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Improved mapping of in-mouth creaminess of semi-solid dairy products by combining rheology, particle size, and tribology data

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ABSTRACT

The effects of fat, protein, and casein to whey protein ratio on lubricating properties of stirred yogurt were determined and the relation of those to the sensory properties graininess, viscosity, and creaminess was assessed. Results demonstrated decreased friction effects with increasing fat and protein level, and decreasing proportion of whey protein. The predictive ability of in-mouth viscosity ($r^2 = 0.91$) and in-mouth creaminess ($r^2 = 0.97$) could be improved by combined assessments of rheological, particle size, and tribological characteristics. Graininess was not affected by friction data. To this end, the applicability of generated models has been tested. This study depicts a better understanding of the key drivers for creaminess and enables food manufacturers to develop fat-reduced dairy products without compromise on sensory properties.

1. Introduction

The favorable role of dairy products on risk factors associated with the metabolic syndrome (Da Silva & Rudkowska, 2014; Louie, Flood, Hector, Rangan, & Gill, 2011), the potential of enrichment with probiotic bacteria (Cruz et al., 2012; Lollo et al., 2013), and the increased awareness of consumers to well-balanced diets based on naturally healthy products has significantly contributed to increased consumption of fermented dairy products over the last years. Despite the above cited benefits of fermented dairy products, yogurt is expected to a have a white color, a soft and smooth body, a thick and creamy texture, a good spreadability with little syneresis, and a flavor that is clean and slightly acidic (Nsabimana, Jiang, & Kossah, 2005). However, yogurt products perceived as creamy and mouth-coating are generally complex and multiphase in structure. Most often, difficulty arises when one wants to describe multidimensional sensorial attributes such as creaminess perceived by consumers. Creaminess is an intrinsic positive hedonic component and since it covers various product properties it is a key driver of sensory appeal (Frøst & Janhøj, 2007). Mapping sensory perception of yogurts by instrumental tests, mainly particle size, bulk rheology, and Posthumus funnel (Alting et al., 2009; Cayot, Schenker, Houzé, Sulmont-Rossé, & Colas, 2008; Janhøj, Petersen, Frøst, & Ipsen, 2006; Krzeminski et al., 2013; Torres, Janhøj, Mikkelsen, & Ipsen, 2011) showed a good correlation to in-mouth creaminess, however, these approaches did not fully capture the dynamic aspects of oral processing. Several authors have noted the relevance of friction processes while consuming for depicting sensory properties of food (Dresselhuis et al., 2007; Giasson, Israelachvilib, & Yoshizawa, 1997; Lee, Heuberger, Rousset, & Spencer, 2004; Stokes, Boehm, & Baier, 2013; de Wijk & Prinz, 2005). Therefore, in the present work we studied whether the combined consideration of rheology, particle size, and friction data of stirred yogurt systems improves the predictive value for textural in-mouth sensations. Thereby, lubricating properties of whey protein enriched yogurt systems as affected by protein and fat content are discussed and the applicability of generated models is tested. As far as we know, this is a first study that tests the predictive ability of instrumental parameters, derived from rheology, particle size, and tribology analysis, to in-mouth creaminess, for stirred yogurts.

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2. Materials and methods

2.1. Stirred yogurt preparation

Stirred yogurt was produced as described by Krzeminski, Großhable, and Hinrichs (2011). Briefly summarized, raw milk was pasteurized (74 °C, 30 s) and standardized in fat content, protein content, and casein to whey protein ratio according to the experimental design (Box-Behnken design). Table 1 outlines the composition of the yogurt systems tested within the present study. After heating (95 °C, 256 s) in a tubular pilot plant (150 L h^{-1}), the yogurt milk was cooled and fermented at 35 °C with 0.02 g/100 g FD-DVS Yo-Flex 812® (Chr. Hansen GmbH, Nienburg, Germany) over a period of 14 h to a pH of 4.4–4.2. Subsequently, fermented yogurt was sheared with a needle valve and filled into 500 mL plastic containers.

2.2. Structural analysis

Particle size and rheological (large deformation) analyses of stirred yogurt were performed according to Krzeminski et al. (2011), tribological analyses according to Krzeminski, Wohlhüter, Heyer, Utz, and Hinrichs (2012). Among friction tests, a stainless steel ball represents the palate and an elastic pad made of styrene butadiene rubber with a regularly structured surface simulates the roughness, softness, and deformability scales of a human tongue surface. Stribeck curves were obtained at a rotation speed $v_s = 0.001–1000\ min^{-1}$ and a normal force $F_N = 3$ N. 1.5 g of each yogurt sample was gently added onto the surface of the elastic pad by the use of a micropipette.

