Food Hydrocolloids 44 (2015) 244–259

Contents lists available at ScienceDirect

Food Hydrocolloids

journal homepage: www.elsevier.com/locate/foodhyd

Fat droplet characteristics affect rheological, tribological and sensory properties of food gels

Kun Liu [a, b], Markus Stieger [a, c], Erik van der Linden [a, b], Fred van de Velde [a, d, *]

[a] TI Food & Nutrition, P.O. Box 557, 6700 AN Wageningen, The Netherlands
[b] Laboratory of Physics and Physical Chemistry of Foods, Wageningen University, Agrotechnology & Food Sciences Group, P.O. Box 17, 6700 AA Wageningen, The Netherlands
[c] Division of Human Nutrition, Wageningen University, Agrotechnology & Food Sciences Group, P.O. Box 8129, 6700 EV Wageningen, The Netherlands
[d] NIZO Food Research, P.O. Box 20, 6710 BA Ede, The Netherlands

ARTICLE INFO

Article history:
Received 18 July 2014
Accepted 28 September 2014
Available online 7 October 2014

Keywords:
Emulsion-filled gels
Tribology
Sensory perception
Solid fat content
Rheology
Microstructure

ABSTRACT

This work aims to investigate the effect of fat droplet characteristics in emulsion-filled gels on their dynamic rheological, tribological and microstructure properties during breakdown, and their sensory perceptions.

Fat droplet characteristics investigated were the interaction of the fat droplet with the gel matrix (modulated by using different emulsifiers to yield droplets being either bound or unbound to the matrix) and the solid fat content (SFC, varying from 4% to 48%). Fat content was varied from 0% to 20%.

Elastic modulus and fracture properties of these gels (determined under uni-axial compression) were affected by droplet–matrix interaction, fat content, and SFC. A mouth-mimicking tribometer connected to a CLSM was used to determine tribological properties (friction) and microstructural evolution (fat coalescence) of gels under shear. Gels with unbound droplets led to more coalescence (than bound) and increased fat content also led to more coalescence. The observed increase in fat coalescence related to a decrease in friction, which was also related to an enhancement of the perception of fat-related sensory attributes (determined by quantitative descriptive sensory analysis).

The effects of unbound droplets and higher fat content on increasing coalescence and decreasing friction were further enhanced by increasing SFC. Having found that decrease in friction and increase in coalescence relates to an enhancement of perception of fat-related attributes, one would expect that increasing SFC would further enhance the perception of fat-related attributes. This was not found. We attribute this to the fact that our systems are gels that have complicated breakdown behavior.

1. Introduction

Emulsion-filled gels as models for semi-solid and solid foods have been well studied because they allow to investigate the relationships between food structure and sensory perception (Dickinson, 2012). Emulsion-filled gels are model foods for a wide range of palatable products including yoghurt, cheese and processed meat products (Foegeding et al., 2011). In these foods emulsified fats play an important role by providing an appealing texture and enhancing creamy mouthfeel (van Aken, Vingerhoeds, & de Wijk, 2011). Overconsumption of fat, however, contributes to health problems such as overweight, obesity, and heart diseases (Drewnowski, 1997; van Aken et al., 2011). Therefore, it is of great interest for the food industry to develop fat-reduced foods without compromising on texture and mouthfeel perception. The sensory perception of food is strongly influenced by its composition, interactions between its components and the dynamic oral processing (Dickinson, 2012; Hutchings & Lillford, 1988; Stokes, Boehm, & Baier, 2013). In order to maintain or enhance the sensory appreciation of fat-reduced foods, a comprehensive understanding of the influence of fat properties on sensory perception during oral processing is needed.

