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Evaluation of alpha-tocopherol stability in soluble dietary fiber based nanofiber

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ABSTRACT

Alpha-tocopherol (α-TOC) has low stability, poor water solubility, and variable bioavailability that could limit its application in food products. In this study, α-TOC was entrapped in nanofibers and films containing soluble dietary fiber (SDF) to protect the compound from undesirable conditions and maintain its bioactivity. The stability of α-TOC in soluble dietary fiber (SDF) based nanofiber (SDF-nanofibers) and film (SDF-film) was investigated after exposure to heat and UV irradiation, as well as during storage at room temperature. It was found that retention of α-TOC in SDF-nanofibers and SDF-film was higher ($p < 0.05$) than in nanofibers and film without SDF (NoSDF-nanofibers and NoSDF-film, respectively) after heating, exposing to UV irradiation, and storing at room temperature. The highest of α-TOC retention after heating was found in SDF-film (87.85 μg/100 μg), while SDF-nanofibers showed highest α-TOC retention when they were under UV irradiation (85.21 μg/100 μg) and during storage (73.29 μg/100 μg). The degradation of α-TOC in both nanofiber and film treatments at 40 °C and under UV irradiation could be described by the second order kinetics, while the second and zero order kinetic models could be used to predict the degradation of α-TOC in nanofibers and films during storage, respectively.

1. Introduction

Vitamin E as an essential micronutrient is widely used as functional ingredients in food and pharmaceutical products (Yang & McClements, 2013). It plays an important role in maintaining human health. Vitamin E protects membrane lipids from oxidation by capturing free radicals in cell membranes and breaking lipid peroxidation chain reactions (Khayata, Abdelwahed, Chehna, Charcosset, & Fessi, 2012). As the result, vitamin E inhibits effects of oxidative stress, reduces the risk of chronic diseases, such as cancers, cardiovascular diseases, and diabetes, and delays aging (Herrera & Barbas, 2001).

Alpha-tocopherol (α-TOC) is the main biologically active form of vitamin E, commonly applied in food and beverage products and used as supplements (McClements, Decker, Park, & Weiss, 2009; Yang & Huffman, 2011). However, use of α-TOC has some limitations such as low stability, poor water solubility, and variable bioavailability (Cheong, Tan, Man, & Misran, 2008). Alpha-TOC is highly sensitive to oxygen and light, leading to loss of its bioactivity (Gawrysiak-Witulska, Siger, & Nogala-Kalucka, 2009; Yoon & Choe, 2009). High temperature also influences α-TOC degradation (Shin, Godber, Martin, & Wells, 1997). Alpha-tocopherol in olive oil degrades faster at 100 °C versus 60 °C (Nissiotis & Tasioula-Margari, 2002). Photooxidation is also one of the reasons causing α-TOC degradation. Under artificial light (λ > 290 nm), fifty percent of α-TOC in olive oil was degraded after 500 min exposure and only 17% of α-TOC remained after exposure to the artificial light for 2500 min (Pirisi et al., 1998). In addition, as α-TOC is highly lipophilic, it has poor water solubility and cannot be directly used in aqueous media (Sagalowicz, Leser, Watzke, & Michel, 2006; Velikov & Pelan, 2008). Therefore, to overcome these limitations, development of α-TOC carriers has gained attention. Ideal carriers/vehicles of α-TOC should be able to not only protect the compound from physical and chemical degradations, but also maintain its bioactivity during processing and storage.

Electrospinning is a new nanoencapsulation technique used to protect bioactive compounds from unfavorable conditions and maintain their bioavailability. A polymer solution is flowed through a high voltage capillary tip, and the solution is then spun to obtain nanofiber (Hamori et al., 2014). Anu Bhushani and Anandharamakrishnan (2014) have revealed that electrospinning

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techniques provided high encapsulation efficiency, sustained release of encapsulated material, greater thermal, light and storage stability, and enhanced protection of bioactive compounds from chemical degradation. Bioactive food compounds, such as vitamins, probiotics, proteins and functional lipids, have been successfully encapsulated into nanofibers and exhibited better bioactivity compared with non-encapsulated components (Chen et al., 2010; Fernandez, Torres-Giner, & Lagaron, 2009; Lopez-Rubio, Sanchez, Sanz, & Lagaron, 2009; Opanasopit et al., 2008). Nanofibers also have been reported to have potential for thermal protection of the encapsulated probiotic *Lactobacillus acidophilus* (Fung, Yuen, & Liong, 2011).

Soluble dietary fibers (SDF) are well known for their beneficial functional properties. They are antioxidants, hypocholestrolemic agents, immune-modulators, and anticancer agents (Anderson et al., 2009; Daou & Zhang, 2011; Lattimer & Haub, 2010). Wan, Bankston, Bechtel, & Sathivel (2011) have suggested that SDF extracted from rice bran helps reduce lipid oxidation of menhaden oil during the spray drying process. Coatings or films made from hemicellulose, a major component of SDF, were reported to function as oxygen barriers (Hartman, Albertsson, Lindblad, & Sjöberg, 2006; Krawczyk, Persson, Andersson, & Jönsson, 2008). Therefore, incorporating SDF in nanofibers may reduce degradation of α-TOC caused by oxidation process and allow its bioactivity to be maintained during processing and storage. The objective of this study was to investigate the stability of α-TOC entrapped in SDF nanofibers after exposing to heat and UV light and during storage, compared to SDF films containing α-TOC.

