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Rheological and textural characteristics of black soybean touhua (soft soybean curd) prepared with glucono-δ-lactone

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ABSTRACT

Viscoelastic studies on the mixture of black soymilk and glucono-δ-lactone (GDL) have been done to analyse the gelation process of touhua. The isothermal gelation curves of touhua were well predicted by first-order reaction kinetics. The saturated storage modulus (G'_{sat}) of touhua was affected by the solids content, coagulation temperature and GDL concentration. The G'_{sat} value was proportional to the 1.68th power of solids content. The rate constant of gelation increased with increasing coagulation temperature and GDL concentration, but decreased with increasing solids content of soymilk. The gelation time decreased with increasing coagulation temperature and GDL concentration, and increased with increasing solids content. The hardness and adhesiveness values of packed touhua, measuring by textural profile analysis, increased with increasing solids content, GDL concentration and coagulation temperature. The storage modulus of touhua, during gelation, correlated positively with the textural characteristics of the packed touhua.

1. Introduction

Soybean is nutritionally attractive in having a high protein content of good quality. Black soybean is one variety of soybeans (*Glycineax* (L.) *Merrix)* and has a black seed coat. Isoflavone contents of black soybean (Kim et al., 2007) and tofu (Shih, Yang, & Kuo, 2002) are higher than those of yellow soybean and tofu. Soybean isoflavone helps to prevent osteoporosis, breast cancer and cardiovascular diseases (Song, Paik, & Joung, 2008), and few people are allergic to soy proteins (Wilson, Blaschek, & de Mejia, 2005). Soybean is extensively utilised for food processing. Touhua, a soft soybean curd, is a traditionally popular dessert in Taiwan and is a soy protein gel-like product. Production of touhua is similar to that of packed tofu. Touhua is usually produced from a low solids content cooked soymilk with coagulants, such as glucono-δ-lactone (GDL) or calcium sulphate. High-quality touhua has a fine, smooth, even and elastic texture, as well as good flavour.

Both touhua and tofu are gel products relating to the aggregation and gelation of soy proteins. Factors affecting the quality of soy protein gels include soybean varieties (Shih et al., 2002), the water/bean ratio during grinding or solids content of soymilk (Beddows & Wang, 1987a; Kohyama & Nishinari, 1993; Kohyama, Yoshidaa, & Nishinari, 1992), kinds and concentrations of coagulants (Kohyama, Sano, & Doi, 1995; Prabhakaran, Perera, & Valiyaveettil, 2006; Shih, Hou, & Chang, 1997), coagulation temperature (Beddows & Wang, 1987b; Shih & Shiau, 2003; Wang & Hesseltine, 1982), and pressure (Saowapark, Apichartsrangkoon, & Bell, 2008).

GDL is a GRAS substance and is a weak acid, which converts to gluconic acid in water and slowly dissociates into hydrogen ions with time. As the pH of soymilk is lowered to the isoelectric point of soy protein, coagulation of soy protein occurs; then a protein gel forms under proper conditions. The higher the concentration of GDL used, the lower is the pH value of the tofu prepared (Kohyama et al., 1992). Calcium sulphate has very low solubility in cold water and needs to mix with hot soymilk to produce touhua. GDL is easily soluble in water and its solution can be used in cold soymilk. Therefore, GDL is widely used as a coagulant in packed touhua and tofu products and calcium sulphate is used in traditional touhua and Momen tofu (Kohyama et al., 1992).

Kohyama and Nishinari (1993) found that the gelation times of 7S and 11S proteins became shorter with increasing concentration of GDL. The aggregation rates of soy proteins with GDL were in the order, 11S > 2S > 7S (Tay, Xu, & Perera, 2005). Kohyama et al. (1995) found that the rate of gelation for soy protein isolated by GDL was slower than that by calcium sulphate, and suggested that the addition of GDL or calcium ion induced gelation by promoting

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protein aggregation via hydrophobic interaction. Optimum processing conditions for making packed touhua, according to the result of a RSM study, were 3.67% solids content, 0.0225 N GDL and 71 °C coagulation temperature (Shih & Shiau, 2003).

Heating results in the denaturation of soy proteins. The denatured proteins are easy to aggregate and they form soy gels, with or without coagulants. In the absence of coagulants, soy proteins at a high concentration could form heat-induced gels. Bikbov, Grinberg, Antonov, Tolstoguzov, and Schmandke (1979) reported that, within a 10–20% solids concentration range, the relation between storage modulus (G') and protein concentration (C) was $G' \propto C^{4.67}$. Renkema and van Vilet (2004) indicated that the critical concentrations of purified glycinin and β-conglycinin for gelation differed according to pH and ionic strength.

Coagulation temperature affects the rate of gelation and the quality of soy gel products. The gelation rate of 11S protein in the presence of GDL increased with coagulation temperature, increasing from 50 to 90 °C (Kohyama et al., 1992). The hardness value of packed touhua and the amount of exuded water increased with coagulation temperature, increasing from 65 to 85 °C (Shih & Shiau, 2003). At a higher temperature, a more rapid aggregation and precipitation of soy protein may occur and, consequently, this reduces the retention of water. Beddows and Wang (1987b) reported that the optimum coagulation temperature was 75–80 °C for making silken tofu.

