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Use of Ultrasound for Measuring Tofu Texture*

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Abstract

The microstructure of a tofu gel network determines the firmness and hence the taste of the tofu. The structure of a tofu network can be observed with a microscope, and the mechanical properties may be determined through textural analysis. These approaches are destructive and sometimes prohibitively expensive; hence they are unsuitable for on-line measurement of tofu properties in a production line. Therefore, this study uses ultrasound for non-destructive measurement of tofu's structure with scanning electronic microscopy and textural analysis as calibrators. Glucono-delta-lactone (GDL) and $CaSO_4{\cdot}2H_2O$ tofu curds from the market were examined using microscopic analysis, textural analysis, and ultrasonic measurement. There is a positive correlation between the area percentage of pores in a network and the attenuation coefficient of ultrasound. Hence, ultrasonic power attenuation can be a potential means of exploring the microstructure of tofu gel.

[Keywords] tofu properties; image analysis; textural analysis; microstructure; microscopy

I Introduction

Tofu is a salt- or acid-coagulated water-based gel, with soya lipids and proteins as well as other constituents trapped in gel networks (Kohyama et al., 1995). It is made by coagulating soya milk – followed by either pressure or heat treatment after the addition of a coagulant. The taste of tofu is significantly affected by its final texture (Jackson et al., 2002), i.e., by the firmness of the tofu gel's structure. The textural property is determined by the concentration of soya milk, the type and concentration of coagulant, the gelating pressure and temperature, and the gelating time (Hou et al., 1997; Cai and Chang, 1998; Cheng et al., 2005; Ting et al., 2009).

Microscopy of tofu gel demonstrates that the distribution of proteins, fats, water, and air throughout the network structure correlates with the aforementioned gelation parameters (Kohyama et al., 1995; Saowapark et al., 2008), i.e., the structure of tofu gel varies in gelation. The microstructure of a gel network can be explored using a scanning electronic microscope (SEM), and the distribution of compositions in the network can be identified using a confocal scanning laser microscope (CSLM). However, these two microscopy approaches, which demand time-consuming and costly intensive laboratory work, are not suitable for on-line applications (Ting et al., 2009).

Ultrasonics have been demonstrated as a good means of identifying the structural variation of a medium, as the behavior of an ultrasound wave travelling in a medium correlates with the structure of the medium (McClements, 1995; Gur and Ogel, 2001; Llull et al., 2002; Kuo et al., 2008). An ultrasound wave travelling in a medium will have its propagation velocity altered by the density and viscoelasticity of the medium and its power attenuated by the heterogeneous structures in the medium. The viscoelasticity of a medium varies in response to the change of its rheological and textural attributes (Toubal et al., 2003; Foegeding et al., 2003; Wang et al., 2005; Arltoft et al., 2007). Hence, ultrasound possesses the ability to differentiate various media by its propagation velocity and to identify the difference among structures within a given volume by the acoustic impedance of the medium (Knorr et al., 2004; Gan et al., 2006).

The previous work (Ting et al., 2009) adopted ultrasound to explore the mechanical properties of tofu gels in a macroscopic aspect – ultrasonic measurements do have a link with the mechanical properties, especially the ultrasonic power attenuation vs. the firmness of tofu gel. It is the objective of this study to employ ultrasound as a non-destructive means for exploring the microstructure of tofu gel using SEM, CSLM and textural analysis as calibrators. The ultimate aim is to develop an effective, efficient and economical technique for probing the microstructure of tofu gel using ultrasonics.

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II Tofu Gel Network Parameters

1. Microstructure

Tofu gel networks have irregular structures and constitute clusters of proteins, fats, water and air bubbles (Kohyama et al., 1995; Saowapark et al., 2008). Fig. 1 shows an example of the textures of glucono-delta-lactone (GDL) and $CaSO_4{\cdot}2H_2O$ tofu gels under SEM observation and of GDL tofu under CLSM observation. Clearly, the GDL tofu has a structure finer than that of the $CaSO_4{\cdot}2H_2O$ tofu. The microstructure of a tofu gel network can be described with a conceptual model as shown in Fig. 2. The model shows that fats, water, and air are trapped in protein networks structured in gelation and that the mechanical properties depend on the conditions of the gelating process.

