing a controlled release, and bestowing the biological agent with greater effectiveness in cultivation, in addition to facilitating long-term storage (Azaroual *et al.*, 2021; Patel *et al.*, 2005). These characteristics also reduce phytotoxicity and loss of soil nutrients. Moreover, microencapsulation reduces application costs by lowering the number of applications and doses (Tomaszewska and Jarosiewicz, 2006). Table 2 lists some examples of microencapsulated agricultural products.

Table 2. Microencapsulated agricultural products.

Active material (Core)	Coating material	Method used	Author (year)
Azospirillum brasilense	Sodium alginate and skim milk powder	Ionic gelation	Bashan *et al.*, (2002)
*Af*NPV	Corn flour, lignin and sugar	Spray drying	Tamez-Guerra *et al.*, (2002)
Bacillus thuringiensis (Berliner)	Gelatinized tapioca starch, sugar, milk powder, rice bran oil and polyvinyl alcohol	Spray drying	Teera-Arunsiri *et al.*, (2003)
Beauveria brongniartii (Saccardo)	Skimmed milk powder and polyvinylpyrrolidone	Spray drying	Horaczek and Viernstein (2004)
*Cp*GV	Lignin	Spray drying	Arthurs *et al.*, (2006)
NPK Fertilizer 6-20-30	Polysulfone	Spray drying	Tomaszewska and Jarosiewicz (2006)
Soluble granular fertilizer	Soluble starch and polyvinyl alcohol	Ionic gelation	Han *et al.*, (2009)
Beauveria bassiana (Balsamo) Vuillemin	Hydroxy-methyl-cellulose, chitosan, dextrin and skimmed milk powder	Spray drying	Liu and Liu (2009)
Trichoderma harzianum (Rifai)	Sucrose, molasses and glycerol	Spray drying	Jin and Custis (2011)
Heterorhabditis bacteriophora (Poniar)	Sodium alginate	Ionic gelation	Hiltpold *et al.*, (2012)
Pyrethrins	Lignin and calcium lignosulfonate	Spray drying and ionic gelation	Fernández-Pérez *et al.*, (2014)
Bacillus thuringiensis (Berliner)	Amaranth starch	Spray drying	Rodríguez-García *et al.*, (2015)
Metarhizium brunneum (Petch)	Sodium alginate, carboxymethyl cellulose, corn starch and potato starch	Ionic gelation	Przyklenk *et al.*, (2017)
Bacillus sp.	Maltodextrin, sodium alginate and phosphate	Spray drying	Azaroual *et al.*, (2021)

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