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Research review paper

Encapsulation systems for the delivery of hydrophilic nutraceuticals: Food application

N.P. Aditya*, Yadira Gonzalez Espinosa, Ian T. Norton

School of Chemical Engineering, University of Birmingham, Edgbaston, Birmingham B15 2TT, United Kingdom

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ABSTRACT

Increased health risk associated with the sedentary life style is forcing the food manufacturers to look for food products with specific or general health benefits e.g. beverages enriched with nutraceuticals like catechin, curcumin rutin. Compounds like polyphenols, flavonoids, vitamins are the good choice of bioactive compounds that can be used to fortify the food products to enhance their functionality. However due to low stability and bioavailability of these bioactives (both hydrophobic and hydrophilic) within the heterogeneous food microstructure and in the Gastro Intestinal Tract (GIT), it becomes extremely difficult to pass on the real health benefits to the consumers.

Recent developments in the application of nano-delivery systems for food product development is proving to be a game changer which has raised the expectations of the researchers, food manufacturers and consumers regarding possibility of enhancing the functionality of bioactives within the fortified food products. In this direction, nano/micro delivery systems using lipids, surfactants and other materials (carbohydrates, polymers, complexes, protein) have been fabricated to stabilize and enhance the biological activity of the bioactive compounds.

In the present review, current status of the various delivery systems that are used for the delivery of hydrophilic bioactives and future prospects for using other delivery systems that have been not completely explored for the delivery of hydrophilic bioactives e.g. niosomes; bilosomes, cubosomes are discussed.

1. Introduction

In the last decade, the effect of specific food on general wellbeing has gained more importance among the consumers. These food products are usually termed as functional foods or fortified foods (Aditya and Ko 2015; Lam et al. 2014). This has opened the opportunity for the food industries to market the food products with general or specific health benefits (Day et al. 2009; Lam et al. 2014).

In the current scenario, several approaches have been made to add healthy functionalities to the food products e.g. altering their microstructure or composition i.e., designing the specific microstructured food products to obtain the release of nutrients or functional ingredients at specific parts of the GIT, use of nano/micro carriers to add specific bioactives to the food products to protect them from degradation, reducing the fat, salt in the product to minimize the calorie intake.

With regard to the food fortification, food products are normally fortified with health promoting and disease preventing generally recognized as safe (GRAS) approved food grade nutrients and bioactives such as phytochemicals, vitamins, minerals, oils (omega 3 fatty acids). These molecules are obtained from a wide range of plants, animals, and microbes of both terrestrial and aquatic inhabitants (Venugopal 2008; Zhu et al. 2013). However, the formulation and delivery of bioactives in the complex food products poses substantial challenges owing to their unfavorable physicochemical characteristics. The major problems associated with addition of bioactive molecules directly to the product are; their bitter and astringent taste and degradation of ingredients when exposed to unfavorable conditions during processing (temperature, pressure) and storage (presence of oxygen, temperature and light) (Bandyopadhyay et al. 2012; Rothwell et al. 2015; Smuda and Glomb 2013; Wang et al. 2008). These conditions lead to unwanted changes in the product physico-chemical stability, organoleptic properties e.g. color, taste, appearance (Aditya and Ko 2015; Cheynier 2005; McClements 2015; Velikov and Pelan 2008; Zorić et al. 2016). Further problem is that, due to unfavorable environment present in the GIT e.g. the wide range and fluctuation in pH, presence of various enzymes and mucosal barrier etc., bioactives have a very low bioavailability, bioaccessibility and membrane permeability. Consequently at the end, this gives rise to a loss in the commercial value and biological activity

* Corresponding author.
E-mail address: a.nayak.1@bham.ac.uk (N.P. Aditya).

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of the food product (Mirafzali et al. 2014).

In recent years, several strategies have been developed to increase the stability of bioactives during product development, storage and consumption such as

a. Colloidal carrier systems with varied physicochemical properties such as size, shape, surface characteristics, stability, and carrier materials (Velikov and Pelan 2008).
b. Specialized manufacturing and storage techniques like freeze-drying, spray drying, microwave drying (Fang and Bhandari 2012)
c. Use of bioenhancers like piperine in combination with other bioactives e.g. use of piperine increases bioavailability of curcumin by inhibiting glucuronidation in the intestine (Shoba et al. 1998).

Recent advancements in nano/micro delivery technology that originated from the pharmaceutical technology have been increasingly investigated to overcome the drawbacks associated with the direct incorporation of functional ingredients into food products (Aditya et al. 2015b; Aditya et al. 2014; Patel and Velikov 2011). In this respect, over the last decade various types of materials like fats, polymers, lipid-polymer conjugates, proteins, carbohydrates have been used as carrier materials and usually more than 2000 research papers are published annually by scientists both from industry and academia with regarding to application of nanocarriers for food fortification(Patel and Velikov 2011; Yao et al. 2015). However, most of these delivery systems are designed to deliver hydrophobic bioactives (McClements et al. 2016; McClements and Xiao 2014). The main reason is the source of originality of the nano/micro delivery systems. Nano/micro delivery systems like liposomes, solid lipid nanoparticles (SLN) and polymeric nanoparticles are designed to deliver hydrophobic pharmaceutical agents with low bioavailability. In pharmaceutical science, delivery of hydrophilic drug molecules are less challenging due to the possibility of formulating the dosages in various forms e.g. if drug molecules are unstable in the aqueous phase after formulation they can be converted into tablets or capsules. However, such modification of food product is not accepted since they change the aesthetic and organoleptic properties of the product that takes away the pleasure of eating. Hence developing a tailor made delivery systems that can protect the bioactives from degradation during product development, storage and consumption and also keep the original aesthetic and organoleptic property of the fortified food product intact is highly required.

