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Review

Fundamentals of electrospinning as a novel delivery vehicle for bioactive compounds in food nanotechnology

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ABSTRACT

Encapsulation of bioactive compounds and probiotic bacteria within prebiotic substances to protect or even enhance their survival whilst passing upper gastro-intestinal tract, is an area of great interest for both academia and the food industries. Different methods have been suggested, examined and applied to encapsulate and dry probiotics and bioactive compounds, for example spray drying. However, the harsh processing conditions of these methods can significantly reduce the viability of bacteria or damage the structure of the target molecules. Electrospinning (and the related process of electrospraying) both show promise as a novel delivery vehicle for supplementary food compounds because the process can work with an aqueous solution, at room temperature and without coagulation chemistry to produce matrices in the micro- and nano-range. The production of nanofibers (fiber diameters less than 1 μm) is a commonplace. Nanofiber materials produced by electrospinning have attracted particular attention in the food industry because of their potential as vehicles for sustained and controlled release. The room temperature process route is compatible with food grade polymers and biopolymers, and allows efficient encapsulation by reducing denaturation, and enhancing stability of bioactives. Consequently, there is clear potential to develop electrospun fibrous assemblies to advance the design and performance of novel products and delivery systems for supplementary food compounds. To optimize production conditions and maximize throughput, a clear understanding the mechanism of electrospinning is essential. This paper presents a comprehensive review of the fundamentals of electrospinning to produce nanofibers suitable for food technology application particularly for use in encapsulation and as nano-carriers.

Contents

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1. Introduction

Demand for healthy foods has increased substantially over the recent years due to growth in the world population and an increased perception of unhealthy lifestyles. Globally, by 2050, the number of people aged over 65 is expected to reach a total of about 1.5 billion, which is equivalent to sixteen percent of the world population: in 1950, it was only five percent (Haub, 2011). As the population ages, there is expected to be increasing demand for that have a potentially positive effect on health beyond basic nutrition - functional foods. There is now a broad range of cholesterol-lowering functional foods available in market (e.g. Benecol margarine spreads and cream cheese) which contain added esterised fat soluble forms of phytosterols or stanols (plant extracts) (Z.-Y. Chen, Ma, Liang, Peng, & Zuo, 2011). Omega-3 fatty acids, which occur naturally in foods such as oily fish and some plant and seed oils, are the latest substance to be added to a variety of food products including margarine, milk, fruit juice and eggs to make functional foods for cardiovascular risk reduction effect(-Kaushik, Dowling, Barrow, & Adhikari, 2014; Torres-Giner, Martinez-Abad, Ocio, & Lagaron, 2010). Vitamin D and/or calcium, which is added to fruit juice to raise dietary vitamin D, levels in a target population, such as postmenopausal women who are at risk of developing osteoporosis (Heaney, 2007). It is also worth pointing out that intestinal complaints such as constipation, flatulence and bloating are common in older people and can have a considerable impact on their quality of life (Donini, Savina, & Cannella, 2009). Increasing dietary fiber along with the use of probiotic or prebiotic supplements or functional foods, have been suggested to improve digestive and immune health in older people(Donini et al., 2009). Thus there is strong motivation to progressively improve the performance of food products to provide this type of consumer benefit. One approach that could help to address this problem is the development in encapsulation of food ingredients that are rich in vitamins and antioxidants. Encapsulated ingredients can be formulated to survive travel through the gastro-intestinal (GI) system to deliver their payload at a particular point, thus maximizing the beneficial effect. In the case of non-solid and semi-solid foods, it is also essential to decrease the matrix size to allow their incorporation without affecting food sensory qualities (López-Rubio & Lagaron, 2012). More importantly, by decreasing the matrix size from micrometers to nanometers, improved vehicles with highly controllable delivery rate scan be developed (López-Rubio & Lagaron, 2012). For example, the delivery of any bioactive compound to various sites within the body is directly affected by the particle size. In some cell lines, only submicron nanoparticles can be absorbed efficiently but not the larger size micro-particles (Ezhilarasi, Karthik, Chhanwal, & Anandharamakrishnan, 2013; Hughes, 2005). Larger particles generally release encapsulated compounds more slowly and over longer time periods, while particle size reduction introduces several bio-adhesive improvement factors, including increased adhesive force and thence prolonged GI transit time, leading to a higher encapsulated compound bioavailability (Food protein-based materials as nutraceutical delivery systems) (L. Chen, Remondetto, & Subirade, 2006). A control and target release improves the effectiveness of micronutrients, broadens the application range of food ingredients, and ensures optimal dosage, thereby improving the cost-effectiveness of the product (Mozafari et al., 2006). A widely used method for the production of materials on this scale is electrospinning, wherein fiber diameters are commonly less than 1 μm. These nano-fiber materials have attracted particular attention because of their high specific surface area and the ability to modify the bulk properties of a material when introduced as part of a multilayer fibrous assembly (Ghorani, Russell, & Goswami, 2013). Such fibrous materials have been studied as potential vehicles for encapsulation of bioactive compounds, drug delivery, as bimolecular sensors and as ultra-filtration media (Anu Bhushani & Anandharamakrishnan, 2014).

2. Protein based encapsulating materials used in electrospinning

A growing interest in the use of electrospun fibers in the food industries has seen electrospinning of biopolymers and the encapsulation of food ingredients, enzymes and other active compounds related to the food industry (Rezaei, Nasirpour, & Fathi, 2015). The unique characteristics of biopolymers such as biodegradability, biocompatibility, particular physical and chemical behavior of biopolymers and antibacterial activity have created an enormous demand for these products, mainly in encapsulation and delivery systems (Fathi, Martín, & McClements, 2014). Proposed specific applications of such composites are active packaging or preservation of nutrient activity for consumption (Anu Bhushani & Anandharamakrishnan, 2014). Another benefit of electrospinning food material is for the introduction of different textures and mouth feel to the food (Nieuwland et al., 2013). Preservation of active compounds through encapsulation in electrospun fibers is probably the most widely investigated field in the application of food technology(S. Alborzi, Lim, & Kakuda, 2013). Encapsulation of active compounds into fibers is often achieved by mixing the active compounds into the polymer solution and electrospinning. To avoid the use of toxic solvents for the generation of food-related products, most polymers used for electrospinning of food-based application are dissolved in water or ethanol (Kayaci & Uyar, 2012). As a carrier for proteins or active compounds, the selected polymer for electrospinning should be natural, edible, should not require the use of toxic solvents, and can be electrospun to give fibers without the need to introduce man-made polymer as a spinning aid into the mixture (López-Rubio & Lagaron, 2012). Polymer-based delivery systems are widely recognized in biomedical and pharmaceutical sectors (Liechty, Kryscio, Slaughter, & Peppas, 2010). Likewise, the use of food-grade polymers and biopolymers as bioactive molecule delivery devices in food systems is widely being investigated (López-Rubio & Lagaron, 2012; Nieuwland et al., 2013). In this regard, the natural biopolymers, proteins and carbohydrates are commonly used for encapsulation because of the controlled and sustained release properties that can be achieved to deliver the