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Butylated hydroxyanisole encapsulated in gelatin fiber mats: Volatile release kinetics, functional effectiveness and application to strawberry preservation

Linlin Li[a], Hualin Wang[a,c,*], Minmin Chen[a], Suwei Jiang[a], Shaotong Jiang[b,c], Xingjiang Li[b,*], Qiaoyun Wang[b]

[a] School of Chemistry and Chemical Engineering, Hefei University of Technology, 230009 Hefei, Anhui, PR China
[b] School of Food Science and Engineering, Hefei University of Technology, 230009 Hefei, Anhui, PR China
[c] Anhui Institute of Agro-Products Intensive Processing Technology, 230009 Hefei, Anhui, PR China

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ABSTRACT

Butylated hydroxyanisole (BHA) encapsulated in gelatin (GA) (GA-BHA) fiber mats were fabricated *via* electrospinning technique and applied to strawberry preservation. The volatile release kinetics and functional effectiveness of the mats were investigated. BHA was high efficiently encapsulated in GA fibers and the antioxidant activity of BHA could be well protected. The encapsulation of BHA enhanced the stability of GA and favored structure transition of GA from random coil and β-turns to α-helix and β-sheet. The GA-BHA mats showed good antibacterial activity against *Staphylococcus aureus*, and the predominant volatile release mechanism of BHA from mats was Fickian diffusion. Furthermore, the mats also showed broad-spectrum antifungal activity against four mould genera (*Rhizopus* sp., *Mucor* sp., *Aspergillus* sp. and *Penicillium* sp.). The shelf-life of strawberry can be prolonged effectively in the presence of GA-BHA mats during storage. Results suggested that the GA-BHA mats may have a great potential in active food packaging.

1. Introduction

Active food packaging offers new opportunities for food preservation (Etxabide, Uranga, Guerrero, & de la Caba, 2017; Wen, Wen, Zong, Linhardt, & Wu, 2017). Antimicrobial packaging is one of the advanced food packaging technologies and is extensively studied for the application to food preservation. Phenolic compounds (Rui et al., 2017), flavonoids (Aytac, Kusku, Durgun, & Uyar, 2016), bacteriocins (Balciunas, Castillo Martinez, Todorov, Franco, Converti, & Oliveira, 2013), and antimicrobial enzymes (Wang, Yue, & Lee, 2015) are the commonly used entities in antimicrobial packaging. Among them, phenolic compounds have attracted more attention because of their better antibacterial and antioxidant activities (Franco, Galeano-Díaz et al., 2014; Zhang et al., 2014). Butyrate hydroxyanisole (BHA) is a commonly used food antioxidant and antiseptic due to its low cost and availability (Wu et al., 2015; Zhao & Hao, 2013). In order to expand the application of BHA, we evaluated the application of BHA to preservation of strawberries in the present work. As BHA is a volatile compound which is easily oxidized, an effective encapsulation of BHA is needed for the purpose of its control release. However, less relative research work has been done with BHA.

Electrospinning has been widely used as a simple, versatile and efficient technique for the encapsulation of bioactive entities (Neo et al., 2013; Wen et al., 2016). In comparison with the traditional films prepared by casting or coating methods, electrospun fibers are more responsive to surrounding atmosphere change and enable the controllable release of encapsulation entities due to its larger specific surface area and higher porosity (Vega-Lugo & Lim, 2009). Gelatin is a kind of soluble peptidic compound derived from collagen (Gómez-Guillén, Giménez, López-Caballero, & Montero, 2011), which possesses good fiber-forming capacity besides excellent biocompatibility, non-toxicity, abundance and low cost (Torkamani, Syahariza, Norziah, Wan, & Juliano, 2018). Some bioactive entities such as asiaticoside (Sikareepaisan, Suksamrarn, & Supaphol, 2008), vitamin A and E (Li et al., 2016) and curcumin (Deng, Kang, Liu, Feng, & Zhang, 2017) were successfully encapsulated in gelatin matrix *via* electrospinning technique.

In comparison with non-volatile bioactive compounds, the volatile ones encapsulated in packaging matrix can be easily released and volatilize to the limited storage space of food, exerting antibacterial activity towards microorganism or antioxidant towards lipids and protein. There are a few reports regarding the development and application by utilizing the volatility of antibacterial compounds (Avila-Sosa et al., 2012; Shojaee-Aliabadi et al., 2013). Herein, BHA encapsulated in

* Corresponding authors at: School of Chemistry and Chemical Engineering, Hefei University of Technology, 230009 Hefei, Anhui, PR China (H. Wang).
E-mail addresses: hlwang@hfut.edu.cn (H. Wang), lixingjiang1978@hfut.edu.cn (X. Li).

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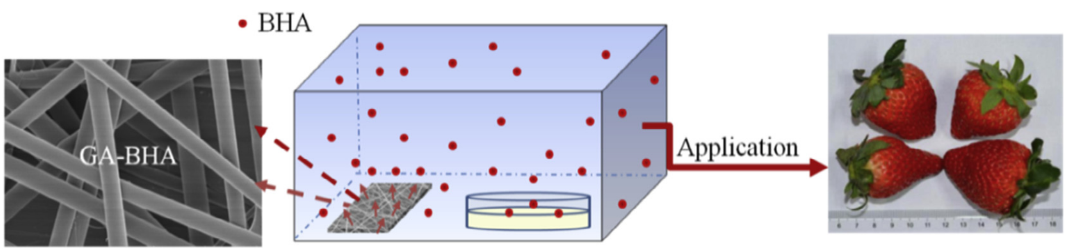

Fig. 1. Schematic illustration of BHA volatile release and application to strawberries.