2. Materials and methods

2.1. Chemicals and materials

Zein (M_w: 14–24 kDa), polyethylene oxide (PEO; M_w: 400 kDa), and α-TOC were purchased from Sigma–Aldrich (St. Louis, MO, USA). Soluble dietary fibers (SDF) were extracted from purple rice bran according to our previous work (Wan et al., 2011).

2.2. Production of nanofibers and films loaded with α-TOC

The production of nanofibers and films loaded with α-TOC was composed of two main steps: 1) preparation of spinning and film casting solutions and 2) electrospinning and film casting. The formulations of spinning and film casting solutions are shown in Table 1, which were selected based on our preliminary study on forming uniform nanofibers with encapsulated α-TOC.

2.2.1. Production of SDF-nanofibers and NoSDF-nanofibers loaded with α-TOC

2.2.1.1. Preparation of spinning solutions loaded with α-TOC. As shown in Table 1, spinning solutions were prepared for SDF-nanofibers loaded with α-TOC (SDF-nanofibers) and α-TOC loaded nanofibers without SDF (NoSDF-nanofibers). First, stock solutions of zein (30 g/100 g) and α-TOC (50 g/100 g) were prepared by dissolving in 75 g/100 g ethanol solution and in absolute ethanol, respectively. SDF (10 g/100 g) and PEO (20 g/100 g) solutions were separately prepared by dissolving in deionized water. The zein-TOC solution was obtained when 0.6 g of α-TOC stock solution was gradually added into 2 g of zein solution with mild stirring for 30 min. The zein-TOC solution was then mixed with 0.5 g of 10 g/100 g Tween 80 and stirred for 30 min. Subsequently, PEO solution (2.5 g) was vigorously mixed with the mixture for 1 h. SDF solution (3 g) and deionized water(1.4 g) were then added, and the solution was stirred for another 30 min to obtain SDF-nanofibers with α-TOC spinning solution. Spinning solution α-TOC NoSDF-nanofibers was prepared as α-TOC SDF-nanofibers without the addition of SDF.

2.2.1.2. Electrospinning. The laboratory scale electrospinning set-up consisted of a high DC voltage power supply (Model: FC30R4, Glassman High Voltage, INC., High Bridge, NJ, USA), a KDS-100 syringe pump (KD Scientific, Hayward, CA, USA), and a 3 mL syringe with a 23 gauge (0.35 mm) needle. Aluminum foil was used as a collector. The electrospinning was set at 20 kV. The spinning solutions were separately fed at 0.2 mL/h flow rate and the distance between the needle tip and the collector was 15 cm. The electrospinning was stopped when the thickness of nanofiber mat was 0.3 mm. After that, the obtained SDF-nanofibers and NoSDF-nanofibers loaded with α-TOC were dried overnight in a vacuum oven at 25 °C and stored at −20 °C.

2.2.2. Production of SDF-film and NoSDF-film loaded with α-TOC

2.2.2.1. Preparation of film casting solutions loaded with α-TOC. Alpha -TOC SDF-film and α-TOC NoSDF-film casting solutions were prepared as described in Table 1. Alpha -TOC SDF-film casting solution was prepared with the same method as α-TOC SDF-nanofibers spinning solution (see Section 2.2.1). For α-TOC NoSDF- film casting solution, 10 g/100g of α-TOC solution and 10 g/100 g of PEO solution were prepared. One gram of the α-TOC solution was then mixed with 5 g of the PEO solution and 4 g of deionized water.

Alpha -TOC SDF-film and α-TOC NoSDF-film casting solutions were separately placed in 70 mm aluminum plates and left at room temperature until the film thickness became 0.30 mm to obtain SDF-film and NoSDF-film (control films) containing α-TOC, respectively. Both films were then dried in a vacuum oven at 25 °C overnight and stored at −20 °C.

2.3. Stability of α-TOC in nanofibers and films after exposing heat and UV irradiation and during storage

2.3.1. Effects of heat on α-TOC stability

The SDF-nanofibers, NoSDF-nanofibers, SDF-film and NoSDF-film were separately transferred in a sealed amber bottle and placed in a preheated incubator (model 3525, LAB-LINE Instruments Inc., Melrose Park, IL) for accelerated storage study at 40 °C under atmospheric pressure. Samples were removed at interval times 0, 12, 24, 36, 48, 60 and 72 h. Alpha-TOC content was then analyzed as described in Section 2.4.

Table 1
Composition of solutions.

Solutions	SDF (g/100g)	PEO (g/100 g)	Zein (g/100 g)	α-TOC (g/100 g)	Tween 80 (g/100 g)	Nanofibers/films
α-TOC SDF-nanofibers spinning solution	3	5	6	50[a]	0.5	SDF-nanofibers
α-TOC NoSDF-nanofibers spinning solution	0	5	6	50[a]	0.5	NoSDF-nanofibers
α-TOC SDF-film casting solution	3	5	6	50[a]	0.5	SDF-film
α-TOC NoSDF-film casting solution	0	5	0	1	0	NoSDF-film

[a] The weight was calculated relatively to zein mass.