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Review

Nanostructured emulsions and nanolaminates for delivery of active ingredients: Improving food safety and functionality

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ABSTRACT

Background: Nowadays, consumers are increasingly demanding high-quality, safe and healthy food products. Nanostructured emulsions and nanolaminates may have the potential to protect and transport lipophilic and hydrophilic active compounds commonly incorporated to food products, such as natural antimicrobials and nutraceuticals, while protecting or even enhancing their functional properties.

Scope and approach: This review deals with the most important aspects concerning to the use of nanostructured emulsions and nanolaminates as delivery systems of active ingredients, including the advantages and challenges of incorporating plant-derived antimicrobials and nutraceuticals in foods, relevant factors affecting the formation of these nanostructures, fabrication methods, their advantages as delivery systems, and the current trends in food applications. In addition, concerns regarding the potential toxicity of nanomaterials are also discussed.

Key findings and conclusions: The successful production of nanostructured emulsions and nanolaminates depends on several physicochemical factors that should be controlled in order to reach stable systems. Research evidences that nanostructured emulsions and nanolaminates are able to improve the delivery and biological activity of encapsulated active compounds. Antimicrobial and bioactive nanostructured emulsions and nanolaminates exhibit some promising advantages in food preservation and may represent a new strategy to produce functional foods. However, the knowledge in this area is still limited. The potential toxicological effects of nanostructured delivery systems are a current concern. Therefore, future investigations should be directed towards more comprehensive studies to shed light on the formation, physicochemical stability, functional performance, interactions with food matrices and toxicity of nanostructured delivery systems before their commercialization.

1. Introduction

The increasing consumer's demand of fresh-like food products and the rejection of synthetic additives are driving the scientific community to pursue natural alternatives that can enhance food preservation while having a minimum effect on the organoleptic and nutritional attributes of the product. Moreover, consumption patterns are changing toward a healthy diet owing to an evident relationship between food and health. As a result, there is a global trend towards the intake of food products with health-promoting properties beyond their nutritional value. There are a number of antimicrobials and nutraceuticals from natural sources with great performance that allow reducing or even replacing the use of their synthetic counterparts in foods (Irkin & Esmer, 2015; Oliveira, Ramos, Ramos, Piccoli, & Cristianini, 2015). However, an effective incorporation of active compounds to foods may be restricted by their physicochemical properties, stability under certain conditions or low bioavailability. As a result, there is a need of encapsulating them into delivery systems, understood as those in which an active compound is entrapped into a carrier (Fathi, Mozafari, & Mohebbi, 2012), that allow overcoming these issues.

Nanotechnology is offering innumerable approaches in the food field (Cushen, Kerry, Morris, Cruz-Romero, & Cummins, 2012; Durán & Marcato, 2013). Nanostructured delivery systems constitute one of the most explored approaches. Their nanostructured architecture enables to improve protection of encapsulated compounds, increase solubility and dispensability of lipophilic ingredients in water-based environments, modulate the compound release, or even increase bioavailability of nutraceuticals, exhibiting

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better performance than systems of bigger particle sizes (Augustin & Hemar, 2009; Ezhilarasi, Karthik, Chhanwal, & Anandharamakrishnan, 2013). In particular, emulsion-based delivery systems of either one single layer, such as nanoemulsions, or multiple layers have been proposed as those capable of effectively encapsulating lipophilic active compounds (Augustin & Hemar, 2009). On the other hand, nanolaminates are systems that can be applied directly onto food surfaces as an edible coating or to functionalize the surface of conventional packaging. The most important advantage is their ability of serving as reservoirs of active compounds, either hydrophilic or lipophilic, protecting them and modulating its release in response to certain triggers (Kuan, Yee-Fung, Yuen, & Liong, 2012; Rojas-Graü, Soliva-Fortuny, & Martín-Belloso, 2009). The use of nanostructured emulsions and nanolaminates for delivery of active ingredients to foods represents a promising alternative to improve the quality, safety and functionality of food products. In this review we discuss the properties and limitations of incorporating plant-based antimicrobials and nutraceuticals in foods, and overview the recent developments concerning the formation, physicochemical characteristics, fabrication techniques, advantages as delivery systems, and food applications of a selected number of nanostructured emulsions and nanolaminates (Fig. 1). Finally, the toxicological aspects associated to the incorporation of nanomaterials in foods are presented.