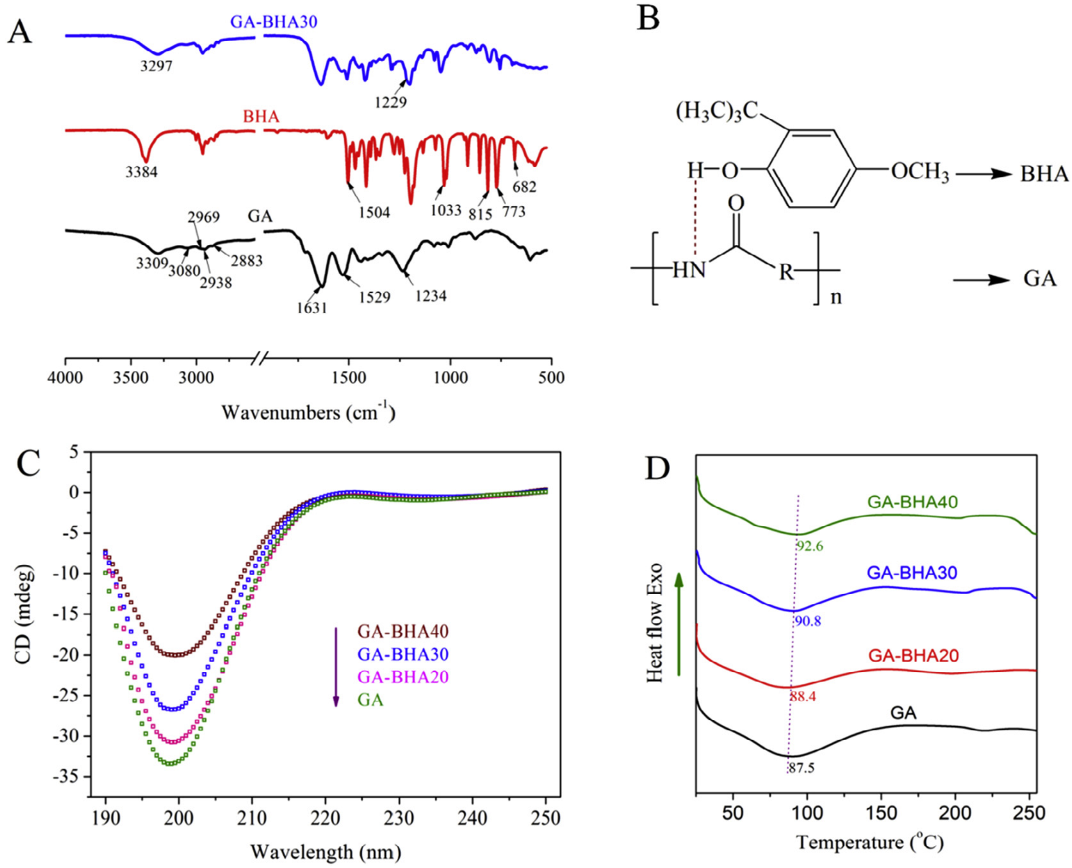

Fig. 2. (A) FTIR spectra of BHA powders, GA and GA-BHA fiber mats, (B) Hydrogen bond between GA and BHA, (C) CD spectra of GA-BHA solutions at 25 °C, and (D) DSC curves of GA and GA-BHA fiber mats.

Table 1
Secondary structure proportions of GA obtained from deconvoluted CD spectra.

	α-helix (%)	β-sheet (%)	β-turns (%)	Unordered (%)
GA	27.2 ± 0.6^{a}	7.0 ± 0.2^{a}	18.9 ± 0.7^{a}	48.2 ± 1.1^{a}
GA-BHA20	28.9 ± 0.7a	7.3 ± 0.3^{a}	16.1 ± 0.5^{b}	47.5 ± 0.9^{a}
GA-BHA30	29.1 ± 1.1^{a}	11.0 ± 0.5^{b}	13.2 ± 0.4^{c}	46.9 ± 0.4^{a}
GA-BHA40	31.9 ± 0.9^{b}	23.1 ± 0.5^{c}	13.0 ± 0.3^{c}	31.8 ± 0.5^{b}

Data with the same superscript letter in the same column indicate that they are not statistically different ($p > 0.05$). The data (mean ± SD) are results from three independent experiments.

gelatin fiber mats were fabricated *via* electrospinning technique and applied to strawberry preservation. Attentions were focused on the volatile release kinetics in limited space and functional effectiveness (antioxidant, antibacterial and antifungal activities) of the mats.

2. Materials and methods

2.1. Materials

Porcine gelatin (from porcine skin, G2500, type A) with moisture content no higher than 15% was bought from Sigma (St Louis, MO, USA). Hydrochloric acid (HCl), sodium chloride, sodium bicarbonate and sodium carbonate were supplied from Sinopharm (Shanghai, China). Glacial acetic acid (> 99%), butylated hydroxyanisole (BHA, > 99%), and ethyl alcohol (> 99%) were provided by Aladdin (Shanghai, China). Folin-Ciocalteu's reagent, phosphate buffered solution (PBS, 1X) was obtained from Beijing Solarbio Science & Technology Co., Ltd (Beijing, China). Beef extract and peptone were bought from Sangon Biotech Co., Ltd (Shanghai, China). Strawberries (*Fragaria × ananassa* Akihime) were purchased from commercial greenhouses in a local farm (Hefei, Anhui) in November. All fruits without additional pretreatment were selected based on the same maturity (> 75% red surface color), no physical damage and uniform size. Milli-Q water from a Millipore purification system (Bedford, MA, USA)