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Recent developments in nanoformulations of lipophilic functional foods☆

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ABSTRACT

Recently, nutraceuticals have great attention due to their excellent functional properties for health promotion and disease prevention. Especially, lipophilic materials could give various health benefits such as antioxidant, anti-inflammatory, wound healing, and even anti-cancer effects. However, there are some limitations to apply them into food system and oral administration due to their poor water solubility, low oral absorption, and poor bioavailability which are pivotal issues to overcome for lipophilic nutraceuticals. In this review, various nanoformulations have been introduced with their advantages and disadvantages, including those that can enhance solubility and bioavailability of bioactive compounds.

1. Introduction

Functional foods include all ranges of food compounds such as vitamins, mineral supplement, herbs, phytochemicals (e.g. polyphenols and carotenoids), and probiotics which are tied up with disease prevention and health promotion (Jackson & Paliyath, 2011). Lipophilic functional foods have been great attention because of their diverse health benefits such as excellent nutritional value, antioxidant, anti-inflammatory, wound healing, and anti-cancer. However, these lipophilic compounds have been limited in their application to food system due to their extremely poor aqueous solubility, low oral bioavailability, easy to oxidize, and immiscible feature with other major hydrophilic compounds (Ezhilarasi, Karthik, Chhanwal, & Anandharamakrishnan, 2013). Therefore, numerous technologies have been developed to improve the aqueous solubility, to protect the degradation and oxidation, and to raise oral bioavailability (Anandharamakrishnan, 2000; Augustin & Hemar, 2009; Fathi, Mozafari, & Mohebbi, 2012; McClements, Decker, Park, & Weiss, 2009).

Among various strategies, nano-carrier systems have been popularly developed worldwide for effective delivery of lipophilic nutraceuticals. Due to their extremely small size, nano-carriers have shown many advantages such as improvement of the aqueous solubility, enhancement of residence time in gastrointestinal (GI) tract regions, better physicochemical stability in GI tract, increase the intestinal permeation, controlled release in GI tract, intracellular delivery, and transcellular delivery (Oehlke et al., 2014). When nano-carriers are applied in food system or oral delivery system, it should be considered that they must be stable in food formulations, non-toxic, biodegradable, and applicable to various foods processing system (McClements et al., 2009).

Recently developed novel nanoformulations for lipophilic

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compounds were discussed from their manufacturing process to their applications and potentials. Fig. 1 shows various nanoformulations for lipophilic nutraceuticals. Nanoformulations could be classified into three categories according to the types of wall materials; lipid and surfactant-based nano-carriers, polysaccharide-based nano-carriers, and protein-based nano-carriers (Oehlke et al., 2014; Pradhan, Singh, & Singh, 2013). Lipid and surfactant-based nano-carriers contain nanoliposomes, nanoemulsions, solid lipid nanoparticles (SLNs), nanostructured lipid carriers (NLCs), micelle, self-emulsifying drug delivery systems (SEDDSs), and nanosuspensions whereas polysaccharide-based nano-carriers contain polymer nanoparticles, polymeric micelles, and inclusion complex. Protein-based nano-carriers include casein micelles and various protein complexes such as albumin, gelatin, whey protein, soy protein, milk protein, and zein. Since each nanoformulation has its own distinct features such as encapsulation efficiency, particle stability, aqueous solubility, oral absorption, and bioavailability, it is necessary to fully understand the characteristics of core compounds and nanoformulations to design and develop the best delivery system for lipophilic nutraceuticals.

2. Lipophilic functional materials

Many nutraceuticals are inclinable to lose their inherent functional features by oxidation, degradation, and reaction with other materials during processing and storage. In order to protect their own features from harsh external environment or to deliver them to the target site and on time, they should be encapsulated by using diverse technologies. For example, lipids (which are sensitive to oxidation and have an off-flavor), minerals and vitamins (sensitive to light, degradation, and oxidation), food coloring, food additives, and flavoring agents (for controlled release) could be all encapsulated (Fathi et al., 2012). However, most challenged and targeted compounds in food system have poor water solubility and low bioavailability. Table 1 shows major lipophilic functional food ingredients, their food sources, potential health benefits, and limitations. These ingredients have been shown a lot of health benefits such as antioxidant, anti-aging, anti-inflammatory, anticancer, lower blood lipid, and so on. Based on the biopharmaceutical classification system (BCS), most functional foods could be classified into four different systems depending on their solubility and permeability. As shown in Fig. 2, most lipophilic components belong to class II or class IV in which low solubility is the major problem (Velikov & Pelan, 2008). Low solubility and poor adsorption of bioactive compounds would be also closely related to the low oral bioavailability due to lower stability of compounds and poor hepatic first pass metabolism (Oehlke et al., 2014; Patel & Velikov, 2011; Velikov & Pelan, 2008). Therefore, proper nanoformulation for lipophilic functional components is the key issue to improve their solubility, stability, encapsulation efficiency, permeation, and bioavailability.