2. Active ingredients: advantages and limitations of their incorporation in foods

2.1. Plant-based antimicrobials

Antimicrobial compounds that come from plant sources exhibit outstanding efficacy against most pathogenic microorganisms responsible of foodborne illnesses and food spoilage (Tiwari et al., 2009). There is a strong consumer's perception that natural preservatives have less side effects to health that their non-natural counterparts, although in some cases the concentration required to achieve an antimicrobial effect is greater than that needed with synthetic preservatives (Carocho, Barreiro, Morales, & Ferreira, 2014). Antimicrobials derived from plants are substances originated from their secondary metabolism, which plays a protective role against predators or stressing conditions (Solórzano-Santos & Miranda-Novales, 2012). Table 1 summarizes some types of plant-based antimicrobials commonly used in foods. Essential oils (EOs), the most significant group of plant-based antimicrobials, are complex mixtures of volatile compounds present in many herbs and spices (Burt, 2004). The main groups of compounds responsible for their antimicrobial and antioxidant properties include phenolic acids, quinones, saponins, flavonoids, tannins, coumarins, terpenoids and alkaloids (Bassolé & Juliani, 2012; Lai & Roy, 2004).

Despite the increasing interest in applying EOs for food preservation, there are several factors affecting their antimicrobial activity, such as the poor-water solubility, partitioning behavior, mass transfer, volatility or reactivity can influence its efficacy in food systems (Donsì & Ferrari, 2016; Prakash, Kedia, Mishra, & Dubey, 2015). In addition, the use of EOs significantly changes the organoleptic profile of foods or may be toxic at high concentrations (Dima & Dima, 2015). Antimicrobial efficacy of EOs may be also influenced by the pH, fat content or water activity present in the food matrix. Plant-derived antimicrobials may bind to lipids, proteins or carbohydrates in foodstuffs, requiring higher concentrations than those used in *in vitro* studies to achieve the same effect (Weiss, Loeffler, & Terjung, 2015).

2.2. Nutraceuticals

There are several nutraceuticals that can be incorporated into food formulations with the purpose of providing well-being while reducing the incidence of diseases in humans. Table 1 presents some of the nutraceutical compounds that could be potentially included in foods. The intake of recommended doses of these compounds has been associated with prevention of coronary heart disease, diabetes, obesity, hypertension, and cancer (Cencic & Chingwaru, 2010; Espín, García-Conesa, & Tomás-Barberán, 2007). Being isolated from natural sources, nutraceuticals are expected to exhibit relatively less toxicity and less secondary side effects than drugs used to treat similar symptoms (Ting, Jiang, Ho, & Huang, 2014).

However, effective enrichment and fortification of food products using nutraceuticals represents a major challenge. The chemical stability of most bioactive compounds is highly influenced by pH, temperature, oxygen, light or specific chemicals that promote the loss of the biological properties. Moreover, the oral bioavailability of nutraceuticals depends on their solubility in the gastrointestinal tract, stability during digestion and intestinal permeability (Gleeson, Ryan, & Brayden, 2016). Therefore, nutraceuticals may have poor oral bioavailability as a result of several physicochemical and physiological processes occurring after intake in the gastrointestinal tract.

3. Nanostructured delivery systems

3.1. Nanoemulsions

Nanoemulsions are oil-in-water systems containing oil droplets with mean diameters between 20 nm and 200 nm (Solans, Izquierdo, Nolla, Azemar, & Garcia-Celma, 2005). In an emulsion,

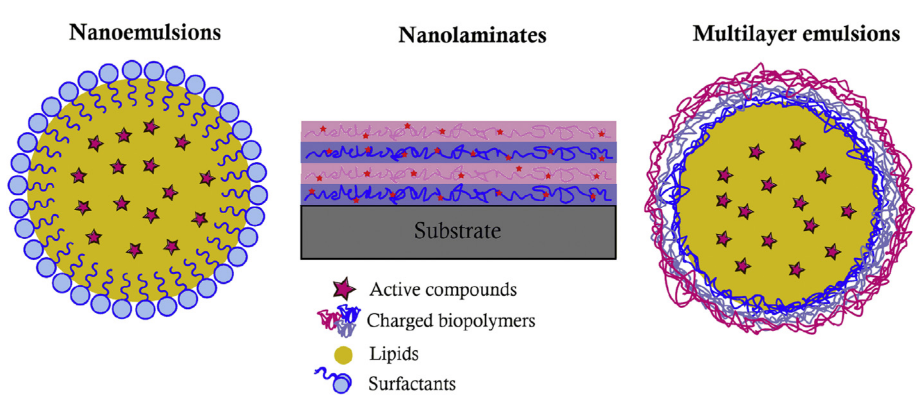

Fig. 1. Food nanostructured systems for encapsulating active ingredients with potential applications in beverages or edible coatings.