Food Chemistry 212 (2016) 274–281

Contents lists available at ScienceDirect

Food Chemistry

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

A new kinetic model of ultrasound-assisted extraction of polysaccharides from Chinese chive

Wei-Nan Zhang [1], Hai-Lin Zhang [1], Chao-Qun Lu, Jian-Ping Luo, Xue-Qiang Zha *

School of Biotechnology and Food Engineering, Hefei University of Technology, People's Republic of China

ARTICLE INFO

Article history:
Received 28 March 2016
Received in revised form 17 May 2016
Accepted 23 May 2016
Available online 24 May 2016

Keywords:
Chinese chive
Kinetic model
Polysaccharide
Ultrasound-assisted extraction
Extraction process
Degradation process

ABSTRACT

Chinese chive, a famous green vegetable, is widely cultivated in the Asia. In the present study, we found that ultrasound caused the degradation of Chinese chive polysaccharides (CCP) in the process of extraction. Since lacking the consideration of polysaccharide degradation, the traditional kinetic models can not reflect the real extraction process of CCP. Therefore, a modified kinetic model was thus established by introducing a parameter of degradation coefficient based on the Fick's second law, suggesting the diffusion and degradation of CCP is highly dependent on the ultrasonic power, extraction temperature and solid-liquid ratio. According to this modified model, the maximum CCP yield was obtained under an optimal extraction condition including extraction temperature 37 °C, ultrasonic power 458 w, extraction time 30 min and solid-liquid ratio 1:32. The objective polysaccharides responding to ultrasound were shown to be four different fractions, contributing to the increased diffusion and degradation of CCP by ultrasound treatment.

1. Introduction

Chinese chive (*Allium tuberosum* Rottl. Ex Spreng) is a well-known green vegetable in China, Japanese, Korea and some other Asian countries. As a commercial crop, it is widely cultivated in the East and Southeast Asia (Pandey, Pradheep, & Gupta, 2014). The leaves and seeds of this plant are often used in traditional folk medicines for the treatment of impotence and nocturnal emission in China (Hu et al., 2009). According to the records in traditional Chinese medicine, the leaves of Chinese chive can also treat abdominal pain, diarrhea, hematemesis, snakebite and asthma (Liu, Zhao, Su, Wang, & Zhang, 2006). These suggest that the Chinese chive has functional components being beneficial for human health. Up to date, some new steroidal saponins, alkaloids and amides have been isolated and characterized from the seeds of *Allium* genus, as wells as sulfur-containing compounds (Mnayer et al., 2014). Polysaccharides, an important type of natural biopolymers, have been suggested to possess various nutritional values and health functions (Shashidhar, Giridhar, & Manohar, 2015). In recent years, polysaccharides extracted from the plants of *Allium* genus have been reported to exhibit prominent benefits to human health, including antioxidant, antitumor and immunostimulating activity (Lee et al., 2009; Mladenovic et al., 2011; Nikolova et al., 2013). Recently, adenine-induced experimental mouse model was employed to screen the bioactive ingredients with protective effects on kidney in our research group. We found that the protective ability of Chinese chive against chronic renal failure is positively associated with the intake of polysaccharide dosage, indicating polysaccharide is one of the main bioactive compounds of Chinese chive to protect kidney.

Quantity and quality of extracts from raw material are powerfully related to the extraction method. With respect to the polysaccharide extraction from plants, the conventional extraction technology is hot-water extraction (HWE) involved in heating or boiling (Cheung & Wu, 2013). However, these methods exhibited inherent shortcomings of high-energy consumption, more extraction time consuming and limited polysaccharide production (Cheung & Wu, 2013). To overcome these drawbacks of hot-water extraction method, the application of new technologies in the extraction of polysaccharides has been concerned by the food, pharmacological and chemical scientists in recent years. Among different innovative extraction methods, ultrasound-assisted extraction (UAE) has been recognized as an efficient and environment-friendly extraction technique with strong advantages of high extraction yield, low energy input and short extraction time (Chen, You, Abbasi, Fu, & Liu, 2015), suggesting UAE is an ideal alternative to extract polysaccharides from raw materials. It is well

* Corresponding author at: School of Biotechnology and Food Engineering, Hefei University of Technology, Hefei 230009, People's Republic of China.

E-mail addresses: jianpingluo@hfut.edu.cn (J.-P. Luo), zhaxueqiang@hfut.edu.cn (X.-Q. Zha).

[1] These authors are co-first author.

http://dx.doi.org/10.1016/j.foodchem.2016.05.144
0308-8146/

accepted that the enhancement of extraction yield by ultrasound is attributed to the ultrasonic cavitation, as well as the accompanied physical and chemical effects (Hashemi, Michiels, Yousefabad, & Hosseini, 2015). Actually, an efficient extraction process should maximize the recovery of target compounds with minimal degradation. Literature survey revealed that the diffusion of polysaccharides is commonly accompanied by their degradation in the process of ultrasonic-assisted extraction (Yu et al., 2015; Zhao, Zhou, & Liu, 2012). Therefore, it is really needed to take some measures to control the degradation of polysaccharides in the extraction process. To solve this problem, some theoretical, empirical and semi-empirical models have been developed to describe the behavior of diffusion and degradation of polysaccharides in the extraction process. From an engineering point of view, the establishment of these kinetic models would be helpful to facilitate the design, optimization and control of the extraction process, as well as provide useful information for scaling up the industrial production (Imamoglu & Sukan, 2013; Wang & Sun, 2003). In recent years, several mathematical models like pseudo first-order model, diffusion model, Weibull-type model, saeman's model and two site kinetic model have been employed to simulate the extraction process of polysaccharides in the solid-liquid extraction system (Cheung, Siu, & Wu, 2013; Zhao, Morikawa, Qi, Zeng, & Liu, 2014). Unfortunately, they only considered a single process of diffusion or degradation of polysaccharides. As far as our best knowledge to be ascertained, the kinetic model for simultaneous consideration of diffusion and degradation has not been reported to simulate the real ultrasound assisted extraction process of polysaccharides.