Dynamic viscoelasticity measurement has been used to study the gelation process of protein gels, such as GDL-induced soy protein (Kohyama et al., 1992; Kohyama et al., 1995), heat-induced soy protein (Ahmed, Ramaswamy, & Alli, 2006; Bikbov et al., 1979; Renkema & van Vilet, 2004), heat-induced whey protein (Aquilera & Rojas, 1997) and enzyme-induced casein (Tokita, Hikichi, Niki, & Arima, 1982). However, data on the change of viscoelasiticity of soymilk during touhua preparation and the effect of coagulant concentration on the textural quality of touhua are rare so far. The purposes of this study were to investigate the gelation process of black soybean touhua with GDL by dynamic rheometry and to observe the correlations between the dynamic rheological properties and textural parameters, such as the hardness and adhesiveness, of touhua.

2. Materials and methods

2.1. Materials

Black soybeans (Tainan No. 5), having a black seed coat and yellow cotyledon, were obtained in a single batch from the local Tainan Farmers' Association. The proximate composition of the soybean was 8.92% moisture, 38.6% crude protein, 17.5% crude fat, and 5.34% ash (as is basis). GDL was purchased from Sigma–Aldrich Co. (St. Louis, MO, USA). Silicone defoamer KM 72S, food-grade anti-foaming agent, was purchased from Shin-Etsu Chemical Co. Ltd. (Gunma, Japan).

2.2. Preparation of soymilk powder

Black soybeans (100 g) were washed and soaked at 4 °C in 500 ml of distilled water for 18 h. After being rinsed, soaked beans were weighed (about 200 g) and subsequently blended with 800 ml of distilled water using an Osterizer blender at low and high speeds for 1 min. The slurry was filtered through muslin cloth and 100-mesh screen to obtain raw soymilk. To the soymilk, distilled water was added to make the volume up to 1000 ml, and two drops of anti-foaming agent were also added. The soymilk was heated and allowed to boil for 10 min. After cooling, the soymilk was frozen and lyophilised in a freeze-dryer (Stoppering Tray Dryer System, Labconco Co., Kansas City, MO, USA) for preparing soymilk powders.

2.3. Isothermal gelation process

Gelation of soymilk was observed by using of a controlled stress rheometer (Carri-Med CSL-100, TA Instrumental Ltd., Surrey, England) operated with a double-cylinder geometry. Dynamic rheological measurements were performed at a constant strain of 0.1%, which was within the linear region, and at a frequency of 1 Hz.

Soymilk solutions (19 ml), with different solids contents, were prepared from the soymilk powder (0.4–1.4 g) with distilled water. The soymilk solutions were heated at different temperatures (55–80 °C) for 10 min. Then, 1 ml of freshly prepared GDL solution was mixed into each soymilk solution. The mixture solutions with final concentrations of 0.01–0.05 N GDL and 2–7% solids contents were stirred for 10 s, and 3.5 ml of the mixture solutions were immediately injected into the gap between the double-cylinders of the rheometer, which was pre-heated to the same temperature. A taylor-made lid covered the top of the double-cylinder geometry to minimise water evaporation during measurements. The sample solution was subjected to sinusoidal shear oscillations. The G', loss modulus (G'') and loss tangent (tan δ) were recorded as a function of time (90 min in total). Zero time was taken as the time when GDL was added to the soymilk. The observed data were fitted to an empirical formula proposed by Kohyama et al. (1992)

$$G(t) = G'_{sat}(1 - e^{-k(t-t_0)}) \quad (1)$$

where $G(t)$ is the G' at time t, G'_{sat} is the saturated G', k is the rate constant of gelation, and t_0, gelation time, is defined as the time when the G' begins to rise from the baseline. Values of G'_{sat} and k were estimated by a nonlinear regression method from the curve fitting the exponential equation i.e. $y = a\,(1-e^{-bx})$, where y is $G(t)$, x is time ($t-t_0$), and a and b are constants.

2.4. Non-isothermal gelation process

Soymilk solution (19 ml) was heated at a set temperature (60–80 °C) for 10 min. A freshly prepared GDL solution (1 ml) was added to the soymilk. Dynamic rheological properties of the mixture with 4% solids content and 0.02 N GDL were measured from the set temperature to 5 °C at a descending rate of 1 °C/min. When the non-isothermal gelation process was finished, the frequency sweep of the gelled sample at 5 °C was immediately measured from 0.1 to 10 Hz at 0.1% strain.

2.5. Preparation of packed touhua

Packed touhua was prepared according to the procedures proposed by Shih and Shiau (2003) with some modifications. Black soybeans (400 g) and distilled water were used to prepare 3200 ml of the cooked soymilk, with an average 7.8% solids content. The mother soymilk was cooled to room temperature and was diluted to different concentrations with distilled water if necessary. In each experiment, the cooked soymilk was freshly prepared, daily. The Brix of soymilk in each batch was monitored by digital refractometer (Pocket PAL-1, Atago Co. Ltd., Japan).

Cool soymilk (195 ml) was heated up to the set temperatures (60–80 °C), 5 ml of a freshly prepared GDL solution was added, and the mixture was stirred for 5 s at 200 rpm by using a mixer (Variomag Multipoint HP 15, Germany). The mixture solutions with 0.01–0.05 N GDL were transferred to plastic cups (92 mm in height, 90 and 55 mm in upper and lower diameters), and were stood at room temperature for cooling and gelation. The touhua samples were sealed and stored in a refrigerator (5 °C) overnight.