This review article will emphasize nano/micro delivery systems that have been used in food products to deliver the nutrients or active ingredients (bioactives), which have documented health benefits. Information regarding other approaches that can be used to provide the functionality to the food products can be obtained by reading other review articles (Gregersen et al. 2015; Norton et al. 2015).

2. Need for colloidal delivery system for hydrophilic molecules

The major challenges for the development of food products fortified with hydrophilic molecules are their physical and chemical susceptibility within the complex food matrix. Here we explain the need for suitable delivery systems for food fortification at various stages of product development and marketing.

2.1. Low bioavailability

In general, bioavailability is compromised in hydrophobic molecules due to their low aqueous solubility. However, in certain instances, where hydrophilic molecules have high molecular weight, irreversible binding of hydrophilic molecules with proteins in the GIT, degradation of molecules before reaching their active adsorption site due to different environment e.g. pH, enzyme composition, ionic strength etc., within the GIT compromises their bioavailability. Some of the hydrophilic nutraceuticals that require delivery systems to overcome the bioavailability problems are polyphenols (quercetin, catechin), proteins and peptides (Aditya et al. 2015b). This necessitates colloidal delivery system for hydrophilic molecules.

2.2. Product development

In general, instability during product development occurs due to chemical instability and physical instability. However, both are interrelated and lead to product destabilization.

Often the food matrix contains ingredients with varying physicochemical properties. High solubility of hydrophilic bioactive compounds increases their interaction with co-ingredients such as oxidizing and reducing agents, transition metals, hydrogen ions which stimulate their chemical degradation. Further, some of the bioactives like ascorbic acid, catechin, anthocyanins are highly susceptible to conditions like high temperature, presence of oxygen and light. Since, during product development ingredients are exposed to various extreme conditions e.g. thermal sterilization, high-pressure mixing and blending etc., bioactives undergo rapid oxidation, hydrolysis, reduction which results in their degradation or less active by-product formation(Aditya et al. 2015a).

Another important factor is the presence of multiple ingredients within the food matrix with different physicochemical properties e.g. presence of hydrophobic molecules like lipids. Feasibility of adding hydrophilic bioactive to lipid-enriched products like margarine and butter depends mainly on two factors i.e. solubility of the hydrophilic compound in the lipid phase and water phase. If solubility is less in water, then the total amount of bioactives that can be added is very limited compared to food products, which contain higher proportion of water e.g. beverages, soup. Similarly, if the hydrophilic bioactives even have the slightest solubility in lipid, then that compromises products physico-chemical stability and sensorial properties due mass transfer of bioactives from one region to another (McClements 2015; Patel and Velikov 2011; Velikov and Pelan 2008). Thus, to fortify the lipid-enriched products, hydrophilic bioactives should have extremely low solubility in the lipid phase (to avoid mass transfer) and very high solubility in water (to entrap more bioactives).

2.3. Obtaining the consumer and regulatory acceptance

Some of the bioactive molecules induce undesired organoleptic properties to the food products e.g. addition of catechin causes bitterness, addition of ascorbic acid induces sour or tart taste. These undesired changes compromise the consumer acceptability (Drewnowski and Gomez-Carneros 2000). Further, since most of these bioactives are highly susceptible for degradation in GIT, after consumption, major portion of the bioactives are degraded e.g. catechin stability decreases in the presence of oxygen, alkaline pH, and high temperature and also it has low cellular permeability. Thus, the fortified food products fail to pass on the real health benefits associated with these bioactives consumption (Janaswamy and Youngren 2012; McClements et al. 2009). Thus obtaining consumer and regulatory acceptance becomes a major hurdle.

3. Delivery systems for hydrophilic bioactives

Though several GRAS approved materials like lipids, polymers, carbohydrates, proteins can be used to fabricate nano/micro carrier, only a few of them are suitable for regular consumption. Among the materials that can be used to fabricate carrier structures for the delivery of hydrophilic bioactives are: polysaccharides (pectin, gum arabica, carrageenan, chitosan), polymers (poly(lactic-*co*-glycolic acid), poly(organophosphazene), poly(lactic acid)), lipids (phospholipids, fatty acids), proteins (whey protein, soy proteins, casein) and surfactants (polysorbates, soy or egg lecithin). In general, a tailor made approach is required to design the delivery system that are suitable for the specific