Thus, to unravel the effects of ultrasonic power, extraction time, extraction temperature and solid-liquid ratio on the extraction yield of polysaccharides from Chinese chive, the present study was aimed to establish a suitable kinetic model considering both polysaccharide diffusion and degradation processes under ultrasound-assisted extraction. Based on this model, the extraction conditions were optimized for obtaining the maximum yield of polysaccharides from Chinese chive. Meanwhile, the ultrasound-acted target of polysaccharide was also determined through comparison with that extracted by the conventional technology.

2. Materials and methods

2.1. Material preparation

Chinese chive used in the present study was purchased from local supermarket in Hefei city of China. It was dried at 40 °C and smashed to fine powder. The particle size of the powder was determined to be the mean value of 114 μm by laser particle size analyzer (BT-9300HT, Beijing Hongxianglong Biotechnology Development Co. Ltd., Beijing, China).

2.2. Reagents and equipments

Standard dextran (T-2000, T-700, T-580, T-110, T-80, T-70, T-40 and T-11) were purchased from Sigma-Aldrich company (Louis, MO, USA). All other reagents were of analytical grade. The ultrasound-assisted extraction was carried out in a thermostatic ultrasonic processor (SY-1000E, Beijing Hongxianglong Biotechnology Development Co., Ltd., Beijing, China). The ultrasonic extractor was equipped with a digital controlled low-frequency sonotrode (25 kHz) and a powerful probe-shaped ultrasonic transducer. The sonotrode can change the ultrasonic power from 0 to 900 W. Moreover, this extractor was equipped an automatic temperature controlling system.

2.3. General methods for the extraction of polysaccharides from Chinese chive

The powder of Chinese chive (18.0 g) was mixed with distilled water in a 1000 mL reaction vessel and the ultrasonic probe was inserted into the mixture about 3 cm deep. The extraction temperature was controlled by an automatic temperature controlling system. For all ultrasound-assisted extraction, the ultrasonic processing was set 5 s followed by 1 s interval. At the end of each extraction, the crude extracts were centrifuged at 10,000 rpm for 5 min to separate the liquid extract from the solid residue. After the liquid extract was condensed to 40 mL, the concentrate was further mixed with ethanol at final concentration of 80% (v/v) to precipitate overnight at room temperature. The precipitates were further performed to remove proteins using Sevag method (Staub, 1965), dialyzed with 3500 Da dialysis bags and freeze-dried, giving the crude polysaccharide of Chinese chive (CCP).

2.4. Experimental design

The effects of ultrasonic power, extraction time, extraction temperature and solid-liquid ratio on the extraction yields of CCP were investigated in the present study. For the effect of solid-liquid ratio, it was performed at three different levels of 1:20, 1:30 and 1:50 (w/v) while the ultrasonic power was set at 160 and 320 W. To explore the effects of ultrasonic power and extraction temperature, sonication was carried out at four levels of 160, 240, 320 and 480 w, meanwhile the extraction temperature (Kelvin temperature, k) was set at 303, 313, 323, 333 and 343 k. For all experiments, the extraction time was set at seven levels of 0, 5, 10, 20, 40, 60 and 80 min.

2.5. Changes in the particle size of Chinese chive by ultrasonic treatment

After the powder of Chinese chive was extracted for 30 min under the treatment with ultrasound at 320 and 640 w, the particle size was determined by laser particle size analyzer and compared with that of original powder without ultrasound treatment.

2.6. Comparison of extraction performance

The performance of ultrasound-assisted extraction was compared with that of conventional hot-water extraction (HWE). For the extraction of CCP using UAE method, the Chinese chive powder was extracted under an optimal extraction condition obtained from the established kinetic model of present study. For the extraction of CCP using HWE method, the extraction condition was set as the same as that of UAE method except using ultrasonic power.

2.7. Analysis of polysaccharide content

The phenol-sulfuric acid method was employed to determine the polysaccharide content for each experiment (Dubois, Gilles, Hamilton, Rebers, & Smith, 1956).

2.8. Analysis of target CCP fractions responding to ultrasound

After the crude CCP was prepared using UAE and HWE, fractional precipitation was employed to purify the crude polysaccharide using ethanol at final concentration of 40%, 60% and 80% (v/v) in turn, giving three different polysaccharide fractions. Subsequently, the molecular weight distribution were analyzed by High Performance Liquid Chromatography system (HPLC, 1260 Infinity, Agilent Technologies) equipped with TSKgel column G4000PWXL and G5000PWXL connected in series. The column temperature