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Sonication induced particle formation in yogurt: Influence of the dry matter content on the physical properties

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A B S T R A C T

Yogurt texture can be adjusted by various compositional and processing factors. The factors protein content and type, heat treatment, and fermentation temperature are well-known and studied. In a previous study we were able to show sonication as an additional parameter affecting texture. The aim of this study was to test the hypothesis that sonication during fermentation induces large particles which, thus, have an impact on the texture perception of stirred yogurt. 26 stirred yogurt systems, differing in the fat (0.1–3.5%) and protein content (3.8–5.2%) were produced and a short sonication (35 kHz, 5 min) was applied within the pH range 5.1–5.2. Image analysis was performed to quantify the number and size of visually detectable particles/grains. Furthermore, the physical properties were studied by means of static light scattering and rheological measurements. Multivariate data analysis was used to discriminate between the effects of sonication and dry matter. Sonication resulted in new larger particles whereas an increase in dry matter content mainly affected the rheological properties. Above a dry matter content of 14.2%, no significant effect of the sonication was distinguishable.

1. Introduction

Yogurt microgels are made by acidifying milk with lactic acid producing microbial starter cultures (LAB) (Courtin and Rul, 2004; Lucey, 2004; Settachaimongkon et al., 2014). In upstream processing, the milk is often concentrated prior to the fermentation or enriched with milk powder or single milk protein fractions (Sodini et al., 2004). A heat treatment improves the protein yield and results in tailored textural properties (Dannenberg and Kessler, 1988; Tamime and Robinson, 2007). During acidification a continuous gel network is formed. For stirred yoghurt, the gel network is broken up by post-fermentative mechanical processing resulting in microgel particles with diameters of about 2–100 μm dispersed in milk serum (van Marle et al., 1999; Mokoonlall et al., 2016; Nöbel et al., 2014). In terms of sensorial attributes, stirred yogurt and other microgel suspensions, i.e., fresh cheese, are intended to be soft and viscous with a creamy texture, expel little whey, and a slightly acidic taste (Sonne et al., 2014).

A textural defect often occurring in fermented dairy products is graininess, which affects the visual assesment and in-mouth perception of the milk gel. Graininess arising due to sensorially detectable particles has been quantified using static light scattering (Cayot et al., 2008; Hahn et al., 2012a,b; Jørgensen et al., 2015; Krzeminski et al., 2013; Sonne et al., 2014) or image analysis (Küçükçetin et al., 2008, 2009; Remeuf et al., 2003; Sodini et al., 2005). Static light scattering analyzes the microgel particles at the micrometer-scale. In contrast, larger particles at the millimeter-scale (0.7–7 mm) were identified by image analysis. Large particles have a negative impact on the visual assessment like graininess and lumpiness (Nöbel et al., 2016; Küçükçetin et al., 2009). Small microgel particle are able to aggregate beyond a certain threshold of $d_{75,3} \approx 40$ μm and $d_{90,3} \approx 100$–150 μm, indicating the 25th- and 90th-percentile of the volume weighted particle size distribution, and are perceived as grainy (Hahn et al., 2012b) and less creamy (Cayot et al., 2008) respectively. Krzeminski et al. (2013) reported that the in-mouth graininess of stirred yogurt was directly linked to the proportion of large particles.

Besides the visual appearance, the large particles also affected the rheological properties since stirred yogurt is considered to be a microgel particle suspension (van Marle et al., 1999). The firmness and flow properties are directly related to the size and distribution of the particles constituting the suspension (Hahn et al., 2015). Briefly, shear viscosity as well as moduli of soft sphere suspensions increase with an increasing effective volume fraction ϕ_{eff} (−) and

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decreasing maximum packing fraction $\phi_m(-)$, where sticking occurs (Shewan and Stokes, 2015). An increased polydispersity of monomodal suspensions results in a higher maximum packing fraction and, thus, a lower viscosity of suspension. In multimodal suspensions, small particles become entrapped between large particles. Hence, the maximum packing fraction increases with the number of different particle size classes n, the size ratio of large and to small particles $\lambda(-)$ and with an increasing fraction of large particles $\xi_L(-)$ (Dörr et al., 2013). Several rheological parameters have been reported to be correlated to the texture or microstructure of fermented dairy products (Krzeminski et al., 2013; Lucey et al., 1998; Norton et al., 2011). Non-destructive oscillatory tests, usually evaluated at a constant frequency such as $f = 1$ Hz or $\omega = 10$ rad s^{-1} have been attributed to the gel strength, stiffness, or firmness (Lucey et al., 1998; Jaros et al., 2007; Norton et al., 2011). The flow properties, determined from destructive large deformation tests, resulted in a progressing structural breakdown during the measurement (Abu-Jdayil et al., 2013). Sonne et al. (2014) provided the most complete picture of relevant parameters by adding tribology data to conventional rheology. Further approaches endeavoured to gain insight into the microstructural levels by decomposing the mechanical spectra from rheological measurements into the contributions of the substructural elements within the microgel suspension (Pitkowski et al., 2008; Nöbel et al., 2014).

