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Yield and textural properties of tofu as affected by soymilk coagulation prepared by a high-temperature pressure cooking process

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ABSTRACT

The cooking of raw soymilk is a necessary procedure prior to the production of tofu. The effects of the high-temperature pressure cooking (HTPC) and traditional cooking methods on the yield and textural properties of tofu products were investigated. Results showed that when HTPC was applied, the content of protein particles increased, thereby contributing to the formation of a dense network of tofu gel. Thus, significant improvement of textural properties, including hardness, chewiness and springiness, was observed. Moreover, HTPC contributes to the change in the composition of the particulate protein, whereas the proportion of β-conglycinin in the non-particulate protein increased. The start and end points of the protein coagulation induced by Ca^{2+} moved backward, and slowed the coagulation process, which was conducive to the incorporation of water or dry matter into the gel.
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1. Introduction

Tofu is a widely consumed soy product that is popular in China and other Asian countries. Recently, the abundance of nutritious proteins in soy products has been accepted by western consumers (Friedman & Brandon, 2001; Potter, 2000), thereby boosting its annual consumption. The textural property of tofu determines the quality and the consumer acceptability of the product (DeMan, DeMan, & Gupta, 1986).

Cooking methods and cooking temperature influence the yield and quality of tofu products (Liu & Chang, 2004; Toda, Chiba, & Ono, 2007; Wang et al., 2007). Cooking raw soymilk prior to the production of tofu is necessary. During this process, soymilk proteins are denatured, and the dissociation and re-association of protein subunits occur when their denaturation temperatures are exceeded. Nearly 50% of the formed protein aggregates exist as protein particles with a diameter larger than 40 nm (Guo, Ono, & Mikami, 1997). The Ca^{2+}-induced coagulation of soymilk is normally described as a three-stage process. First, phytic acids interact with Ca^{2+} and form non-ionizing products, which weaken the electrostatic screening effects of ions on protein molecules and allow the interaction between Ca^{2+} and proteins. Second, Ca^{2+} preferentially interacts with non-particulate proteins and forms new protein particles. Finally, protein particles associate with each other to develop the gel network (Guo, Ono, & Mikami, 1999;

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Wang, Xie, & Guo, 2015). In soymilk, protein particles are more sensitive than non-particles to Ca^{2+} as they more easily lose solubility at a low Ca^{2+} level. The higher the content of protein particles, the lower the level of Ca^{2+} in which soymilk forms precipitates and the harder the texture of the tofu product (Guo & Ono, 2005; Ono, Katho, & Mothizuki, 1993; Tezuka, Taira, Igarashi, Yagasaki, & Ono, 2000). Thus, both the content and composition of protein particles affect the coagulation process of soymilk and the textural property of tofu product.

Cooking at atmospheric pressure is a traditional process. However, this traditional cooking (TC) method has low efficiency. In the industrial scale of production, the TC process normally leads to the non-uniform heating on soymilk and the difficulty in quality assurance of tofu products. To increase the cooking temperature and heating efficiency, raw soymilk can be processed at relatively high pressures (>1 atm). This high temperature pressure cooking (HTPC) method helps decrease heat loss during manufacturing; thus, this is an economical technology. Nevertheless, previous studies have not investigated the effect of HTPC on the texture of tofu until now. This study examined the coagulation process of soymilks prepared by HTPC (0.17 MPa, 115 °C) and TC (0.10 MPa, 97 °C) methods. Through the analysis on the content and composition of protein particles, the yield and textural property of HTPC tofu gel were clarified. The results provide useful information on the application of HTPC-based technology in tofu production.

2. Materials and methods

2.1. Materials

Soybeans were purchased from the local market. Comass G-250 was acquired from Sigma Chemical Co., Ltd. (St. Louis, Mo., USA). The chemical reagents used in this study were all of reagent grade.

2.2. Preparation of soymilk

Soybeans were washed and soaked in distilled water for 8 h at room temperature (20 ± 2 °C). The hydrated soybeans were drained and ground with distilled water (water to soybean ratio is 7:1) in a soymilk grinder (Model FSM-100, Kangdeli Machinery Factory, China) equipped with an automatic centrifugal 120-mesh filter to separate the okara. The raw soymilk (protein content, 3.05 ± 0.17 g/100 g soymilk; dry matter, 6.07 ± 0.24 g/100 g soymilk; pH = 6.8 ± 0.05) was divided into two parts and used for either the TC or HTPC process.

