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Molecular migration in high-protein intermediate-moisture foods during the early stage of storage: Variations between dairy and soy proteins and effects on texture

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ABSTRACT

Effect of molecule migration on the hardening of high-protein intermediate-moisture foods (HPIMF) in the early stage of storage was investigated through low-field NMR, texture analysis, confocal laser scanning microscopy, scanning electron microscopy, and protein solubility analysis. Model systems were made of water, glycerol and sorbitol, together with sodium caseinate (NaCN), soy protein isolate (SPI) or whey protein isolate (WPI), and stored at 25 °C to monitor molecular migration and the changes of texture, microstructure, and protein solubility. Both yield strain and yield stress of NaCN and SPI systems increased rapidly right after preparation, together with decreases in small molecules mobility and changes of microstructure, while WPI system showed more uniform structure without significant change of small molecules mobility. In addition, changes in protein solubility were observed in the SPI systems, but not in NaCN and WPI systems. These results suggested that the migration of small molecules (water, glycerol, and sorbitol) into protein particles during the early stage of storage could reduce the mobility of small molecules and might cause changes in microstructure, which could further cause hardening of HPIMF. In addition, the variation in protein sources was also a major factor contributing to the difference in texture properties.

1. Introduction

High-protein intermediate-moisture foods (HPIMF), with 0.5–0.8 water activity at 25 °C, mainly consist of protein, carbohydrate, fat, and some humectants (Hogan, Chaurin, O'Kennedy, & Kelly, 2012; Taoukis, Breene, & Labuza, 1998). The most commonly used proteins in HPIMF are dairy and soy proteins, such as sodium caseinate (NaCN), whey protein isolate (WPI) and soy protein isolate (SPI), with the protein content in the range of 15–45% (Banach, Clark, & Lamsal, 2014; Imtiaz, Kuhn-Sherlock, & Campbell, 2012). Small molecules of polyhydroxy-compound such as glycerol and sorbitol are often added as humectants and plasticizers to control water activity and maintain texture of such foods. HPIMF have many advantages (Taoukis et al., 1998), such as high nutritional value, convenient transportation, endowing such foods wide applications as nutritional foods and sport foods (Childs, Yates, & Drake, 2007).

Typically, HPIMF stored at room temperature should have a shelf life of at least six months to one year. Physical and chemical changes during storage would introduce adverse effects on color (Banach et al., 2014), flavor (Massaro & Labuza, 1990), texture (Loveday, Hindmarsh, Creamer, & Singh, 2010) and other properties. One of the major problems for HPIMF development is the hardening of the matrix during storage, making the foods difficult to eat (Hogenkamp, Stafleu, Mars, Brunstrom, & de Graaf, 2011), which greatly limits the shelf life and thus hinder the development of such products. The mechanisms for the hardening of HPIMF are rather complicated according to previous research works, and can be attributed to the aggregation of proteins (Zhou, Liu, & Labuza, 2008a), Maillard reaction (Chen, Liang, Liu, Labuza, & Zhou, 2012; Imtiaz et al., 2012), sugar crystallization (Belcourt & Labuza, 2007), phase separation (Loveday, Hindmarsh, Creamer, & Singh, 2009; McMahon, Adams, & McManus, 2009) and moisture migration (Loveday et al., 2009, 2010; McMahon et al., 2009).

The previous research findings showed that the hardening process of HPIMF can be divided into two stages, the early stage and the mid-late stage of storage (Hogan et al., 2012; Loveday et al., 2010; McMahon et al., 2009). Protein aggregation, phase separation and Maillard reaction have been proven to be major factors that contribute to the hardening occurred during the later period of storage (Chen et al., 2012; McMahon et al., 2009). However, at the early stage of storage, HPIMF may exist in a non-equilibrium thermodynamic multi-component state (Mezzenga, 2007; Tolstoguzov, 2003), small

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molecules of water and humectants such as glycerol in the matrix may migrate and redistribute, causing changes in structure and texture. And in recent years, the relationship between moisture migration and bar hardening is gaining more interest (Loveday et al., 2009, 2010; McMahon et al., 2009).

NMR is an effective way to study the migration and changes in state of water and other small molecules in food matrix (Li et al., 2012). The changes in distribution and mobility of these molecules are analyzed by monitoring the relaxation behavior of protons during food manufacture and storage. Li et al. created an NMR state diagram to predict overall performance of powdered proteins in high-protein food bars (Li, Szlachetka, Chen, Lin, & Ruan, 2008). Lin et al. also presented the NMR state diagram to analyze the relationships among NMR relaxation, molecular mobility and the stability of foods, which had potential applications in the quality and safety control of food products (Lin et al., 2006).

In the present research, we constructed the simplified non-heat finished model systems according to the commercial formulations of high-protein nutritional balls by using NaCN, WPI or SPI, and studied the influence of molecular migration and variation in protein sources on the texture changes of such systems during the early stage of storage through low field NMR, texture analysis, scanning electron microscopy (SEM), confocal laser scanning microscopy and protein solubility analysis, with the purpose to provide a further insight into the underlying mechanisms for the hardening of such food matrix.

2. Materials and methods

2.1. Materials

Sodium caseinate (NaCN, 87% protein, w/w) was supplied by Fonterra Co., Ltd. (Auckland, New Zealand). Whey protein isolate (WPI, 90% protein, w/w) was obtained from Davisco Foods International Inc. (Eden Prairie, MN, USA). Soy protein isolate (SPI, 87% protein, w/w) was purchased from Sun-Green Bio-Tech Co., Ltd. (Jiangsu Province, China). Sorbitol and glycerol were purchased from Sinopharm Chemical Reagent Co., Ltd. (Shanghai, China). FITC (fluorescein isothiocyanate), glutaraldehyde, and high molecular weight standard proteins were purchased from Sigma-Adrich (St. Louis, MO, USA).

