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Ultrasonic frequency effect on corn starch and its cavitation

Aijun Hu*, Shuting Jiao, Jie Zheng, Li Li, Yanshu Fan, Lin Chen, Zhihua Zhang

Key Laboratory of Food Nutrition and Safety, Ministry of Education, College of Food Engineering and Biotechnology, Tianjin University of Science & Technology, Tianjin 300457, PR China

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ABSTRACT

With the same ultrasonic power, time and temperature, different ultrasonic frequency (20 kHz, 25 kHz and 20 kHz + 25 kHz) effects on the structure and properties of corn starch in water were studied, as well as its cavitation. Brabender viscometer and Scanning Electron Microscope (SEM) were used to determine the viscosity and microstructure of starch respectively. The experimental results indicated that the peak viscosity of starch without ultrasound was 1076.0BU, however it decreased by 18.87% and 17.66% with 25 kHz and 20 kHz, respectively. Ultrasound could significantly change the thermal stability, retrogradation, gel properties of starch, and caused depression on the surface of starch granules. Iodine release yield was used to present the cavitational yield at different frequencies of ultrasound. Compared to these with each single frequency ultrasound, the change of the above properties of corn starch granules microstructure with dual-frequency (20 kHz + 25 kHz) ultrasound were smaller, but had much more depression on their surfaces. Dual-frequency ultrasound produced more cavitation yields and caused faster collapse of bubbles than each single frequency. In conclusion, (20 kHz + 25 kHz) proved an more evident effect on corn starch structure and properties, and as a possible mechanism, it has more ultrasonic cavitations.

1. Introduction

Starch is one of the most abundant natural carbohydrates stored in plants. It is found in many different plant organs including seeds, fruits, tubers and roots, and functioned as a source of energy. Although starch is widespread, abundantly available, cheap, degradable, pollution-free and renewable (Gao, 2001), it has many short falls, i.e., insoluble in cold water, easy to dehydration, low emulsifying power and unstable in acid, due to which commercial application is limited. In order to improve starch properties, starch modification is a major issue and has attracted the attention of researchers. Generally, there are three major starch modification methods, which include chemical, biological and physical modifications, of which, ultrasonic modification being as an eco-friendly, high efficient and safety physical method, is attaining more attentions.

Till now, most of the researches focused on the application of single frequency ultrasound. Dual-frequency ultrasound can significantly increase the cavitation effect to enhance the sonochemical yield, it has attracted interests of many researchers (Bi & Qiu, 2006; Zeng & Qiu, 2005). However, preparation of modified corn starch by dual-frequency ultrasound and different ultrasonic frequency effect on starch have not yet been reported.

Ultrasound is a sound wave with frequency ranges from 2×10^4 to 10^9 kHz. And ultrasonic device is simple, easy to handle and atomize (Bartsch & Schmidt-Naake, 2006). It has been applied in extraction, emulsification, homogenization, crystallization, filtration, separation, viscosity alteration, defoaming, and extrusion. Ultrasound can also inactivate enzymes and bacteria by breaking cell membranes due to the violence of cavitation and the formation of free radicals (Jambrak, Mason, Lelas, & Herceg, 2008). Ultrasonic cavitation is a series of dynamic processes of bubbles in the liquid when they are exposed to ultrasonic field. Cavitation is the formation of cavities filled with gas or vapor as the pressure decreases, and they collapse as the pressure increases again. When the cavities collapse, hot spots will appear, creating high temperature and pressure area (pressure up to several hundred MPa, temperature above 5000 °C), with a strong shock wave and a jet at the speed of 400 km/s accompanied (Hemwimol, Pavasant, & Shotipruk, 2006; Swamy, Narayana, & Vibhuti, 2005). Due to this extreme and special physical environment, ultrasonic cavitation not only can be used in the field of cleaning, but also in the medicine, biology,

* Corresponding author. Key Laboratory of Food Nutrition and Safety, Ministry of Education, College of Food Engineering and Biotechnology, Tianjin University of Science & Technology, No. 29, 13th Avenue, Tianjin Economical-Technological Development Area, Tanggu District, Tianjin 300457, PR China. Tel.: +86 13512056805; fax: +86 22 60912431.
E-mail address: huaijun@tust.edu.cn (A. Hu).

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marine science, aviation, food industry, chemical engineering, and light industries (Zheng, Li, & Hu et al., 2013; Zeng & Qiu, 2005). In the light of ultrasonic cavitation application in various fields, many researches diverted their attention towards it.

Compared to single frequency ultrasound, in the field of dual frequency ultrasound, significant increase of the cavitational event, the reduce of the dead angle caused by standing wave, and the improvement on sonochemical productivity has been reported in many studies (Bi & Qiu, 2006; Jambrak et al., 2010). Manickam Sivakumar and his colleagues used the dual-frequency ultrasound system to study the kinetics of degradation of p-nitrophenol (Sivakumar, Tatake, & Pandit, 2002). Feng and his colleagues combined 28 kHz and 0.87 MHz ultrasound into a new device for the first time, and used the electrochemical method and the iodine release method to study the cavitational yield (Zhu, Feng, Xu, & Yin, 2000). They found that the cavitational yield using dual-frequency ultrasound was higher than the amount of two single ultrasound's total productions. Zeng and Qiu (2005) used dual-frequency ultrasound to study cavitational yield by iodine release yield of KI solution. The results showed that, using dual-frequency ultrasound, the cavitational yield was higher than that by using a single frequency ultrasound under the same experimental conditions. But the studies of ultrasonic frequency (20 kHz, 25 kHz and 20 kHz + 25 kHz) effect on corn starch and its cavitation have not yet been reported.

