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Original Article

Characterization of yogurts made with milk solids nonfat by rheological behavior and nuclear magnetic resonance spectroscopy

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ABSTRACT

The effect of adding milk solids nonfat (MSNF) on the physical properties and microstructure of yogurts was investigated. The physical properties of fat free yogurt, fat free with MSNF yogurt, whole fat yogurt, and whole fat with MSNF yogurt were analyzed using shear viscosity, viscoelasticity, and texture analysis. The two yogurts with MSNF had higher consistency coefficient (*K*), storage modulus (*G*′), yield stress, and hardness. To gain insight into the multiphase system, nuclear magnetic resonance (NMR) and brightfield microscope images were acquired. The addition of MSNF significantly modified NMR relaxation time; T_1 values were reduced significantly. Brightfield microscope images showed that the size of the protein network of the two yogurts with MSNF added was greater than that of the two yogurts without MSNF added. The microstructural information supported the physical information. The results showed that the increase in MSNF contributed positively to strengthening the physical/mechanical properties of yogurt.

1. Introduction

Yogurt, a cultured dairy product, is milk fermented by lactic acid bacteria, mainly *Lactobacillus delbrueckii* ssp. *bulgaricus* and *Streptococcus thermophilus*. Because of the existence of a large number of live bacteria, yogurt has therapeutic effects, such as digestion enhancement, enterogastric peristalsis boosting, appetite enhancement, anticarcinogenic activity, and reduction of serum cholesterol [1]. Yogurt also contains many bioavailable proteins, minerals, and vitamins [2]. Therefore, yogurt has become a popular favorite among consumers around the world. In China, yogurt production has risen dramatically with an annual growth rate of more than 10% in 2009–2013 [3].

Yogurt is a complex gel that is mainly composed of denatured protein and milk fat globule. The fat content of yogurt directly influences the final strength of the gel network structure [4]. When the fat content of yogurt decreases, a more

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fragile gel network structure of yogurt forms, and this also leads to less desirable rheological properties, texture characteristics, taste, and flavor [5].

In order to produce good-quality fat free, low fat, and reduced fat yogurt, it is a common practice to add stabilizers to yogurt, such as pectin, gelatin, and κ-carrageenan [6,7]. The addition of stabilizers in yogurt has a negative influence on consumers' acceptance, because more natural yogurt products are preferred [8]. Under the premise of not using stabilizers, it is a challenge to manufacture fat free, low fat, and reduced fat yogurt with the desired gel network structure, creamy aroma, mouthfeel, and little whey-off during storage [9].

Increasing the protein content of yogurt offers an alternative way to strengthen the gel network structure [10]. Denatured proteins act as fillers or binders within a casein matrix [5]. The main components of denatured protein are caseins that are mainly composed of four kinds of monomeric protein: α_{s1}-casein, -α_{s2}-casein, β-casein, and κ-casein [11]. The content of these four kinds of monomeric proteins directly influence the final strength of the gel network structure [8]. Ozlem and Nursel [12] assessed the gel network and water holding capacity of yogurt with the increasing protein content. In the research of Denin-Djurdjević et al [13] and Fetahagić et al [14], the viscosity of yogurt with added dry matter was investigated. In 2006 and 2008, Isleten and Karagul-Yuceer [15,16] compared the physical and sensory attributes of the fat free yogurts made from reconstituted skim-milk powder with the fat free yogurts fortified with whey protein isolate, sodium caseinate. Peng et al [17] monitored the pH, storage modulus, loss tangent, yield stress, and permeability values of yogurts with milk protein isolate and micellar casein as the protein reinforcer during fermentation.

To analyze the effect of milk solids nonfat (MSNF) on the physical behavior of yogurts, the physical/mechanical properties fat free yogurt, fat free with MSNF yogurt, whole fat yogurt, and whole fat with MSNF yogurt were compared through rheological measurements in this work. The structural characterization of the four types of yogurts was performed using nuclear magnetic resonance (NMR) relaxometry and brightfield microscope images.

2. Materials and methods

2.1. Materials

Pasteurized, homogenized whole fat, and fat free milk fortified with Vitamins A and D were purchased from a local supermarket in Davis, CA, USA. Instant nonfat dry milk solid (total fat 0%, total carbohydrate 52.2%, protein 34.8%) was also purchased from a local supermarket.

Yogurt Bulgarian starter culture (skim milk and/or lactose, lactic culture, ascorbic acid) was purchased from New England Cheese Making Supply Company (South Deerfield, MA, USA).

2.2. Yogurt preparation

The MSNF (39.4 g) and a portion of the whole fat milk (1 L) or a portion of the fat free milk (1 L) were mixed thoroughly at room temperature. The yogurt was prepared using two different procedures to address the constraints of the characterization methods. Yogurt was prepared in a 2-L batch using Yogotherm Yogurt Incubator (New England Cheese Making Supply Co.; www.cheesemaking.com) and also prepared in reusable glass jars using the Automatic Yogurt Maker (New England Cheese Making Supply Co.; www.cheesemaking.com). For the 2-L batch, the ingredients (1 L fat free milk, mixture of 1 L fat free milk and 39.4 g MSNF, 1 L whole fat milk, mixture of 1 L whole fat milk and 39.4 g MSNF) were heated to 88°C, maintained between 85°C and 90°C for 30 minutes, and cooled to 43°C. The starter culture was added to the cooled milk and incubated for 6 hours. After the incubation was complete, the yogurt was stored at 4°C for 15 hours.

The procedure was the same for the yogurt made in the Automatic Yogurt Maker except that the yogurt was incubated in glass jars with screw-on plastic caps.

Samples prepared for the rheological property measurements and the yield point determinations were incubated in the Yogotherm Yogurt Maker. The other samples were incubated in the automatic yogurt makers.

2.3. Property measurement

2.3.1. Kinematic viscosity of milk samples

The kinematic viscosity of the four milk samples was determined using the Cannon Fenske-Routine Viscometer (Cole-Parmer North America, Vernon Hills, IL, USA, Size 200; Cole-Parmer, www.coleparmer.com). The values are given as the average and 1 standard deviation of four measurements.

2.3.2. Moisture content of yogurt samples

An HR83 Halogen Moisture Analyzer from Mettler Toledo LLC (Columbus, OH, USA) was used for moisture content determination. Measurements were performed in triplicate.

2.3.3. Shear viscosity of yogurt samples

The shear viscosity tests were performed using a rotational rheometer (CVO 50, Bohlin Rheometer; Malvern Instruments Ltd, Malvern, UK) with a cone and plate measuring system at 25 ± 0.1°C. The shear viscosity tests were performed under the controlled rate mode. The shear rate range was 0.1–100/s. For each experimental run, the yogurt sample was stirred for 30 seconds with a tablespoon and recovered 10 minutes in the container prior to the shear viscosity tests. Measurements were performed in triplicate.

2.3.4. Viscoelasticity: dynamic testing

The dynamic viscoelastic properties of the yogurt samples were measured on the CVO 50 rheometer with the cone and plate measuring system at 25 ± 0.1°C. The amplitude sweep tests were performed at 0.1 Hz, 1 Hz, and 10 Hz to identify the linear viscoelastic range for the yogurt samples. The amplitude sweep tests were performed under the controlled stress mode in the range of 0.03–50 Pa. The frequency sweep tests were performed in the frequency range of 0.1–10 Hz under constant stress. Measurements were performed in triplicate.

2.3.5. Viscoelasticity: transient testing

The stress relaxation test was performed on a TA-XT2i Texture Analyser (Texture Technologies Corp., Scarsdale,