Food Chemistry 268 (2018) 86–93

Contents lists available at ScienceDirect

Food Chemistry

journal homepage: www.elsevier.com/locate/foodchem

Nanoencapsulation by electrospinning to improve stability and water solubility of carotenoids extracted from tomato peels

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ARTICLE INFO

Keywords:
Electrospinning
Carotenoids
Tomato peel
Gelatin
Nanoencapsulation
Solubility

ABSTRACT

The current study demonstrated the electrospinning technique to stabilize the carotenoids. Gelatin nanofibers containing the carotenoids extracted from tomato peel (TP) were successfully fabricated with above 90% encapsulation efficiency by electrospinning. SEM analysis revealed that the extract-loaded fibers exhibit similar morphology as the neat fibers with a bead-free, smooth, and homogeneously-distributed morphology. Thermal stability of the extract was improved by nanoencapsulation. FTIR spectra showed that the TP extract could be compatibly entrapped into the gelatin fibers. Compared to non-encapsulated extract, the encapsulated one inside gelatin fibers had better retention of lycopene and antioxidant activity during 14-days storage. More interestingly, the water solubility of the carotenoid extract was highly enhanced compared to non-encapsulated one. By this study, it was realized that nanoencapsulation by electrospinning is an effective way to stabilize carotenoids and improve their water solubility, therefore it is promising to use them in food processing, especially including aqueous food matrix.

1. Introduction

Tomatoes are one of the most widely used and cultivated fruit crops. They are commonly consumed fresh and in the form of processed products such as tomato juice, canned tomato, ketchup, paste, and so on. The processing of tomatoes generates significant amounts of tomato waste (seeds, skins, and pulp) which is usually used for animal feeds or similar areas having low economic value. However, tomato waste, especially skin, is a rich source of antioxidant compounds including carotenoids mainly in the form of lycopene (80–90% of total carotenoids) (Knoblich, Anderson, & Latshaw, 2005; Riggi, Patané, & Ruberto, 2008). Moreover, Sharma and Maguer (1996) proved that the tomato peel could contain about 5 times more lycopene than tomato pulp. Tomato carotenoids are generally intended for use as natural food colorants and antioxidants in a wide variety of food areas including dairy products, baked goods, beverages, breakfast cereals, candy, soups, salad dressings and many others (Choksi & Joshi, 2007). They can be also used as food supplement providing health benefits such as modulation of the immune system, vitamin A precursor, prevention of the risk of cancer and cardiovascular diseases (Arab & Steck, 2000; Palozza, Simone, Catalano, & Mele, 2011).

However, it is difficult to incorporate the carotenoids into different food formulations because they are insoluble in water and partially soluble in oils at room temperature. Additionally, they are relatively unstable in food systems because they are susceptible to oxygen, light, and heat (Xianquan, Shi, Kakuda, & Yueming, 2005). Fortunately, encapsulation of carotenoids can be an efficient way in order to improve their solubility and preserve them from deterioration during processing.

Among the many different encapsulation techniques, considerable attention is currently being centered on electrospinning technique due to their versatility, simplicity and cost effectiveness. Additionally, nanofibers produced by electrospinning have many structural and functional advantages, such as a large surface-to-volume ratio due to high porosity, high encapsulation efficiency without heat application and enhanced stability of encapsulated compounds (Bhardwaj & Kundu, 2010). Although in the past few years, electrospinning technique has been established in several fields, including tissue engineering, enzyme immobilization, and wound dressing, etc., it is comparatively new in food science and less explored (Wen et al., 2016). In the food area, electrospun fibers have a strong potential to be used mainly in packaging, encapsulation and controlled release of food ingredients (Bhushani & Anandharamakrishnan, 2014). For this reason, natural polymers have attracted more attention of researchers in the field of electrospun nanofibers because of their better biocompatibility and non-toxicity, compared to synthetic polymers (Aceituno-Medina, Mendoza, Lagaron, & Lopez-Rubio, 2013; Moomand & Lim, 2014). In this study, gelatin was selected as an encapsulant material because of its good electrospinnability (Okutan, Terzi, & Altay, 2014). Gelatin is

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https://doi.org/10.1016/j.foodchem.2018.06.017
Received 19 February 2018; Received in revised form 28 May 2018; Accepted 4 June 2018
0308-8146/