The perception of food texture is regarded as a multidimensional sensory experience that is perceived during all phases of oral processing: initial phase (first bites), masticatory phase (chewing and bolus formation) and residual phase (swallowing and oral

* Corresponding author. NIZO Food Research, P.O. Box 20, 6710 BA Ede, The Netherlands. Tel.: +31 318 659 582; fax: +31 318 650 400.
E-mail addresses: sweetpie386@gmail.com, kun.liu@wur.nl (K. Liu), fred.vandevelde@nizo.com (F. van de Velde).

http://dx.doi.org/10.1016/j.foodhyd.2014.09.034
0268-005X/

coating) (Brandt, Skinner, & Coleman, 1963; Chen, 2009; Stokes et al., 2013). During each phase texture perception changes as the food structure and its properties constantly vary as a result of mechanical deformation and interaction with saliva (Chen & Stokes, 2012). Rheological and tribological properties at different oral processing phases have been demonstrated to strongly influence texture perception (Bellamy, Godinot, Mischler, Martin, & Hartmann, 2009; van Aken et al., 2011). For emulsion-filled gels, the attributes firmness and brittleness are usually perceived in the first phase of oral processing. These attributes are primarily related to large deformation properties of foods (rheology dominant) (Brandt et al., 1963). Mouthfeel attributes, such as chewiness, stickiness and creaminess, are often perceived in the masticatory phase (Brandt et al., 1963). During this phase of oral processing the bolus is subjected to shear, flow, and displacement which are strongly influenced by both the rheological and tribological behavior of the bolus. In the last phase of oral processing the bolus is swallowed. Food residuals that adhere to oral surfaces are often sensed as creamy, smooth and velvety after-feel. After-feel perception is determined more by the tribological behavior of food residuals and their interactions with saliva (Prakash, Tan, & Chen, 2013). In summary, oral processing is dynamic and entails a "transition from rheology-dominant processes to tribology-dominant processes" (Stokes et al., 2013).

Under conditions relevant for oral processing, tribology has been employed to study lubricational properties of foods and boli. Most studies on tribology focus on liquid (model) foods such as milk (Chojnicka-Paszun, de Jongh, & de Kruif, 2012), cream (Baier et al., 2009; Kokini & Cussler, 1983), biopolymer solutions (Malone, Appelqvist, & Norton, 2003) and emulsions (Dresselhuis, de Hoog, Cohen Stuart, & van Aken, 2008; Dresselhuis, de Hoog, Cohen Stuart, Vingerhoeds, & van Aken, 2008; Malone et al., 2003). It was found that coalescence of fat droplets occurring during oral processing led to a decrease of friction and to an increase of perception of fat-related sensory attributes, such as creaminess (Chojnicka-Paszun et al., 2012; Dresselhuis, de Hoog, Cohen Stuart, Vingerhoeds, et al., 2008; Dresselhuis et al., 2007; Dresselhuis, Stuart, van Aken, Schipper, & de Hoog, 2008). The sensitivity of emulsion droplets towards coalescence under conditions mimicking oral processing behavior was found to change as a function of the stability of emulsions. The stability was modified by changing droplet size, emulsifier type and concentration, and solid fat content (SFC) (Dresselhuis, de Hoog, Cohen Stuart, Vingerhoeds, et al., 2008).

Emulsions with higher SFC (palm fat) were found less stable than emulsions prepared with lower SFC (sunflower oil). The emulsions with higher SFC were also reported to coalesce more than emulsions with lower SFC under shear in a mouth-mimicking tribometer (Dresselhuis, de Hoog, Cohen Stuart, Vingerhoeds, et al., 2008). This higher coalescence at higher SFC is presumably due to a higher sensitivity to rupture of the droplet interface upon deformation, where the rupture is caused by the presence of fat crystals penetrating the interface. The emulsions with higher SFC also related to higher fat-related perception (Benjamins, Vingerhoeds, Zoet, de Hoog, & van Aken, 2009; Dresselhuis, de Hoog, Cohen Stuart, Vingerhoeds, et al., 2008). These results suggest that SFC, coalescence of droplets in a tribometer and fat-related perception are related. However, the increased coalescence in a tribometer was not always found to relate to in-mouth coalescence (Dresselhuis, de Hoog, Cohen Stuart, Vingerhoeds, et al., 2008). In addition, we think that instability of the emulsion droplets (against coalescence) is the most prominent reason for fat perception and that SFC is only one of the contributing factors. The effect of SFC can be overruled by other factors affecting the stability. For example, no influence of SFC is found when sodium caseinate is added as an extra emulsifier (Dresselhuis, de Hoog, Cohen Stuart, Vingerhoeds, et al., 2008), and a less pronounced effect exists by adding not enough emulsifier (Dresselhuis, de Hoog, Cohen Stuart, Vingerhoeds, et al., 2008) or by adding unsaturated mono-glycerides (Benjamins et al., 2009).

