Journal of Food Engineering 90 (2009) 511–516

Contents lists available at ScienceDirect

Journal of Food Engineering

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

Effect of inulin on the rheological properties of silken tofu coagulated with glucono-δ-lactone ☆

Yen-Chang Tseng, Youling L. Xiong *

Department of Animal and Food Sciences, University of Kentucky, Lexington 40546-0215, KY, USA

ARTICLE INFO

Article history:
Received 16 March 2008
Received in revised form 12 July 2008
Accepted 24 July 2008
Available online 30 July 2008

Keywords:
Silken tofu
Soy proteins
Inulin
Glucono-δ-lactone
Prebiotic
Gelation

ABSTRACT

This study investigated the rheological properties of inulin-containing silken tofu coagulated with glucono-δ-lactone (GDL) upon heating. Inulin (Raftiline® HP-gel) was added to a soy protein isolate-enriched cooked soymilk at 0%, 1%, 2%, 3% and 4% (w/v) levels along with 0.4% (w/v) GDL to prepare acid-induced silken tofu. Gelation was induced by heating the soymilk mixture from 20 to 90 °C at a constant rate (1 °C/min) or isothermally at 90 °C for 30 min. The gelling properties were measured with dynamic small-deformation mechanical analysis and static large-deformation compression tests. The rheological changes in soymilk during gelation were dependent upon both the pH decline (hydrolysis of GDL) and the specific temperature of heating. Control samples heated to ~50 °C, with the pH lowered to 5.95, started to gel, showing a rapid increase in storage (G') and loss (G'') moduli afterwards. The addition of 2% inulin lowered the on-set gelling temperature by 2.8 °C and improved ($P < 0.05$) both rheological parameters of the tofu gel as well as hardness and rupture force (textural profile analysis) of the formed silken tofu. The results indicated that inulin enhances the viscoelastic properties of GDL-coagulated silken tofu, and the textural effect of inulin is an added benefit to its current application mainly as a prebiotical ingredient in food.

1. Introduction

An ancient legume, soybean has been cultivated and consumed in Asia for centuries. Not only does soybean provide an inexpensive source of dietary protein and fiber, it offers numerous health benefits. Clinical studies have shown that consumption of soy proteins may reduce the risk of cardiovascular diseases, certain types of cancers, and osteoporosis (Messina, 1999). Moreover, some short peptides isolated from hydrolysates of soy proteins were found to inhibit lipid oxidation in food and to alleviate paraquat-induced oxidative stress in animals (Peña-Ramos and Xiong, 2003; Takenaka et al., 2003).

Tofu, also known as soybean curd prepared by curdling soymilk with proper coagulants, is arguably the most popular gel-type soy food. Today, tofu is gaining an increasing popularity throughout the world as a valuable dietetic replacement for meat, fish, and cheese because it has a high protein content and is cholesterol-free and low in saturated fat (Liu, 1997). The relatively high concentrations of bioactive compounds existing in soybean, such as isoflavones, phytic acids, and saponins, add to the claim of soy as a healthful food. Many different types of tofu can be found in the market. Based on the water content and textural characteristics, tofu is generally classified into soft, firm and extra firm type (Liu, 1997). Traditionally, tofu with a firm texture was made by using minerals (calcium sulfate or magnesium chloride) to curdle the protein. After the curdling process, the whey is removed and the curd is transferred to perforated boxes and pressed until a coherent block of curd is obtained. The pressed curd is then cut to retail-sized portions and packaged for sale (Berk, 1992). On the other hand, glucono-δ-lactone (GDL), an acid precursor, is now used as a protein coagulant especially in making "silken" and softer tofu. Pasteurized pre-cooked soymilk with a high content of solids (10% instead of 5–6% in regular tofu) is mixed with GDL and the resulting mixture is filled into the retail containers. The filled containers, after sealing, are heated in a water bath at 80–90 °C for 40–60 min (Berk, 1992). At this temperature, the gradual release of gluconic acid from GDL hydrolysis allows soymilk to be slowly acidified, which induces protein gelation with minimal syneresis. The shelf-life of silken tofu produced in this manner is greatly extended. Without removing the whey from the curd, GDL-coagulated silkn tofu has a custard-like texture and smooth mouthfeel.

Inulin, a group of naturally occurring fructans with a DP (degree of polymerization) between 2 and 60, contains mostly linear chains

☆ Approved for publication as journal article number 08-07-036 by the Director of Kentucky Agricultural Experiment Station.

* Corresponding author. Tel.: +1 8592573822; fax: +1 8592575318.
E-mail address: ylxiong@uky.edu (Y.L. Xiong).

0260-8774/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jfoodeng.2008.07.017

of fructose with β(2→1) linkages that generally terminate with a glucose unit (De Leenheer and Hoebregs, 1994). Both recognized as functional food ingredients, inulin and its hydrolyzed product (oligofructose) are particularly attractive to people pursuing healthy diet. They function as a soluble dietary fiber and a prebiotic in the human's body, promoting the host's gastrointestinal tract health as well as exerting antitumorigenic, antiosteoporotic, hypolipidemic and hypoglycemic effects (Boeckner et al., 2001). In the food industry, inulin is being used as a fat replacer or texture modifier, and in many cases it is just simply added to a variety of items to create the so-called "functional foods" (Hennelly et al., 2006). Presently there is a lack of knowledge about the role of fructan-type prebiotics in the texture development of soy protein-based gel products. To expand the use of these health-promoting carbohydrates in food application, especially for developing protein-based gel products, this study was conducted to examine the effect of inulin (Raftiline® HP-gel) on the viscoelastic properties of silken tofu using GDL as a coagulant.

