Factors affecting the rheological properties of a structured cellular solid used as a fat mimetic

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ABSTRACT

The effects of water content, monoglyceride chain length and concentration, oil type, and the addition of oil-phase and water-phase additives on the elastic modulus and yield stress of a structured oil in water were evaluated. The goal was to increase the elastic modulus of the original emulsion from $8.42 \times 10^3 \pm 11.3$ Pa to $1.55 \times 10^6 \pm 2.1 \times 10^5$ Pa, and the yield stress from 112 ± 2.31 Pa to 835 ± 227 Pa. The addition of wax at greater than 10% (w/w), the use of palm oil or the gelation of the liquid oil phase with 5–7.5% rice bran wax, the use of C-18 saturated monoglyceride at 6%(w/w), and 4% (w/w) for C-22 saturated monoglyceride molecules were effective modifications capable of improving the mechanical behavior of the emulsion so that it can be used as a zero *trans* and reduced saturated fat laminating shortening substitute for puff pastry products.

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1. Introduction

The negative effects of *trans* and saturated fatty acids on high and low density lipoprotein serum levels (i.e. cholesterol) and overall health are well established (Eckel, 1997; Keys, Anderson, & Grande, 1965; Mensink & Katan, 1990, 1992; Mensink, Zock, Kester, & Katan, 2003). This knowledge has prompted new health concerns regarding dietary fat consumption and shaped consumer demands, motivating food manufacturers to reduce and, if possible, completely eliminate the use of *trans* and saturated fatty acids in food products.

However, this has proven to be a challenge due to the intrinsic contributions of these ingredients provided to the overall sensory and textural attributes of a food product. A reduction in fat often results in severe deterioration of the quality of the product in question, inspiring the recent search for fat alternatives that do not compromise the sensory characteristics of the product but offer a reduction in total fat and caloric content.

Baked goods prepared with margarines or shortening, such as puff pastry products, are one class of baked items that would greatly benefit from a substitution of these unhealthy fats. Margarine and shortening ingredients are both high in calories and fat and offer no positive nutritional value to the baked product. Considering that the total fat content of a puff pastry product ranges between 15–35% by weight, the use of a shortening substitute would significantly reduce both the caloric and total fat content of the puff pastry product (Huschka, Challacombe, Marangoni, & Seetharaman, 2011; Nor Aini & Miskandar, 2007).

Lipids are added to baked products for lubrication, taste, texture, to extend the product's shelf life, and in the case of shortenings, to inhibit the formation of the gluten network (Ghotra, Dyal, & Narine, 2002; Huschka et al., 2011; Nor Aini & Miskandar, 2007; Patient, 2006). This functionality is a consequence of the fat crystal network and composition unique to the shortening or margarines (Marangoni et al., 2012; Tang & Marangoni, 2006). Margarines are, in essence, a water in oil (w/o) emulsion with a minimum oil content of 80%, while shortening products are typically 100% fat (Aguilera & Stanley, 1999; Codex Standard 256–2007, 2009). Certain shortening products, such as those used in puff pastries, often contain up to 16% water for enhanced lubrication, spreadability, and puff (Patient, 2006).

While a variety of alternative margarines are commercially available, the task of creating a shortening alternative remains (for the most part) unrealized, particularly for roll-in shortenings, also known as laminate fats. This specific type of shortening product is responsible for the open structure and flaky texture characteristic of puff pastry products, including croissants and danishes.

As the name implies, roll-in shortenings are folded into dough to form hundreds of micrometer thin fat "laminated" layers sandwiched

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between dough layers (Patient, 2006). During baking, the moisture in the dough converts to steam and begins to evaporate, causing the dough to expand in a process known as leavening (Rogers, 2004). The alternating layers of dough remain separated by thin layers of shortening. Thus, each dough layer bakes individually, yielding an open-structure appearance comprised of many flaky pastry layers.

A shortening substitute would have to mimic this functionality, which can be summarized by the following criteria. First, the substitute must be plastic so that it spreads easily into thin sheets between dough layers during the folding process (Nor Aini & Miskandar, 2007; Rønholt, Kirkensgaard, Høyer, Mortensen, & Knudsen, 2013). Like plastic fats, this means that the rheological behavior of substitute must be solid-like during initial deformation, followed by viscous liquid flow once the network deforms at the yield point (S. Narine & Marangoni, 1999). Secondly, the melting temperature of the shortening substitute must be greater than the working temperature of the dough to prevent the shortening from melting and the dough layers from touching during the folding process (Litwinenko, Rojas, Gerschenson, & Marangoni, 2002). Thirdly, the consistency of the shortening material must be similar to that of the dough. A soft shortening will mix in with the dough and fail to achieve lamination, while a very hard or brittle shortening will tear through dough layers during folding, failing to produce a flaky pastry (DeMan, DeMan, & Blackman, 1991).

Typically, these criteria are met by incorporating solid fat with high melting triacylglycerol (TAG) components into the shortening composition (Garcia-Macias, Gordon, Frazier, Smith, & Gambelli, 2012). This obviously reduces the nutritional quality of the food product. Ideally, a substitute should meet these criteria without the addition of solid fat in order to maximize the reduction of *trans* saturated, total fat, and caloric content.

