Journal of Food Engineering 190 (2016) 116–122

Contents lists available at ScienceDirect

Journal of Food Engineering

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

Effect of freeze-thaw treatment on the structure and texture of soft and firm tofu

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ARTICLE INFO

Article history:
Received 16 February 2015
Received in revised form
15 June 2016
Accepted 24 June 2016
Available online 26 June 2016

Keywords:
Tofu
Freeze-thaw treatment
Texture profile analysis
Cellular materials
Soft protein solids

ABSTRACT

The effects of freeze-thaw treatments on the microstructural and textural properties in two kinds of commercial tofu were studied. Tofu samples obtained from a commercial supplier were placed in a freezer at −16 °C for various times, then removed and thawed at 20 °C for 20 min. Subsequently, the samples were examined by scanning electron microscopy (SEM) and thermogravimetric analysis (TGA) to assess the structural changes during the freeze-thaw treatment. Static compression tests and texture profile analysis were conducted on both freeze-thawed and fresh tofu samples. An analysis of the tofu structure based on the Gibson-Ashby model indicated that freeze-thawed tofu exhibits a reduction in water content compared to fresh tofu. The texture profile analysis results indicated that tofu was harder, springer, gummier and more cohesive after the freeze-thaw treatment. This increase in textural properties of tofu may satisfy consumer preferences for a harder and springier tofu.

1. Introduction

Tofu is a widely consumed food due to its rich nutritional value and health benefits to the human body (Li et al., 2011). Structurally, tofu is a hydrated, gelatinous product with a protein network as backbone. Its microstructure is affected by various factors associated with the manufacturing process, such as soymilk concentration, coagulant types and compression time (Wang et al., 1983; Kao et al., 2003).

There are three principal sensory acceptability factors in food characterization: texture, appearance and flavor (Bourne, 2004). Among them, texture is a crucial one that affects consumers' decision whether or not to purchase that food again. Prior to digestion, solid and semi-solid food must be converted into a swallowable liquid through mastication, which is a synergistic effect of mechanical deformation via teeth and chemical decomposition through interaction with saliva (Bourne, 2004). The texture of food will be sensed in the form of chewing accessibility during mastication, so it is important to develop a comprehensive analysis on the textural properties. Texture profile analysis (TPA) is a widely used method for quantitatively analyzing food textures, which was first illustrated by Friedman and later modified by Bourne (Friedman et al., 1963; Bourne, 1978). During the TPA test, the specimen experiences at least two successive compression ramps that simulate the first several chews applied on a food, and the measured forces are recorded as a function of time (Chen and Opara, 2013). Parameters that are useful in characterizing the texture of semi-solid food are hardness, springiness, cohesiveness and gumminess. Hardness is defined as the highest force under a given deformation during the first compression ramp. Springiness refers to the amount a deformed material recovers to its original condition when the force is removed. Cohesiveness is defined as the work needed to overcome the intrinsic bonding of the material. Gumminess is defined as the product of hardness and cohesiveness, which refers to the energy required to disintegrate semi-solid food into a swallowable state (Yuan and Chang, 2007).

Freezing is a well-established process for food preservation and is confirmed to increase the storage time significantly (van der Sman et al., 2013). Frozen foods are thawed before consumption. The freeze - thaw treatment may change the texture of food (Fuchigami et al., 1998). During freeze-thaw cycles, the volume expansion of low density ice crystals during phase transformation may cause irreversible change of food texture. The effects of high pressure freezing on the texture of foods have been studied previously. Fuchigami and coworkers analyzed the effect of high-pressure-freezing on the structural change in tofu (Fuchigami et al., 1998). They indicated that freezing of tofu at 200 MPa and

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http://dx.doi.org/10.1016/j.jfoodeng.2016.06.022
0260-8774/

from −18 to −20 °C is beneficial for maintaining its initial smooth texture. Although high-pressure-freezing is able to essentially maintain the original structure of ice crystals and minimize damage to the original texture, it is limited to industrial processing. Based on previous investigations, it can be stated that in areas with high tofu consumption, Asian consumers like firmer tofu, and western consumers prefer tofu that is firmer and chewier (Cai and Chang, 1997). Many households may use a simple atmospheric pressure freezing to preserve homemade tofu. The textural changes that may occur during this atmospheric freezing have not been studied.

The textural properties of different kinds of virgin (unfrozen) tofu have been thoroughly analyzed at a variety of strain rates by various investigators. Yuan and coworkers correlated the instrumental texture profiles and sensory results of 13 types of unfrozen tofu. These data indicate that the best correlation between texture and sensory perception was obtained with no-skin tofu for a strain rate of 100 mm/min and 75% penetration (Yuan and Chang, 2007). They recommended these conditions for evaluating the texture of tofu. Lee and coworkers (Lee and Kuo, 2011) examined the structure of fresh tofu microscopically, and highlighted the honeycomb-like structure. The changes that may occur in this honeycomb structure during a freeze-thaw treatment have not been well documented. An understanding of the texture and the structural changes occurring during the freeze-thaw treatment is essential in developing a product that meets consumer preferences. The objective of this study was to investigate the effect of various freeze-thaw treatments on the textural properties and cellular structure of typical commercial tofu. TPA was conducted for textural characterization, and the well-known Gibson and Ashby model was used to analyze the effects of freeze-thaw treatments on the cellular structure.