2.2. Sample preparation

The intermediate-moisture foods model systems were made up of 45% (w/w) protein powder, 25% (w/w) sorbitol, 17.5% (w/w) glycerol and 12.5% (w/w) water. Sorbitol was first dissolved in water, followed by addition of glycerol to obtain a uniform solution. Protein powder was then added into the solution and the matrix was mixed manually using a spatula until a uniform texture was achieved. The mixture was then reshaped into small spherical balls, 5 g each, with diameters of around 2 cm, and placed into plastic cups subsequently (Decagon Device, Inc., Pullman, WA, USA), then tightly covered with lids and double sealed with Parafilm (Pechiney Plastic Packaging, Chicago, IL, USA) to avoid moisture loss. The sample cups were finally placed into a sealed glass jar and incubated at 25 °C for up to 7 days. Water activities of fresh prepared samples were 0.51 ± 0.01 (NaCN), 0.54 ± 0.01 (SPI) and 0.58 ± 0.01 (WPI) respectively, which was measured at 25 °C using an AquaLab 4TE water activity meter (Decagon Devices, Inc.).

2.3. Texture analysis

Changes in ball texture of the three model systems were determined using a TA-XT plus Texture Analyzer (Stable Micro Systems, Ltd., Surrey, UK) with a 30 kg load cell. A strain-recovery test with cylindrical probe (35 mm diameter) was used for 50% of deformation. Compared with the puncture test, the data obtained during compression test provided more information (Figs. 1 & 2), and showed the significant difference among the samples and the changes during storage. 50% deformation level

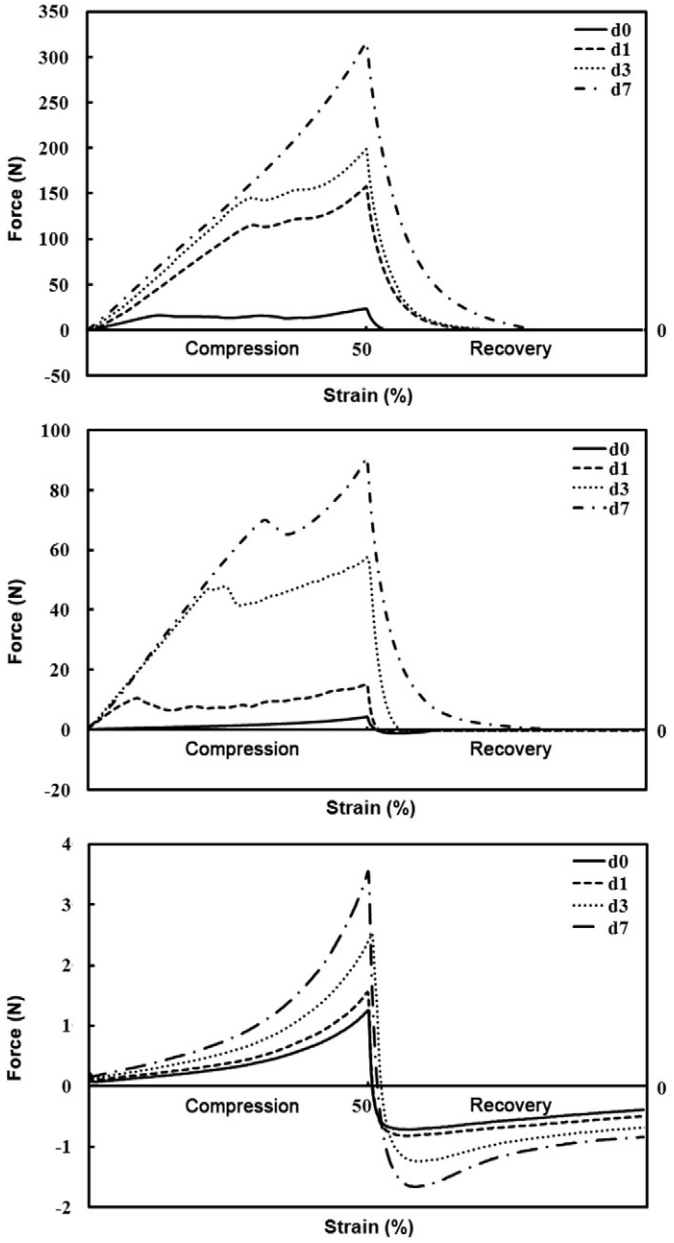

Fig. 1. Changes of strain-recovery curve compression and strain-recovery of model systems made with sodium caseinate, soy protein isolate and whey protein isolate during storage.

was chosen to obtain a non-reversible large strain deformation. The crosshead speed was set at 1 mm/s and the activation force was 0.05 N. For each interval, 3 samples were tested for each model system and the force during the test was recorded. Particularly, as WPI samples were more viscous and might collapse into mud like condition after 1 h or more, they were then reshaped into spheres before being adapted to the test. Reshaping of the WPI samples might have some effect on texture in certain level, but the purpose of reshaping was to analyze all the samples in the same shape, and reflect the soft and sticky texture of WPI systems, which was quite different when compared with the other two model systems. Adhesiveness was defined as the maximum negative force detected for the WPI sample, and was 0.7 ± 0.0, 0.8 ± 0.1, 1.2 ± 0.0, 1.7 ± 0.1 at 0, 1, 3, 7 day, respectively, which shifted during the storage.

The point when the force detected significantly reversed from increasing to decreasing during compression process was defined as the yield point, which implied structural fracture of the sample. Strain and