These requirements complicate the development of a laminating fat substitute. In the interim, food manufacturers have opted for other approaches such as the hydrogenation of liquid oils, interesterification, or the extensive use of fat with palm oil (Garcia-Macias et al., 2012; Nor Aini & Miskandar, 2007). Naturally *trans*-fat free, palm oil is solid at room temperature and prone to crystallization in the β′ polymorph which is favorable for margarines and shortenings (DeMan & DeMan, 2005; Nor Aini & Miskandar, 2007). In addition, interesterification and fractionation can be used to obtain modified palm oil components, making it a highly versatile ingredient.

In this study, a commercial shortening alternative, Coasun™, is modified to obtain a functional laminate fat alternative. This novel oil-in-water structured emulsion was developed by our group, and can be used as an all-purpose zero *trans* and low saturated shortening in many bakery and spread applications (Batte, Wright, Rush, Idziak, & Marangoni, 2007a; Batte, Wright, Rush, Idziak, & Marangoni, 2007b). In one study, the use of Coasun as a shortening substitute for cookies was found to provide a 20% decrease in saturated fat and 43% decrease in *trans* fat (Lin & Appleby, 2012).

This material is structured as a close-packed ensemble of oil globules surrounded by crystalline walls composed of several emulsifier bilayers interspersed with water. The preferred composition contains 3–5% monoglyceride, 0.15–0.25% co-surfactant, and 35 to 40% water, with the balance being liquid oil. Despite the low solid content of this emulsion, the product is solid at room temperature.

The original formulation does not include high-melting hard fats, as they contain *trans* and saturated fats. To optimize the caloric and fat reduction achieved by substituting commercial shortening with Coasun, liquid oil is used instead of solid fat. Unfortunately, this composition is not suitable for use as a laminate fat or in applications where solid fat contributes to both functional and sensory characteristics of the finished food product.

Thus, the goal of this study is to modify the Coasun™ formula to obtain laminate fat substitute. The rheological properties of the modified Coasun™ product will be compared to those of an industrial high-*trans* commercial roll-in shortening product.

2. Materials and methods

2.1. Materials

Rice Bran Wax (RBX), Carnauba Wax (CRX), Candelilla Wax (CLX) and Sunflower Wax (SFX) were supplied by Koster Keunen Inc. (Connecticut, USA). Stratas Foods supplied the fully-hydrogenated soybean oil (FHSB), while the alphadim SBK 90 monoglyceride and sodium stearoyl lactylate (SSL) were provided by Caravan Ingredients (Lenexa, KS, USA). Additional monoglyceride samples, monobehenate and HP K-A were supplied by Palsgaard (Morris Plains, NJ, USA) and Dimodan Danisco (ON, Canada), respectively. Palm oil and a commercial laminate shortening were provided by Bungee (Toronto, ON), and guar gum and lambda-carrageenan by Danisco (Scarborough, ON). Soybean oil and palm kernel oil were supplied by Caldic Canada (Mississauga, ON), and canola oil by Loblaws Inc. (Toronto, ON). Potassium sorbate was supplied by Sigma Aldrich (St. Louis, MO, USA). Akzo Nobel (Toronto, ON) provided polyquaternium-4 (Celquat H-100), polyquaternium-10 (Celquat SC-240C), and hydroxypropyl starch copolymer (Celquat LS-50). Redpath (Toronto, ON) supplied granulated sucrose, while Sigma Aldrich (St. Louis, MO, USA) supplied xanthan gum, guar gum, and carrageenan.

2.2. Emulsion preparation

Emulsions were prepared by combining all oil-phase ingredients (oil, monoglyceride, sodium stearoyl lactylate (SSL), antioxidants, and any wax or fat additive) separately from the water-phase ingredients (water and, in certain cases, polysaccharides and or mono-, di-, and oligo-saccharides). Both phases were heated to 75 °C, which is above the melting point of the emulsifiers in the oil, but below the lamellar to cubic phase transition of the saturated monoglyceride in water and stirred before adding the oil-phase to the water-phase. External shear was applied to the mixed phases until the sample appeared homogenous. The emulsions were statically cooled at room temperature for 12 h before placed in a 5 °C fridge for storage.

The formulation of the emulsions varied with respect to monoglyceride type and concentration, as well as oil, water, and additive concentration, in order to determine the effect and limitations of each component of the system. Monoglyceride concentrations varied between 2–6% (w/w), water between 20–40% (w/w), wax additives between 1–15% (w/w), and oil between 50–77% (w/w). When used, guar gum and λ-carrageenan comprised a total of 0.5% (w/w) of the sample in a 1:1 ratio, while the potassium sorbate was present at 0.1% (w/w) concentrations of the total emulsion.

To distinguish between samples, a labeling mechanism has been devised that clearly indicates the water content, monoglyceride content, and oil type of the formulation. The generic form of the label is #W-#MAGX-#O, whereby # denotes concentration, W, MAG, and O represent water, monoglyceride, and oil type, and X denotes monoglyceride chain length. The oil type is denoted by a letter preceding O, such as S (soybean), C (canola), or P (palm). Other additives such as wax or hydrocolloids are expressed similarly following the oil-phase expression.

Such variance in the formulations allowed for a thorough assessment of the contribution from different phases to the overall performance and behavior of the emulsion.

2.3. Small angle controlled stress rheology

The elastic modulus (G′) and yield stress of the emulsion samples were determined using a TA Instrument AR2000 Controlled Stress Rheometer (Mississauga, ON, Canada). The yield stress was determined as the value of stress at which the value of G′ deviated from the linear viscoelastic regions. These two parameters were obtained from stress sweeps carried out from 0.1 Pa to 1500 Pa at a constant frequency of