3. Carrier materials

To being a good carrier material, it should be satisfied several requirements. Important criteria to consider selecting delivery systems are listed in Table 2. Firstly, the carrier materials in food system should be compatible with other food matrix and not significantly change the original features of the food such as appearance, texture, stability, and flavor (McClements et al., 2009). For examples, oil phase in the traditional micro emulsion may bring the product about turbid or opaque due to light scattering of the droplets. However, oil phase in nanoemulsions may not affect food color and appearance due to its transparency (McClements & Li, 2010; McClements, 2012). Secondly, the carrier materials should maintain the stability and bioactivity of the functional core materials during its processing, storage, and utilization because many functional materials are chemically unstable and could be easily oxidized or degraded by light, oxygen, temperature, and pH (Ezhilarasi et al., 2013; McClements et al., 2009). Thirdly, the carrier materials have to protect the core materials from harsh external environments such as severe acidic condition in stomach and high activity of digestive enzymes in GI tract (McClements et al., 2009). Polysaccharides, proteins, lipids, and low molecular surfactants are popularly used as a carrier material to design nano-carrier systems for foods and all these materials should be approved from generally recognized as safe (GRAS) (Augustin & Hemar, 2009).

4. Nanoformulations for functional foods

Table 3 summarized core and wall materials, preparation techniques, and the main purpose of various nanoformulations such as

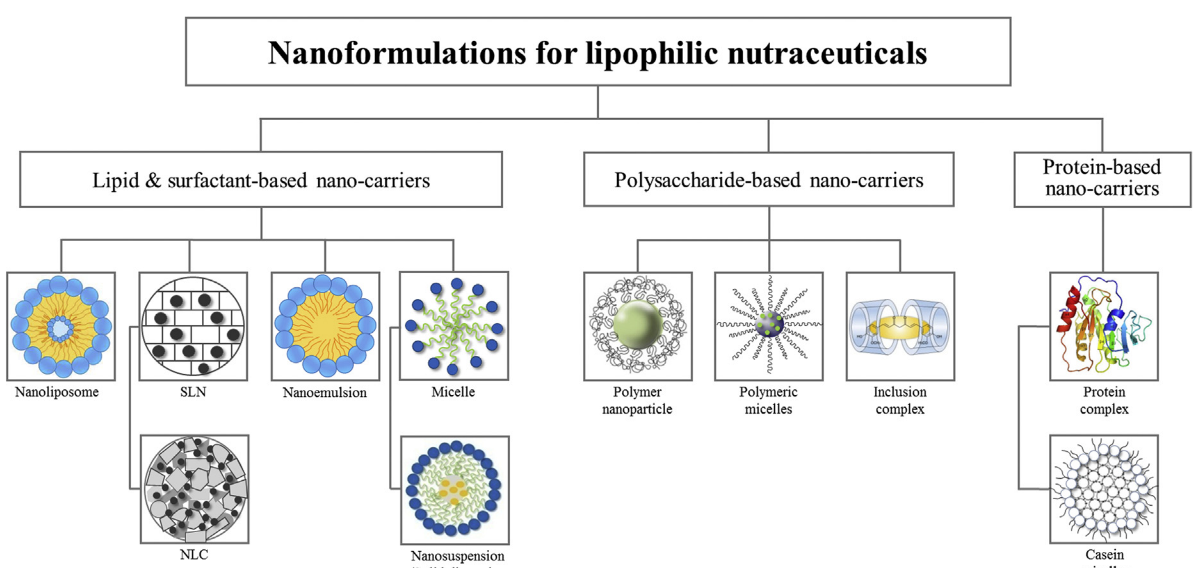

Fig. 1. Nanoformulations for lipophilic nutraceuticals (Pradhan et al., 2013) (not drawn to scale).