The aim of this research is to study the ultrasonic frequency effect, its cavitational yield and bubble movement models under different frequency ultrasound, which can provide some theoretic foundation of sonochemistry and its applications in development of modified starch using ultrasound with the suitable frequency.

2. Materials and methods

2.1. Materials and equipments

Commercially available corn starch (12.6% moisture) was obtained from Jiaozuo (Henan, China). Sodium hydroxide, and AR, was supplied by Tianjin Deen Chemical Reagent Company (Tianjin, China). Hydrochloric acid was purchased from Tianjin Kemiou Chemical Reagent Company (Tianjin, China). Iodine, potassium iodide, sodium thiosulfate, and carbon tetrachloride were purchased from Tianjin Jiangtian Chemical Reagent Company (Tianjin, China).

Tri-frequency ultrasound device (SB-1680DTY) shown in Fig. 1 was supplied by Ningbo Xinzhi Bioscience Co., Inc (Ningbo, China), with adjustable electric power maximum up to 400 W for each frequency (40 kHz, 25 kHz and 20 kHz) ultrasound. Vacuum pump was purchased from Zhengzhou Changchen Company (Henan, China). Brabender Micro Visco-amylo-graph with variable speed (803,202) was purchased from Brabender GMH Co. (Germany). Scanning electron microscope (SEM) was purchased from Hitachi high-Technologies (Japan). Electric blast oven (ZSD-5110) was purchased from Shanghai Zhicheng Analytical Instruments Manufacturing Company (Shanghai China).

2.2. Methods

2.2.1. Sample preparation

5% (w/w) starch slurry was prepared by adding 5 g starch (on the dry basis) to 95 g distilled water. After treating 40 min at 30 °C by different ultrasound, it was washed and filtered repeatedly with distilled water, and then dried at 40 °C and milled to powder.

2.2.2. Determination of the viscosity

10% starch suspension (on dry basis) was prepared by placing ultrasonicated corn starch in distilled water and mixing them well. Then it was kept in the Brabender viscometer test slot. Its test conditions were: initial temperature was at 30 °C, it increased by 7.5 °C/min to the end temperature of 92 °C, and maintained at 92 °C for 5 min, then it dropped by 7.5 °C/min to 50 °C. The viscosity curve was automatically drawn and saved.

2.2.3. Determination of the microstructure of starch granules

A certain amount of test samples were fully dispersed in ethanol, a definite amount of the sample was taken and applied to the glass, the samples were fixed on the loading platform using conductive double-sided adhesive tape. After drying, the sample was gold plated in vacuum condition. After that, the samples handled was kept in scanning electron microscope and observed. The morphology of particles which are representative were shot.

2.2.4. Cavitational effect detected by aluminum foil

The aluminum foil was used as testing material to investigate the ultrasonic cavitational yield. It was treated 1 min with ultrasound at the corresponding frequency, and then pictures were taken. The pictures revealed the impact of ultrasound on the surface of the aluminum foil. Many pores and damage were visible on the surface. The holes were bigger; the ultrasonic cavitation effect was stronger.

2.2.5. Determination of cavitational yield by iodine release method

Early results (Zhu et al., 2000) showed that, KI solution which included dissolved air could form iodine after ultrasonic irradiation. The reactions could be gotten as follows:

$$H_2O \xrightarrow{\text{ultrasonic cavitation}} \cdot H + \cdot OH$$

$$2 \cdot OH \rightarrow H_2O_2$$

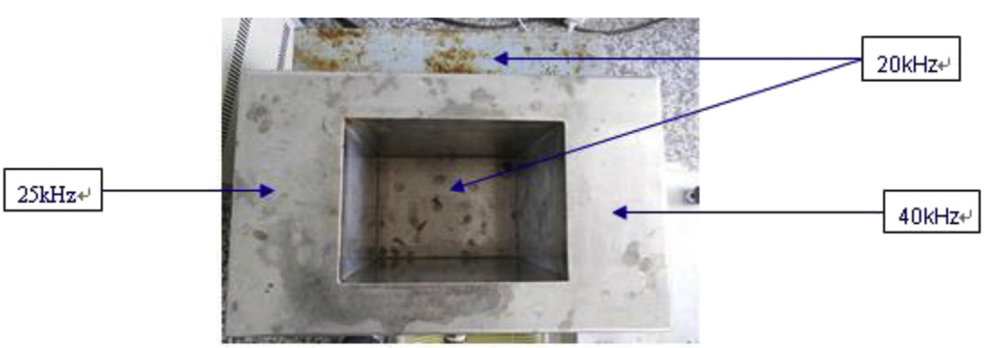

Fig. 1. Tri-frequency ultrasonic device.