Analysis of particle size has been replicated three times, of rheology twice and of tribology five times. All measurements were carried out at 10 °C.

2.3. Sensory analysis

Yogurt samples were evaluated by 22 trained panelists (4 males, 18 females, mean age: 23 years) at the Sensory Laboratory at University of Applied Sciences, Hamburg, Germany. An amount of 60 g of each yogurt sample was served in 100 mL odorless and transparent plastic cups at 10 °C, coded with 3-digit random numbers. Samples were presented in randomized order according to Williams Latin Square (MacFie, Bratchell, Greenhoff, & Vallis, 1989). The list of sensory descriptors for sensory evaluation and their definition are given in Krzeminski et al. (2013). Descriptive analysis was carried out as defined in ISO 13299 (International Organization for Standardization, 2003) using an 11-point categorical scale and is described in detail by Tomaschunas, Hinrichs, Köhn, and Busch-Stockfisch (2012). Sensory evaluation was performed in triplicate for each sample, with three to five yogurts being served per session, whereas the length of one session was at most one hour. After each sensory evaluation session, attribute definition sheets, filtered matzo and tap water for neutralization were provided. The inter-stimulus interval was defined by each panelist. Repeated measures were performed on different days. Sensory data collection was carried out using FIZZ Data Acquisition System (Biosystèmes, Couternon, France, vs. 2.31 G).

Table 1
Fat level (C_F), protein level (C_P), and casein to whey protein ratio (*CWR*) of evaluated yogurt systems, order of experiments was fully randomized (Box–Behnken design).

Yogurt systems	C_F (g/100 g)	C_P (g/100 g)	*CWR*
A	6.0	3.5	80/20
B	6.0	6.0	80/20
C	0.1	4.5	80/20
E	0.1	3.5	60/40
F	0.1	6.0	60/40
G	6.0	3.5	40/60
H	6.0	6.0	40/60
I	6.0	4.5	60/40
J	12.0	4.5	80/20
K	0.1	4.5	40/60
L	12.0	4.5	40/60
M	12.0	3.5	60/40
N	12.0	6.0	60/40
Reference D	3.5	4.5	80/20

2.4. Data analysis

All statistical analyses were performed on raw data using the software XLSTAT (Addinsoft, Andernach, Germany, compared with 2011.2.04) at a 5% significance level. Principal component analysis (PCA) was applied to reduce sensory and structural dimensions and to study the relationship between sensory and instrumental data (Abdi, 2003; Cruz et al., 2013). Thereby, rows represented the yogurt samples (14) and columns the sensory descriptors (7). Instrumental parameters obtained from particle size ($d_{3,2}$; $d_{75,3}$; $d_{90,3}$), rheological (τ<50 s^{-1}>; τ<100 s^{-1}>; η_{app}), and tribological (μ<1 mm s^{-1}>; μ<10 mm s^{-1}>; μ<100 mm s^{-1}>) analyses were used as supplementary variables.

Backward multiple linear regression was performed in order to further study the relation between sensory and instrumental data and to generate regression models for latent sensory variables. Thereby, the regression starts with all explanatory variables included into the model and then removes stepwise the least significant explanatory variable from the model until the optimum model is found. *P*-values for taking a variable into the model were set to 0.05 and to 0.1 for removing it from the model. The values for the latent sensory variables were calculated as means of their respective manifest variables.

3. Results and discussion

3.1. Sensory analysis

Mean values of sensory profiling and significant differences for each attribute are shown in Table 2. Comparing the 14 samples, results revealed significant differences in all sensory attributes. According to the composition (Table 1), the 14 yogurt samples were characterized by grainy attributes (appearance and texture) and fat-related attributes (viscosity [appearance and texture], fatty mouthfeel, slimy, and creamy). Samples with high *CWR* (80/20) showed the lowest scores in graininess and medium values in fat-related attributes. In contrast, samples with lower *CWR* (60/40) and samples with lower *CWR* and high C_P (6 g/100 g) were characterized by an intensive graininess. However, samples with lower *CWR* and high C_P showed higher intensities in fat-related attributes than samples with lower *CWR*. Yogurt samples with high C_F (12 g/100 g) were very high in fat-related attributes and showed medium intensities in graininess.

3.2. Tribological analysis

Stribeck curves (log μ versus log v_s) exhibiting the friction performance of yogurt systems as a function of C_F, C_P, and *CWR* are shown in Fig. 1. The data can be seen has two lubrication regimes: boundary and mixed regime. Boundary lubrication is observed at low sliding speeds, where friction is independent of the speed, and due to the absence of a pressure build-up the load is supported by the asperity contact and the lubricating film. As the speed increases ($v_s \geq 1$ mm s^{-1}), fluid is entrained into the contact, pressure