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Producing a lycopene nanodispersion: The effects of emulsifiers

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ABSTRACT

In the present work, the effect of the emulsifier type, namely Tween 80 (T80), lecithin, sodium caseinate and gum arabic, on the physicochemical properties of lycopene nanodispersions was investigated. A lycopene nanodispersion was produced by emulsification-evaporation method. The lycopene nanodispersion exhibited different physicochemical properties with different types of emulsifiers. The smallest particle size and the highest transmittance of lycopene nanodispersion were obtained by using Tween 80 followed by lecithin, sodium caseinate and gum arabic. The lycopene nanodispersion produced from lecithin was the most stable, exhibiting the lowest polydispersity (PDI) value, narrow and monomodal distribution and high zeta potential value. Sodium caseinate retained the highest lycopene concentration among all the emulsifier types. Transmission electron microscopy (TEM) micrographs revealed sphere-shaped lycopene droplets at different sizes depending on the types of emulsifier used. The results from this study provide useful information to produce desirable properties in lycopene nanodispersions for food applications.

1. Introduction

Lycopene is a fat-soluble carotenoid that is gaining attention because of its health benefits, particularly in preventing cancer, coronary heart diseases and osteoporosis. The advantages of lycopene are related to its powerful antioxidant properties, which can deactivate free radicals effectively and reduce damage to the body's cells (Chen et al., 2009). The regular intake of lycopene also resulted in reduced low-density lipoprotein (LDL) oxidation and thus reduces the risk of atherosclerosis and cardiovascular diseases (Agarwal and Rao, 2000). Structurally, lycopene is made of long, unsaturated straight chain hydrocarbons with 13 double bonds and a molecular formula of C_{40} H_{56}. Lycopene also serves as a pigment that is responsible for the red color of tomatoes and other red fruits such as watermelons, papayas and carrots. Lycopene reportedly represents approximately 80–90% of the total carotenoids in tomatoes (Nobre et al., 2009). Although red fruits and raw vegetables have a relatively high lycopene content, the absorption of this compound by the human body during consumption is low because it is extremely hydrophobic. Mayer-Miebach et al. (2005) reported that only a small amount of lycopene is absorbed by humans from the intake of raw vegetables and fruits. Many studies have demonstrated that cooked tomatoes or tomato-based food products such as tomato puree contained higher amounts of lycopene in comparison with raw products because more lycopene has been released from the tomato. The heat processing causes cell

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wall breakage and facilitates the extraction of lycopene from chromoplasts in tomatoes (Marković et al., 2006). Other food-processing operations such as chopping and pureeing have also been reported to increase the bioavailability of lycopene because of the reduction in food particle size. At present, lycopene extracted from tomatoes in particular has been widely used in the production of functional foods and as nutritional supplements. In spite of various health benefits and easy sourcing, lycopene also has limited solubility in water, which is a limiting factor for its application in various food products, especially in water-based food products. Its poor water soluble properties have also led to its low bioavailability. Therefore, many efforts have been made to increase the solubility and bioavailability of lycopene such as the development of nanoemulsions and nanodispersions. Emulsion-based delivery systems such as nanoemulsions and nanodispersions can be good delivery systems of poorly water soluble compounds such as carotenoids and phytosterols because they can be designed to increase dispersity in water and enhance bioavailability (Huang et al., 2010). Carotenoid-based nanodispersions such as beta carotene and astaxanthin have better solubility in water and are more bioavailable relative to their raw state, which is typically in crystal form (Tan and Nakajima, 2005; Anarjan et al., 2012).

During the production of lipid nanoemulsions or nanodispersions, an emulsifier is one of the most important materials required to keep the immiscible liquids such as oil and water mixed and stable against the destabilization process. An emulsifier is an amphiphilic molecule having both a polar group (hydrophilic head), which is water-loving, and a non-polar group (hydrophobic tail), which is oil/fat-loving. An emulsifier stabilizes an emulsion by positioning itself at the interface between the oil and water phase with the hydrophilic head groups protruding into the water phase and the hydrophobic tail group in the oil phase, and then it reduces the interfacial tension between the water and oil phases to form a stable oil-in-water (O/W) or water-in-oil (W/O) emulsion. During the emulsification process, the emulsifier facilitates the formation of smaller oil droplets by absorbing at the surface of the disrupted droplets (some form coatings), then reduces the interfacial tension between the oil and water phase and prevents droplet coalescence via electrostatic repulsion or steric hindrance. There are many types of emulsifier that can be used for food applications such as the production of beverages. According to Akoh and Min (2008), most of the emulsifiers used in the food industry are lipid-based such as small molecule surfactants (e.g., Tweens, Spans, and fatty acids) and phospholipids (e.g., lecithin). Biopolymer emulsifiers such as proteins (e.g., sodium caseinate and whey protein isolate) and polysaccharides (e.g., gum arabic and pectin) have also been used widely either individually or in combination with other emulsifiers to produce an emulsion with the desired characteristics. Each emulsifier has its own characteristics depending on its structure (Akoh and Min, 2008).