2. Materials and methods

2.1. Soy protein isolate

Soy protein isolate (SPI) was prepared from defatted low-heat soy flakes acquired from Archer Daniels Midland Co. (Decatur, IL, USA) using an alkaline (2 N NaOH, pH 8.0) extraction method described previously (Tseng et al., 2008). Protein content (91.2%) of freeze-dried SPI was determined by the Biuret method using bovine serum albumin (Sigma Chemical Co., St. Louis, MO, USA) as standard (Gornall et al., 1949).

2.2. Inulin

Inulin, with the trade name Raftiline® HP-gel, was donated by Orafti North America (Malvern, PA, USA). The Raftiline® HP-gel was extracted from chicory root, and the average degree of polymerization (DP) was ~23, per the product specifications. The water solubility was 20 g/L at 25 °C and 300 g/L at 90 °C.

2.3. SPI-enriched soymilk

Whole soybeans (donated by Solae LLC., ST. Louis, MO, USA) were rinsed and soaked in double-distilled water overnight. Fully hydrated soybeans (250 g) were blended 3 min with double-distilled water (500 mL) into slurry using a Waring® commercial blender (Model 51BL31, Waring Products, Torrington, CT, USA) at the speed setting "high". After removal of the okara (residue) by filtration through 3 layers of cheese cloth, the raw soymilk (450 mL) was placed in an uncovered pot and boiled for 6 min. After cooling down to room temperature (22 °C), the final volume of cooked soymilk was brought to 400 mL using double-distilled water.

In a separate experiment, a prepared SPI dispersion (10% w/w, pH 7.0) was poured into glass tubes (16 mm i.d. × 125 mm length, 10 mL in each tube) and, without a cap, heated for 3.5 min in a 95 °C water bath (Model Haake L with a D3 heating circulator, Fisher Scientific, Inc., Waltham, MA, USA). The brief heating was necessary to dissociate soy protein oligomers into individual monomers (Sorgentini et al., 1995) to facilitate their interaction with inulin. After cooling down to room temperature, this preheated SPI dispersion was mixed with cooked soymilk at the ratio of 3:2 (v/v) to prepare SPI-enriched soymilk. The final mixture had a protein concentration of 7.28% as determined by the Biuret method (Gornall et al., 1949). Inulin (Raftiline® HP-gel) was then added to this SPI-enriched soymilk at 0%, 1%, 2%, 3% and 4% (w/v) levels, and the pH of all samples was adjusted to 6.4 before subjecting to thermal gelation and rheological testing.

2.4. Dynamic mechanical analysis

Dynamic small-deformation oscillatory shear analysis was conducted to measure the gelling properties of SPI-enriched soymilk with or without inulin using a Bohlin VOR rheometer (Bohlin Instruments, Inc., Cranbury, NJ, USA) (Tseng et al., 2008). Gelling sample solutions were prepared by mixing GDL (0.4 g for every 100 mL of sample) into the SPI-enriched soymilk (pH 6.4) at room temperature with constant stirring for 5 min. After being loaded onto the rheometer, sample was equilibrated for 5 min at 20 °C. Temperature ramp at the heating rate of 1 °C/min, frequency of 1 Hz and strain of 0.02 was then initiated. During heating (to a 90 °C final temperature), the soymilk samples were sheared at a fixed frequency of 1 Hz with a maximum strain of 0.02. Storage (G') and loss (G'') moduli were constantly recorded (Tseng et al., 2008).

2.5. Texture profile analysis (TPA)

The SPI-enriched soymilk (pH 6.4) was mixed with GDL (0.4 g for every 100 mL sample) by stirring for 5 min. The mixture was then poured into glass tubes (20 mm i.d. × 130 mm length, 30 mL in each tube) coated with Rain•X® (Sopus Products, Huston, TX, USA) (Lee et al., 1997). Both ends of the glass tubes were sealed with plastic caps. The Silken tofu gel was formed by heating the glass tubes at 90 °C in a water bath for 30 min (Model Haake L with a D3 heating circulator, Thermo Fisher Scientific, Inc., Waltham, MA, USA). The formed gel was cooled to room temperature and then allowed to age in a 4 °C cooler for 24 h. Before TPA, the glass tubes containing the silken tofu gel were equilibrated at room temperature (22 °C) for 1 h. The gel was then carefully removed from the tubes and cut into cylinder-shaped samples (20 mm i.d. × 20 mm height).

TPA was performed by compressing the samples axially between two parallel plates in an Instron machine (Instron Corp., Canton, MA, USA) to 60% of the original height (40% deformation) in two consecutive cycles at a crosshead speed of 50 mm/min (Bourne, 1978). A 100 N-capacity load cell was used. Peak values from the first and the second compressions were designated as peak A force and peak B force, respectively. Peak A force was designated as "hardness" of the sample, and the percent reduction in the resilient force from peak A value after the second compression (peak B) was defined as "deformability", which was expressed as: [(peak A force − peak B force)/peak A force] × 100% (Xiong et al., 1999). Sample "cohesiveness" (total area of peak B divided by total area of peak A), as defined by Bourne (1978), was computed by dividing the squared peak B value by the squared peak A value (because peaks A and B were similar in shape) (Xiong et al., 1999). To determine the breaking strength, another set of tofu gel samples of the same size (20 mm i.d. × 20 mm height) were compressed until the structure was disrupted. The rupture force, defined as the initial force required to break the gel, was designated as "breaking strength".

2.6. pH Reduction profile of silken tofu

The pH changes of soymilk gelling samples during thermal gelation (1 °C/min) were monitored. All samples were prepared using the same protocol as described in the non-destructive oscillatory shear testing. After adding GDL (0.4 g for every 100 mL of sample) and stirring for 3 min, GDL-soymilk mixture from each treatment was immediately transferred to glass tubes (16 mm i.d. × 125 mm length, 10 mL in each tube) and incubated in a 20 °C water bath