2. Materials and methods

2.1. Materials

Two kinds of commercial tofu products, soft and firm tofu, were purchased from a commercial supplier in Worcester, MA. The main ingredients as indicated by the manufacturer were: 5% total fat, <1% sodium, 1% total carbohydrate, 10% protein, 30% calcium, with the remaining being water. The coagulant in both kinds of tofu was calcium sulphate ($CaSO_4$). They were supplied as a gel in a 100 g package with dimensions 75 mm × 70 mm × 45 mm (length × width × height). Each sample of gel also contained a skin, approximately 4 mm thick at the top and bottom surfaces.

2.2. Sample preparation

Both the commercial tofu products were stored in refrigerator at 4 °C after purchase. When needed, they were taken out from the packages. The top and bottom skins were carefully removed by a sharp knife and samples with approximate dimension of 32 mm × 32 mm × 20 mm were sectioned (Yuan and Chang, 2007). Half of the samples, for both soft and firm tofu, were sealed separately in polyethylene bags, stored at atmospheric pressure in a freezer maintained at −16 °C for various times: 1 hr, 2 hr, 3 hr and 4b hr. Subsequently, the frozen samples in the sealed bag were removed from the freezer and thawed by immersing the bags in running tap water at 20 °C for 20 min (Benjakul and Bauer, 2001). The flow rate of tap water was maintained so as to avoid any significant compression on the samples. The following tests were conducted on two sets of samples: 1) soft and firm tofu samples obtained immediately after opening the package, 2) soft and firm tofu samples frozen and thawed according to the method illustrated above.

2.3. Static compression test

The static compression tests were performed on an Instron 4201 using a 75 mm diameter cylindrical plunger with a clean and smooth surface. The static compression tests were conducted at a strain rate of 60 mm/min to achieve a deformation of 75%. The testing temperature was controlled at 21 ± 1 °C.

2.4. Thermogravimetric analysis (TGA)

The thermogravimetric analysis of the two sets of tofu samples were conducted on a TGA/Q50 under a nitrogen atmosphere (flow rate of 40 L/min). The two sets of tofu samples indicated in Section 2.2 were used to obtain test samples weighing between 5 and 10 mg. These test samples were carefully placed on the thermobalance platinum sample pan. The system was first equilibrated at 35 °C, and then followed at a scanning rate of 10 °C/min till 200 °C.

2.5. Microstructure analysis

The two sets of soft and firm tofu samples were examined by a Hitachi scanning electron microscopy (SEM) at 3 kV with a working distance of 15 mm. The tofu samples used for SEM tests were prepared according to method described previously with some modification (Lee and Kuo, 2011). The fresh soft and firm samples were cut into 5 mm × 5 mm × 5 mm cubes with a sharp blade after removal from the original package. Similarly, the freeze-thawed soft and firm samples were also cut into cubes with the same dimensions. Then the two sets of samples were rapidly frozen in liquid nitrogen and freeze-dried in a lyophilizer for 24 h. After removal from the lyophilizer, the freeze-dried samples were fixed on a metal sample stage by double-side adhesive copper-tapes. The natural broken surface of the samples were sputter-coated with gold and examined in the microscope.

2.6. Texture profile analysis

TPA corresponding to two successive compression bites was conducted on the samples at a strain rate of 100 mm/min on tofu samples with various freeze-thaw treatments (Yuan and Chang, 2007). In this method, the crosshead was moved slowly until a preload of 0.24 N was achieved, and the exact height of the sample was measured at this point. Then the crosshead speed was increased to 100 mm/min until 75% deformation of the sample thickness was reached. After the first downstroke, the plunger was moved upwards to allow recovery of the specimen thickness. After the plunger cleared the specimen upper surface for 2 s, it was moved downwards to conduct the second bite on the sample until 75% deformation of the recovered thickness was reached. Then the plunger was moved upwards and stopped until it cleared the specimen surface again. During the test, the textural parameters including hardness, springiness, gumminess and cohesiveness of each tofu specimen were measured. At least 5 tests were conducted under each condition.

3. Results and discussion

3.1. Static compression test

The force-deformation curves for the fresh soft and firm tofu samples are shown in Fig. 1(a). In general, three regions can be observed: (a) initial non-linear elastic region due to the viscoelastic nature of tofu (Cheng et al., 2005); (b) a plateau region or a fracture peak and (c) a non-linear elastic region with sharp increase in its slope. As pointed out in the inset of Fig. 1(a), the