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Rheological behaviour of fibre-rich plant materials in fat-based food systems

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ABSTRACT

The potential use of fibre-rich materials as bulking agents to replace sucrose in chocolate confectionary products is investigated. Since the rheological behaviour of the molten chocolate mass is key in chocolate production, the rheology of fibre-rich materials in medium chain triglycerides (MCT) is studied and compared to the rheology of sucrose in MCT. The materials studied are side streams of the fruit and vegetable processing industry: lemon peels, spent grain, grape pomace and pecan fibre. All suspensions showed shear thinning behaviour at volume fractions >0.2, where side stream materials showed lower shear thinning behaviour than sucrose. The values for the maximum packing fraction, obtained via the Maron–Pierce equation and using the Casson Plastic Viscosities, were lower for the side stream materials than for sucrose. Addition of lecithin resulted in a decrease in the Casson Yield Value of sucrose suspensions, which was not observed with the fibre-rich materials. The rheological behaviour of the fibre-rich materials suspended in MCT is explained by the effective volume of the irregularly shaped particles. The behaviour of sucrose suspensions is explained by the formation of aggregates, which seem to be promoted by water bridges between the particles. Overall, the behaviour of the sucrose dispersions was very different compared to the other materials with respect to the shear thinning behaviour, the impact of lecithin as well as the impact of water. Therefore it is suggested that only partial replacement of sucrose by fibre-rich materials will be successful in industrial product development.

1. Introduction

The increasing health awareness and the fluctuating cost price of sucrose motivated the food industry to develop reduced sugar food products (Worldbank, 2011). Chocolate, which can be considered a dispersion of milk proteins, cocoa solids and sugar in a continuous fat phase, is consumed at 7.9 kg/person per year in the U.K. (Afoakwa, 2010). Since chocolate consists up to 50% of sucrose, it has been subject to sucrose reduction for many years (Beckett, 2009).

Sucrose is an ingredient that provides sweetness to chocolate products. The sweetness can be mimicked by the addition of high intensity sweeteners, such as acesulfame K, aspartame or sucralose. However, these components provide sweetness in a much more weight effective manner than sucrose. That is why the other function of sucrose, providing bulk, requires the use of other components. The addition of bulk sweeteners, such as maltitol, has been successful, albeit expensive. A more cost-effective method therefore seems to be replacing sucrose by two components: a sweetener and cost effective bulking agent (Beckett, 2009). Current legislation as described in the Codex Alimentarius, allows for the inclusion of bulking agents in chocolate up to 40% (apart from starch).

Bolenz, Amtsberg, and Schäpe (2006) studied the use of dietary fibres as bulking agent in chocolate. The ingredients studied, such as wheat fibre, are relatively cheap because these materials originate from side stream materials of the fruit and vegetable processing industry. The production of side stream materials in Europe is approximately 140 million tonnes per year (Sonesson, 2010; Waldron, 2007). An additional advantage of materials high in dietary fibres is that inclusion of those components might lead to an

Abbreviations: CYV, Casson Yield Value; CPV, Casson Plastic Viscosity; MCT, medium chain triglyceride.

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additional health benefit (Elleuch et al., 2011). Unfortunately, the addition of wheat fibre up to 20% to chocolate had an adverse effect on the flow properties of the molten chocolate (Bolenz et al., 2006).

When replacing part of the sugar, it is important to keep the flow properties of chocolate at different shear rates similar, because those properties determine the efficiency of specific process steps (Afoakwa, Peterson & Fowler, 2007a). Pumping, for example, is limited by a maximum viscosity at high shear rates. In addition, the ability of the chocolate to flow in small holes and sharp edges during moulding requires a certain ability to flow at low shear rates (Holdgaard, 2012). However, a too low viscosity can lead to product deformation during the crystallization process of the cocoa butter. The addition of sugar allows a good balance between the ability of chocolate to flow by giving structure to the chocolate mass. When sugar is replaced by a bulking agent, chocolate producers will insist of having similar flow properties, in order to maintain similar processing and equipment. Obviously, to successfully replace sucrose in chocolate with fibre-rich materials the effect on the flow properties of the chocolate needs to be understood.