Tweens (also known as polysorbates) are synthetic non-ionic small molecule surfactants composed of a non-polar fatty acid group that is esterified to a polar polyoxyethylene sorbitan group (Piorkowski and McClements, 2014). Tweens are primarily non-ionic (Akoh and Min, 2008), and they stabilize emulsions by steric repulsion. Tween 80, which is also known as polyoxyethylene sorbitan monooleate, is made from polyoxyethylene sorbitan and oleic acid. It has a high hydrophilic-lipophilic (HLB) value, i.e., 15, making it predominantly hydrophilic, and it dissolves in water and is capable of stabilizing O/W emulsions (Akoh and Min, 2008). Lecithin, a phospholipid (also categorized as a small molecule surfactant), consists of three primary phospholipids, namely phosphatidylcholine, phosphatidylethanolamine and phosphatidylinositol (McSweeney et al., 2008). Lecithin is a zwitterionic surfactant that stabilizes emulsions by giving negative charges to an emulsion. Lecithin can be found in animal sources and vegetable oils such as in egg yolks, liver, milk, sunflowers and soybeans. Sodium caseinate derived from bovine milk is a flexible protein emulsifier that stabilizes the emulsion by forming a protective layer around the oil droplets and preventing droplet flocculation by electrostatic repulsion. According to Piorkowski and McClements (2014), casein is made of different proportions of protein fractions, i.e., αS1 (∼44%), αS2 (∼11%), β (∼32%) and κ (∼11%). Gum arabic obtained from the Acacia tree is an edible biopolymer made up of three primary fractions, i.e., arabinogalactan (88–90%), which contains a low protein content (∼0.35%), an arabinogalactan-Protein fraction (∼10% of total) with an 11% protein content and a small fraction of glycoprotein (GP) (1% of total) that makes up the highest protein content (50%) (Montenegro et al., 2012). According to Montenegro et al. (2012), the AGP complex is responsible for the ability of the gum arabic to stabilize emulsions where the AGP amphiphilic protein component was attracted to the oil phase while the hydrophilic carbohydrate went towards the aqueous phase. Gum arabic stabilizes emulsions by electrostatic repulsion.

The objective of this research was to investigate the influence of emulsifier types from different groups, i.e., polysorbate (Tween 80), phospholipids (lecithin), protein (sodium caseinate) and polysaccharides (gum arabic) on the physicochemical properties of lycopene nanodispersions prepared by emulsification–evaporation method.

2. Materials and methods

2.1. *Materials*

Lycopene (50%) was purchased from Shaanxi Jinjiankang Biological Technology Co., Ltd. (Xi'an, China). Polyoxyethylene sorbitan monooleate (T80), sodium caseinate, lecithin, HPLC-grade dichloromethane, tetrahydrofuran, methanol and acetonitrile were purchased from Fisher Scientific (Leicestershire, UK). GA was donated by Merck Co. (Darmstadt, Germany).

2.2. *Preparing a lycopene nanodispersion*

2.2.1. *Pre-emulsification step*

An organic phase containing lycopene powder extract (50% purity) was dissolved in dichloromethane by magnetic stirring at room temperature. The aqueous phase was prepared by dissolving an emulsifier in deionized water. Coarse O/W emulsions were obtained by mixing the organic phase with the aqueous phase at a ratio of 1:9 by volume in a conventional homogenizer (Silverson L4R, Buckinghamshire, UK) at 5000 rpm for 5 min.

2.2.2. *Emulsification in a high pressure homogenizer*

The resulting coarse pre-emulsion was passed through a high-pressure homogenizer for 2 homogenization stages (Niro Soavi, Germany) at 300 bar for 2 cycles. The dichloromethane in the fine emulsion was removed by using a rotary evaporator