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Nanotechnology for increased micronutrient bioavailability

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Nanotechnology is utilized by food scientists to create a variety of delivery systems for the encapsulation, protection, and controlled release of micronutrients. These delivery systems typically consist of micronutrients trapped within nanoparticles ($r < 500$ nm) that may be fabricated from surfactants, lipids, proteins, and/or carbohydrates. The small size of the particles in these systems has a number of advantages over conventional delivery systems: higher stability to aggregation and gravitational separation; higher optical clarity; and, improved bioavailability. This article provides an overview of different methods of producing food-grade nanoparticles designed to increase micronutrient bioavailability, and highlights their advantages and disadvantages.

Introduction

There has been a surge in interest in incorporating various kinds of micronutrients into functional food and beverage products to improve human health and wellness through diet (McClements, 2012a, 2014; Sagalowicz & Leser, 2010; Velikov & Pelan, 2008). These micronutrients include vitamins, minerals, and nutraceuticals, which vary greatly in their molecular characteristics, physicochemical properties, and biological effects. Some of these micronutrients are essential for human wellbeing (vitamins and minerals), whereas other molecules derived from food sources provide health benefits in addition to their basic nutritional value (nutraceuticals). Many micronutrients cannot simply be incorporated into commercial food products in their pure form due to various physicochemical and biological constraints (McClements, 2014). They may have low solubility in oil and/or water and must therefore be incorporated in a particulate form. They may be susceptible to physical, chemical, or enzymatic degradation during food processing, transport, storage, or preparation, and must therefore be protected. Some micronutrients have a distinct off-flavor, which reduces the acceptability of the food product to which they have been supplemented, and therefore flavor masking is needed. Some micronutrients adversely interact with other food components, thereby reducing their bioactivity or product stability, and must therefore be isolated from them. Other micronutrients have an inherently low or variable oral bioavailability, and must therefore be encapsulated to improve their bioavailability. For these reasons, there has been considerable interest in the development of food-grade colloidal delivery systems that can encapsulate, protect, and release micronutrients.

The development of nanoparticle-based colloidal delivery systems has been one of the most important applications of nanotechnology within the food industry (McClements, Decker, Park, & Weiss, 2009). Researchers have shown that a wide variety of different kinds of edible nanoparticles can be fabricated from food-grade ingredients, such as surfactants, lipids, proteins, polysaccharides, and minerals (McClements, 2014). Many of these edible nanoparticles are suitable as delivery systems for different kinds of micronutrients. However, the selection of the most appropriate nanoparticle-based delivery system for a particular application requires an understanding of the properties of the micronutrient, as well as the nature of the food matrix that the micronutrient will be incorporated

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into. The purpose of this article is to provide an overview of some of the challenges that need to be addressed when encapsulating micronutrients, and to describe how food-grade nanoparticles can be designed to meet these challenges.

Micronutrient stability and bioavailability

Delivery systems are often needed because many important micronutrients are physically, chemically, or enzymatically unstable when incorporated into food products and are therefore lost during food processing and storage, and because many micronutrients have a relatively low or variable bioavailability after they have been ingested. A successful delivery system must therefore stabilize the micronutrient within a food, but release it in a bioactive form after the food has been consumed.

Stability in products

The susceptibility of a micronutrient to degradation within a food product is highly dependent on its molecular and physicochemical characteristics, as well as the nature of the food matrix and storage conditions. Micronutrients may be susceptible to chemical, enzymatic and/or physical instability within food products. Chemical instability involves changes in the molecular form of a micronutrient, which may lead to appreciable changes in physicochemical properties and nutritional attributes. Typical examples of the chemical degradation of micronutrients include oxidation, reduction, hydrolysis, and isomerization (Boon, McClements, Weiss, & Decker, 2010). These reactions can be catalyzed by enzymes and other activators present within the food matrix. Physical instability is due to changes in the organization or location of the micronutrient molecules in the system, such as phase changes (*e.g.*, crystallization-melting or polymorphic transitions), gravitational separation, and aggregation. To effectively control the chemical, enzymatic, and physical stability of a micronutrient within a food product it is critically important to identify the dominant degradation mechanism(s) for that particular micronutrient, and to establish the major factors that influence degradation (such as pH, ionic strength, temperature, oxygen, light, and water activity). This knowledge can then be used to design an effective delivery system to prevent degradation.

Bioavailability after ingestion

To exhibit its beneficial effects, the active form of a micronutrient must be absorbed by the human body after ingestion. For pharmaceuticals and nutraceuticals, the bioavailability (F) is typically determined by measuring the area under the curve (AUC) in the blood following ingestion of a known amount of bioactive compared to the AUC in the blood following intravenous injection of a similar amount of bioactive. In a food product, the overall bioavailability of a bioactive component also depends on its potential chemical degradation during manufacture, transport and storage, as well as phenomena occurring within the GIT, which can be expressed by the following equation (Bauer, Jakob, & Mosenthin, 2005; Fave, Coste, & Armand, 2004; McClements, 2012a) (Fig. 1):

$$F = F_C \times F_B \times F_A \times F_M \quad (1)$$

Here F_C is the fraction of the micronutrient that remains in an active form within the food product at the time of ingestion; F_B is the bioaccessibility, which is the fraction of micronutrient released from the food matrix and solubilized within gastrointestinal fluids so that it can be absorbed; F_A is the absorption, which is the fraction of micronutrient transported through the intestinal lumen, across the mucus layer, and across the epithelium cells (Singh, Ye, & Horne, 2008); and, F_M is the metabolism, which is the fraction of micronutrient that is in a bioactive

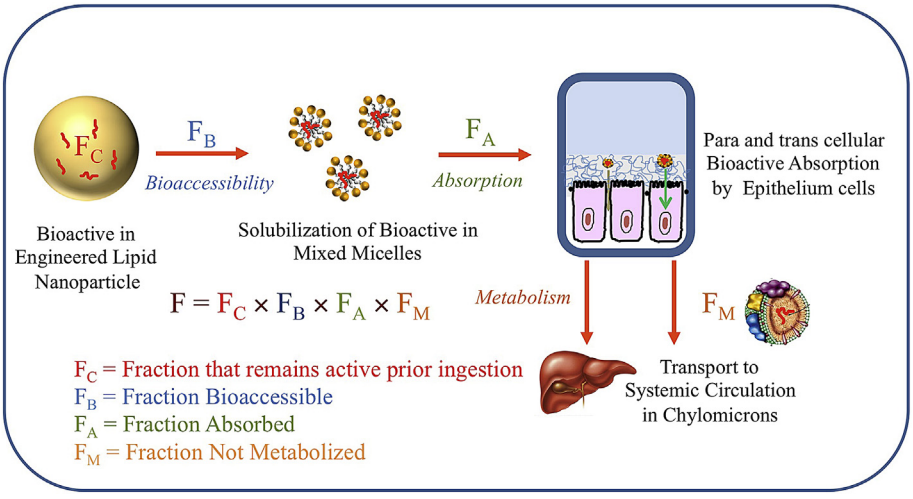

Fig. 1. Schematic representation of the bioavailability of a bioactive component. The bioavailability depends on a number of processes that occur within the gastrointestinal tract, such as solubilization, absorption, and metabolism (not drawn to scale).