One part of the raw soymilk was transferred into cooking equipment (DDJ-80, Kangdeli Mechanical Company, Beijing, China). The raw soymilk was heated at rates of 8 °C/min and kept at boiling temperature for 5, 10, and 15 min with continuous stirring under atmospheric pressure. The heating rate was controlled by adjusting the injection rate of steam. Heated soymilk was quickly cooled in an iced water bath to room temperature. The obtained soymilk is designated as the TC soymilk. The other part of the raw soymilk was cooked using the same equipment in pressure-cooking mode. Raw soymilk was heated until boiling at heating rates of 8 °C/min, when exhaust the excess air in the equipment, the pressure-cooking mode was subsequently applied to raise the temperature to 115 °C (0.17 MPa) respectively for 5, 10, and 15 min. After cooling in an iced water bath, the obtained product is designated as the HTPC soymilk.

2.3. Preparation of tofu

The HTPC and TC soymilk was cooled to the desired temperature of 85 °C. $CaSO_4 \cdot 2H_2O$ was then added with continuous stirring at 150 rpm within 40 s to achieve the final concentration of 0.02 M. The mixture was allowed to coagulate without stirring for 30 min. The coagulated tofu curd was then broken slightly and transferred into a home-made mold (11 cm × 8 cm × 4 cm) lined with cheese cloth. The curd in the mold was pressed to expel the whey under a sequential pressing stress at 500 g for the first 15 min and 1000 g for the next 15 min. The resulting tofu was weighed to calculate the yield and then stored in the refrigerator (4 °C) until the next day of analysis. Yield of tofu was computed as the wet weight (g) of tofu per 100 g raw soybeans as described by Cai and Chang (1999).

2.4. Texture analysis

The textural properties were measured by a texture analyzer (Brookfield CT3, U.S.), according to the method of Bourne (1978) with some modifications. The cubical samples (15 mm × 15 mm × 15 mm) were cut from the central portion of tofu using a razor blade. A TA25 probe was employed, and a 10-mm travel distance and a speed of 0.5 mm/s in the cycle mode were chosen as operating parameters. Textural properties (hardness, chewiness, and springiness) were analyzed.

2.5. Water holding capacity (WHC) of tofu

The WHC of tofu was determined based on the method proposed by Puppo and Anon (1998) with slight modification. Approximately 5 g of tofu was placed on a cotton cloth membrane maintained in the middle position of a 50 ml centrifuge tube. After centrifugation at 800×*g* for 10 min, the sample was weighed as W_1 and subsequently heated to a constant weight (W_2) at 105 °C. The WHC of tofu was calculated as the following equation: $WHC = (W_1 - W_2)/W_1$.

2.6. Scanning electron microscopy (SEM)

The tofu curd was cut into small pieces (<2 mm in side length) with a razor blade, and then immersed in 2.5% glutaraldehyde and rinsed thrice with phosphate buffer (0.1 M, pH 7.2), before stepwise dehydration by 30%, 50%, 70%, 80%, 90%, and 100% ethanol. The sample was frozen in liquid nitrogen and freeze-dried. Dried samples were mounted on stubs and sputter coated with gold. The microstructure of tofu curd was observed under SEM (HITACHI SU8010, Japan) at 5.0 kV.

2.7. The content of soymilk protein particle

Soymilk was centrifuged at 156,000×*g* for 30 min at 20 °C. Protein concentrations of the whole soymilk and the supernatant after centrifugation were measured by the Bradford (1976) method (Ono, Takeda, & Guo, 1996). The content of soymilk protein particle was calculated using the following formula: % Content of protein particle = [(Protein concentration of whole soymilk − protein concentration of the supernatant)/Protein concentration of whole soymilk] × 100%.

2.8. Measurement of protein solubility

Measurement of protein solubility was performed according to the method of Ono et al. (1993). Protein particles (>40 nm in diameter) were prepared from soymilks by centrifugation at 156,000×*g* for 30 min at 20 °C. The supernatant was designated as the soluble protein fraction. The pellets containing protein particles were dispersed into soymilk ultrafiltrate with a Wheaton Potter–Elvehjem tissue grinder and used for particulate protein fraction. The protein content of particulate and soluble protein fractions was adjusted to the same level by ultrafiltration. The ultrafiltrate of soymilk was

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