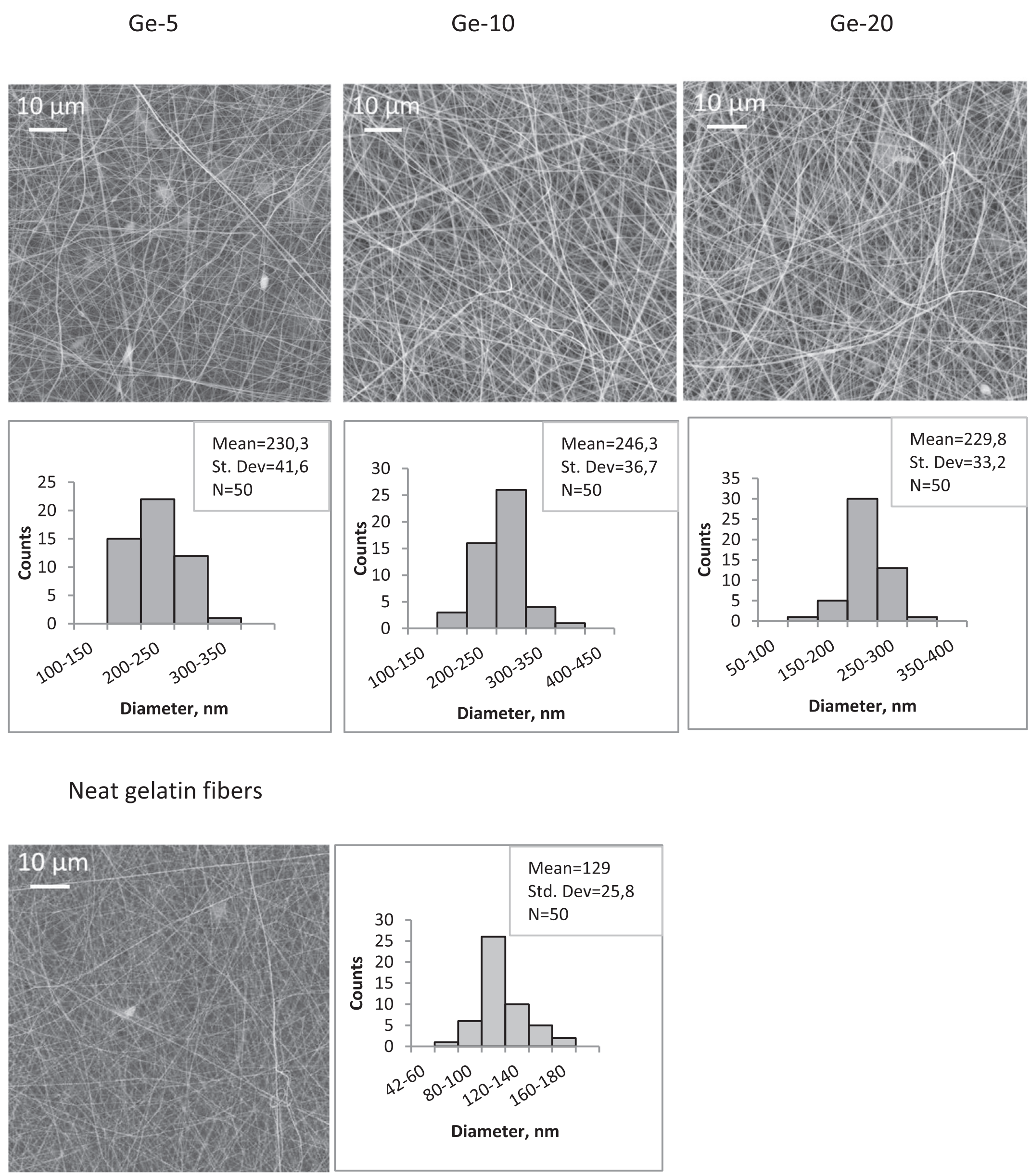

Fig. 1. SEM images with histogram graphs of diameters of TPE-loaded and neat gelatin fibers.

Table 1
Characteristics of prepared gelatin solutions and fiber diameters.

TPE concentration (%)	Viscosity (cP)	Conductivity (mS/cm)	Surface tension (mN/m)	Diameter (nm)
0	256.2 ± 4.2^a	2.51 ± 0.4^a	40.0 ± 0.2^a	129 ± 25.8^a
5	321.1 ± 3.4^b	2.39 ± 0.2^b	38.0 ± 0.4^b	230.3 ± 41.6^b
10	371.4 ± 1.8^c	2.38 ± 0.2^b	37.9 ± 0.2^b	246.3 ± 36.7^b
20	397.1 ± 2.9^c	2.23 ± 0.2^c	37.6 ± 0.0^b	229.8 ± 33.2^b

Data with the same superscript letter in the same column indicate that they are not statistically different ($p > 0.05$).

easily obtained by partial hydrolysis of collagen from animal tissues and widely used in the food industry as an emulsion stabilizer and thickener.

Up to now, the stabilization of carotenoids by electrospinning technique has been less investigated with only a few studies on encapsulation of β-carotene into nanofibers (Fernandez, Torres-Giner, & Lagaron, 2009; Peinado, Mason, Romano, Biasioli, & Scampicchio, 2016; Reksamunandar, Edikresnha, Munir, Damayanti, & Khairurrijal, 2017; Zômpero, López-Rubio, de Pinho, Lagaron, & de la Torre, 2015). These studies focused on encapsulation of only β-carotene, not any other carotenoid. Additionally, no study related to encapsulation of lycopene by electrospinning technique to improve its stability and water solubility has been reported in literature. However, the present study explored the use of electrospinning for encapsulation of total carotenoids extracted from tomato peel (composed of mainly lycopene and moderately β-carotene) into gelatin nanofibers to improve its thermal and storage stability, antioxidant activity, and water solubility. The morphology, structure, encapsulation efficiency of produced composite fibers and the compatibility of components within the fibers were also explored.

2. Materials and methods

2.1. Materials

Type B gelatin powder from bovine skin, lycopene standard, HPLC grade solvents; glacial acetic acid (HAc), hexane, acetone, methanol,