To get a better understanding of the rheological behaviour of chocolate, the rheological behaviour of cocoa and sucrose were separately investigated in different types of fat phases (Babin, Dickinson, Chisholm, & Beckett, 2003; Babin, Dickinson, Chisholm, & Beckett, 2005; Fang, Tiu, Wu, & Dong, 1995). The behaviour of both ingredients could be described with the Casson model, which is often used to describe chocolate rheology (Servais, Ranc, & Roberts, 2004). Fang et al. (1995) identified increasing shear thinning behaviour with increasing volume fraction of cocoa particles in cocoa butter due to aggregate formation. Furthermore, the addition of soy lecithin, an emulsifier often used in chocolate formulations, resulted in a decrease in viscosity at low shear rates. This was explained by considering that the lecithin surrounds the cocoa particles, which reduces the formation of aggregates. Interactions between particles leading to aggregates were also identified with sucrose suspended in different oils by Babin et al. (2003). It was found that the aggregate formation depends on the concentration of sucrose, the type and purity of the oil and therefore the presence of water traces or impurities such as free fatty acids (Babin et al., 2003; Babin et al., 2005; Johansson & Bergenståhl, 1992b). Just as with cocoa particles, it was found that lecithin, which strongly absorbs at the hydrophilic surfaces of the sucrose, lowers the adhesive forces between the particles rendering a lower viscosity (Babin et al., 2005).

There is significant amount of research published on the rheological behaviour of chocolate (see e.g. the review by Afoakwa et al. (2007a)), where the impact of all components together is evaluated. However, as far as the authors are aware of, the rheological properties of powdered side stream materials in oil have not been studied in detail. The purpose of the present paper is to investigate the rheological properties of suspensions of powdered side stream materials in a simple liquid fat matrix, in comparison with the physical properties of sucrose in the same medium. The powdered materials being investigated originate from pecan shells, grape pomace, lemon peel and brewers spent grain. For sucrose, the powdered form icing sugar is used. Medium chain triglyceride (MCT) is chosen as model oil for the fat matrix (resembling the liquid state of cocoa butter during processing), which is liquid at room temperature and possesses a minimum of fat crystals or impurities due to the fact that the oil is highly refined. The results of this study will help evaluating the possibility of replacing sugar in chocolate with dried and powdered side stream materials of the fruit and vegetable industry. The effects of the ingredients are studied by rheological measurement at different volume fractions. Furthermore, the influences of lecithin and water are determined. Finally, to have an indication of the morphology and the structure of the suspensions light microscopy pictures are taken of the suspended materials.

2. Materials and methods

2.1. Materials

The side stream materials were obtained and handled as followed:

- The spent grain was obtained from the York Brewery (U.K). Subsequently the grains were dried for 4 h at 90 °C with a convective oven and the dried grains were stored in aluminium pouches at room temperature.
- The pecan fibre (Lignoflex™) were received from Southeastern Reduction Company (U.S.) as a dried powder in plastic pouches and stored as such at room temperature.
- The lemon peels were obtained from San Miguel (Argentina) as dried shredded peels in plastic pouches and were stored as such.
- The grape pomace of grape variety Chasselas was obtained fresh from Ecole d'Ingénieurs de Changins (CH) and stored in a freezer at −18 °C for 1 week. Subsequently, the wet grape pomace was dried with a laboratory fluidized bed dryer (Huettlin Unilab) for 40 min at 85 °C. The dried grape pomace was stored in closed plastic buckets at room temperature.

The materials did not contain measurable amount of oil or other hydrophobic components.

Furthermore the following materials are used:

Medium chain triglyceride oil (MCT): Neobee M5, Stepan, Food & Health Specialties, US.

Icing sugar: Sugar powder, Zuckermühle Rupperswil, Switzerland. The moisture content was 0.06% according to manufacturer's specification and used without further modifications.

Soybean Lecithin: Alcolec fluid lecithin, American Lecithin Company, United Kingdom.

2.2. Powder preparation

The side stream materials were dried for an additional 3 h at 90 °C with a non-convective oven and then subsequently ground using a kitchen scale coffee grinder and sieved through a sieve with a mesh size of 71 μm. Also, the sucrose was sieved through a mesh size of 71 μm. The resulting water content was 0.6% (spent grain), 0.4% (lemon peel), 1.3% (grape pomace) and 0.6% (pecan fibre). Those values were obtained by drying all materials at 105 °C for an additional 5 h.

2.3. Density

Mixtures of 6% (w/w) of the powders in MCT were prepared and were suspended with an Ultra Turrax in 3 steps of 30 s at speeds of 9500, 13,500 and 24,000 rpm respectively.

Density measurements were performed with an Anton Paar DMA 4500 Density meter. Each sample was measured in triplicate. The system was flushed with isopropanol, water and isopropanol respectively between the measurements.

2.4. Microscopy

Microscopy pictures of the suspensions in MCT were taken using a Nikon Eclipse E800 light microscope at 10× magnification.

2.5. Production of samples

Suspensions of the powders in MCT were prepared at volume fractions 0.05, 0.1, 0.2, 0.3 and 0.4. The suspensions were stirred for 1 h with an overhead stirrer (IKA Eurostar). Furthermore the effect of