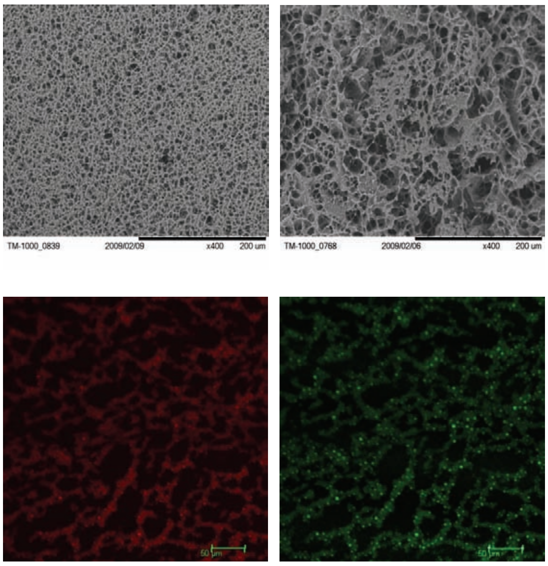

Fig. 1 Microsctructures of tofu gels. SEM (x400): GDL (top left); $CaSO_4{\cdot}2H_2O$ (top right); GDL tofu under CSLM (x400): fat (red in bottom-left); protein (green in bottom-right)

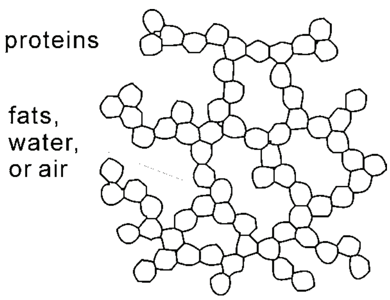

Fig. 2 Conceptual network model of tofu gel (Kohyama et al., 1995)

The structure of a tofu gel network can be categorized into particulate aggregate and filament aggregate, depending on the conditions of gelation. A particulate aggregate gel is opaque and poor in water trapping; a filament aggregate gel is transparent and good in water trapping (Noh et al., 2005). The former is firmer than the latter. The type of aggregate is determined by the ingredients and the gelation condition of the tofu gel. The GDL tofu is a filament aggregate gel, and it is hence less firm and softer than the $CaSO_4{\cdot}2H_2O$ tofu.

2. Ultrasonic characterisation for tofu gel networks

(1) Ultrasonic measurement

Low-power ultrasonics provides an effective means for exploring the structural variation of a medium without altering the nature of the medium (McClements, 1995). When exposing the tofu gel described by Fig. 2 to ultrasonic irradiation, the ultrasound wave travelling in the gel has a kinetic mechanism as shown in Fig. 3. The figure shows a corresponding acoustic model with 2 anticipated boundaries (protein) that separate heterogeneous media (fat, water or air) in the network of Fig. 2. An incident acoustic wave is reflected by boundary #1 and transmits through medium #2 towards boundary #2. The same acoustic phenomenon at boundary #1 occurs again at the #2 and subsequent boundaries. The behavior of the ultrasound wave travelling across the boundaries and hence the textural property of the tofu gel can be examined macroscopically or microscopically, in the subsequent sections.

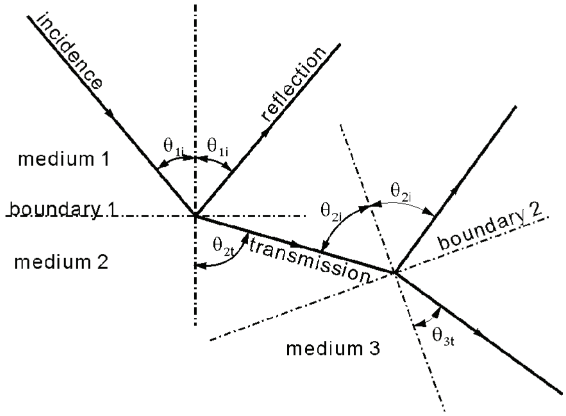

Fig. 3 Acoustic model of two boundaries in a heterogeneous medium (Ting et al., 2009)

(2) Viscoelasticity

Using rheology, the viscoelastic property is described by a complex shear modulus G^* which is the sum of a storage modulus G' and a loss modulus G'', as (Foegeding et al., 2003):

$$G^*(t) = G' + jG'' \tag{1}$$

The storage modulus reflects the degree to which a material stores energy (elastic component), while the loss modulus