Apart from liquid emulsions, semi-solid foods and solid foods are an important class of food products. As mentioned a suitable model system for these food products is an emulsion-filled gel. In contrast to the extensive studies on emulsions in relating microstructure with tribology and sensory, there are much less of these studies performed on emulsion-filled gels. Previous studies linked large deformation rheological properties of emulsion-filled gels to texture perception (Gwartney, Larick, & Foegeding, 2004; Kim, Gohtani, & Yamano, 1996; Sala, de Wijk, van de Velde, & van Aken, 2008). Several experimental techniques that combine rheological and tribological measurements with observations of the microstructure of the food under mechanical deformation have been developed and applied to study composite gels during breakdown and mastication (Abhyankar, Mulvihill, & Auty, 2011; Nicolas & Paques, 2003; Yves Nicolas et al., 2003). It has been demonstrated for emulsion-filled gels that creaminess relates to the type of gel matrix and the oil content. It was also found to relate to the release of oil droplets from the gel matrix during gel breakdown when squeezed out of a syringe (resembling in-mouth conditions) (Chojnicka, Sala, de Kruif, & van de Velde, 2009; Sala, van de Velde, Cohen Stuart, & van Aken, 2007). Release of oil droplets from the gel matrix during mechanical breakdown could be enhanced when oil droplets were unbound to the matrix (i.e. not interacting with the gel matrix) (Chojnicka et al., 2009; Sala, van de Velde, et al., 2007).

In summary, in liquid emulsions fat-related perception can be enhanced by increasing the instability of droplets against coalescence, and in emulsion-filled gels fat-related perception can be enhanced by increase of oil release. We hypothesize that the enhancement of fat-related perception due to increase of oil release can be further enhanced by increasing the instability of emulsion droplets against coalescence. We have tested this hypothesis in emulsion-filled gels where the droplets are bound to the gel matrix, and in emulsion-filled gels where the droplets are unbound. In the current work we have chosen to vary the droplet instability by varying the SFC.

According to the hypothesis we have three expectations. Expectation A is that we expect more droplet release and coalescence under shear in a tribometer by incorporating fat droplets with higher instability towards coalescence (higher SFC) into emulsion-filled gels with high droplet releasing ability (unbound). Expectation B is that the increased coalescence of droplets will give rise to formation of a lubricating fat layer between the shearing surfaces of a tribometer, decreasing friction. This increased coalescence and the formed fat layer is expected to be observable under a microscope. Expectation C is that the above leads to an enhanced fat-related perception. This expectation is based on the assumption that increase of coalescence and formation of fat layer in a tribometer also happens in mouth in a similar way during oral processing. Taking into the account that tribology and sensory are two main aspects of testing our hypothesis we have treated these aspects in two sections of our paper.

Because of the fact that oral processing entails a "transition from rheology-dominant processes to tribology-dominant processes" (Stokes et al., 2013) we also have to consider a third aspect in our study: bulk rheology. Indeed, large deformation rheological properties of semi-solid foods can often be related to their texture perceptions. For example, Young's modulus relates to firmness perception (Kramer & Szczesniak, 1973). It is expected that by changing the SFC in droplets, and by changing the droplet–matrix interaction, the large deformation properties of the gels would be