We have shown in a previous study (Nöbel et al., 2016) that a short sonication of merely 5 min during the fermentation increased the instrumental and sensorial visual graininess of stirred yogurt from skimmed milk. Different pH ranges were tested where pH 5.1–5.4 was identified as critical and causing an increasing the number and size of large microgel particles (millimeter-scale) as well as the average particle size of the small microgel particles (micrometer-scale). In Nöbel et al. (2016), we proposed two feasible mechanisms: a kinematic and a molecular approach. The first mentioned based on the intensified collision probability during ultra-sonication. Vibrations lead to additional shearing in the liquid resulting in particle motion relative to each other and particle aggregation (Johansson et al., 2016). The molecular mechanism draws on the disruption of whey proteins attached to the casein micelles. Sonication promotes the unfolding of the whey proteins and thiol groups get available (Frydenberg et al., 2016) which were reported to induce particle formation (Nguyen et al., 2015).

This study is foremost intended to verify our hypothesis that oscillations during fermentation have an impact on the visual assessment of yogurt (Nöbel et al., 2016). The additional particle formation is proposed as a unique phenomenon apart from graininess occurring due to the yogurt composition under normal non-oscillating conditions. Thus, a wide range of 26 stirred yogurt systems differing in the composition were produced. Particle formation was induced by sonicating in the pH range 5.1–5.2 and studied by means of image analysis and laser diffraction spectroscopy (Nöbel et al., 2016). Various rheological parameters correlating to sensorial attributes and microstructural rearrangements were determined. A further objective of the present study is to discriminate the effects of sonication and compositional changes by means of multiple factor analysis (MFA) in order to identify the structural parameters affected the most by sonication.

2. Materials and methods

2.1. Fermentation and sonication

The preparation of the milk, fermentation, sonication, and mechanical post-processing was carried out according to Nöbel et al. (2016) but altering the fat (0.1–3.5%) and protein content (3.8–5.2%) compared to our previous study (0.1% fat, 3.4% protein). Concisely, the fat and protein content of pasteurized milk was determined in triplicate using a mid-infrared spectrometer (LactoScope FTIR Advanced; Delta Instruments B.V., Drachten, The Netherlands). Based on the analysis, the protein content was standardized by dispersing low-heat skim milk powder Instant C (crude protein: 37%, lactose: 52%; Schwarzwaldmilch GmbH, Offenburg, Germany). By mixing skimmed milk and high-heated cream (90 °C, 120 s) the final fat content was adjusted. After homogenizing (65 °C, 150/30 bar) and high heating (95 °C, 256 s) the whole milk, the final composition was rechecked by FTIR.

Two liters of the milk were warmed up to 42 °C, inoculated with 0.02% (w/v) Yo-Mix 215 (Danisco Deutschland GmbH, Niebull, Germany), and sealed in 100 mL-glass jars. The fermentation at 42 °C was carried out in (1) a standard water bath (K25-MPC, Huber Kältemaschinen GmbH, Offenburg, Germany) without sonication containing eight immersed glass jars and (2) an ultrasonic water bath (RK1028H; Bandelin electronic GmbH & Co. KG, Berlin, Germany) containing eight immersed glass jars. 300 W ultrasonic power at an excitation frequency of 35 kHz were applied to 20 L (500 × 300 × 200 mm) in the water bath. Therein the fermentation temperature was kept constant by an external recirculation (RE212, Lauda Dr. R. Wobser GmbH & Co. KG, Lauda-Königshofen, Germany). pH (BlueLine 14 pH, Schott AG, Mainz, Germany) and temperature (Pt100, Anton Paar GmbH, Graz, Austria) were recorded during the whole fermentation. The sonication was applied for about 5 min after pH 5.2 was reached resulting in the pH range 5.1–5.2 as proposed by Nöbel et al. (2016). During sonication 90 kJ of mechanical energy dissipated in the 20 L-water bath corresponding to an average power density of 15 kW/m^3 in the immersed glass jars. At pH 4.6 the fermentation was stopped by cooling the glass jars for about 15 min on ice. After overnight storage (10 °C) all samples were stirred according to a standard lab-scale procedure (Nöbel et al., 2016).

No change in the fat and protein composition was expected due to the fermentation and post-processing. Solely, the dry matter content of the final yogurt samples was determined with a gravimetric method by drying at 102 °C (Anonymous, 2010; C 35.3). The analysis was performed at least in duplicate.

2.2. Design of experiments

The influence of the preset parameters fat content, protein content, and sonication on the physical properties of stirred yogurt was analyzed using an enlarged Box-Wilson central composite design (Table 1). The dry matter content is determined by the fat and protein content as well. Owing to the large number of parameters and for the purpose of clarity abbreviations in the scheme "group.parameter" will be used in the following. Two ingredients were varied in each case at three levels (center and factorial points) and two unique levels (axial points): fat content (ing.fat = 0.1, 0.6, 1.8, 3.0, 3.5%) and protein content (ing.prot = 3.8, 4.0, 4.5, 5.0, 5.2%). Each experiment was carried out with and without sonication. The yogurt samples of each experimental point were produced and analyzed in duplicate and the center point (ing.fat = 1.8%, ing.prot = 4.5%) in triplicate in a fully randomized order. In the interest of comparability with our previous study (Nöbel et al., 2016), yogurt samples at a fat content of 0.1% and protein content of 3.4% were produced additionally in duplicate, giving a total of 26 differently composed samples (Table 1, sample code A–Z).

2.3. Physical properties of microgel suspensions

2.3.1. Rheological characterization (rheo)

Oscillatory small deformation and destructive large deformation analysis were carried out successively using stress-controlled