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Fiber enriched reduced sugar muffins made from iso-viscous batters

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ABSTRACT

The application of dietary fiber produced from fruit or vegetable by-products in baked foods is of growing interest for the food industry, providing the possibility for delivering reduced energy/sugar products. The aim of this study was to analyze the potential of sucrose replacement by a combination of rebaudioside A and wheat, apple or pea fiber, and the respective influence on batter and product characteristics. The main focus was on the production of muffins from batters with similar viscosity, the formulation of which was realized by the adaption of water levels in the recipes. Small strain oscillatory measurements of muffin batter with temperature sweeps from 25 to 100 °C revealed that thermally induced structure modifications caused by protein denaturation and starch gelatinization were delayed with increasing replacement of sucrose by fiber. Volume, water activity and crumb firmness increased and *in vitro* starch digestion decreased with increasing level of fiber incorporation and sugar replacement. Sucrose replacement of 30% by wheat fiber and rebaudioside A resulted in products close to the reference muffin.

1. Introduction

Overweight and obesity have been gaining relevance in industrial countries, especially in the part of the society which is susceptible to malnutrition. The increase in diet-associated chronic diseases has been related to factors such as inappropriate dietary patterns, decreased physical activity and increased tobacco use (Nishida, Uauy, Kumanyika, & Shetty, 2004). To promote a healthier diet, the food industry frequently focuses on the production of reduced fat/sugar/energy foods with a sensory quality that is comparable to that of conventional products. Quick bread muffins for example are popular breakfast or snack products with high consumer acceptance. Because muffins are high in sugar and fat, several attempts were made to increase their nutritional value by, e.g., replacing sucrose with high intensive sweeteners, or by incorporating dietary fiber.

Glycosides from *Stevia rebaudiana* Bertoni are heat stable natural sweeteners with a relative sweetness of approx. 300 and were recently applied as sugar replacers in sweet baked foods (Manisha, Soumya, & Indrani, 2012; Zahn, Forker, Krügel, & Rohm, 2013). In these products sucrose is one of the main ingredients; it is responsible for sweetness, flavor, and texture formation, and it contributes to volume increase, crust color, shelf life and moisture retention (Nip, 2006). Sucrose reduction causes reduced batter viscosity which results in low product volume and poor cell structure (Manisha et al., 2012). Because of its technofunctional properties and the high proportion in most recipes replacement of sucrose is challenging when product characteristics should be similar to those of full sugar bakery products (Struck, Jaros, Brennan, & Rohm, 2014). As sugar substitutes need to replace all major functions of sucrose, the most promising approach is to use sweeteners with different sweetening intensity, and to combine them with bulking agents that act as structure building substances (e.g., inulin, polydextrose, dietary fiber) (Esteller, Amaral, & Lannes, 2004; Martínez-Cervera, Sanz, Salvador, & Fiszman, 2012; Riedel, Böhme, & Rohm, 2015; Zahn et al., 2013; Zoulias, Piknis, & Oreopoulou, 2000).

To increase dietary fiber in baked goods, products from different sources can be incorporated into the recipe for partially replacing flour, sugar or fat. Fibers that were used in recent studies were from mango or potato peels (Ajila, Leelavathi, & Prasada Rao, 2008; Arora & Camire, 1994), apple pomace (Masoodi, Sharma, & Chauhan, 2002; Sudha, Baskaran, & Leelavathi, 2007), and orange or grape pomace (Mildner-Szkudlarz, Bajerska, Zawirska-Wojtasiak, & Górecka, 2013; O'Shea, Doran, Auty, Arendt, & Gallagher, 2013).

The incorporation of dietary fiber in sweet baked goods is associated with an increase in batter viscosity, which has a great influence on product volume and texture (Lebesi & Tzia, 2011;

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Martínez-Cervera, Salvador, Muguerza, Moulay, & Fiszman, 2011). The increase in batter viscosity is related to physicochemical properties of the fiber such as its high water binding capacity (Gularte, de la Hera, Gómez, & Rosell, 2012), which reduces the water available for other ingredients and, consequently, affects product characteristics such as crumb hardness and chewiness, or volume (Grigelmo-Miguel, Carreras-Boladeras, & Martín-Belloso, 1999; Sudha et al., 2007).

It was our hypothesis that the impact of sucrose replacement and fiber addition on batter viscosity can be balanced by adjusting the water level in the recipes. The aim of this study therefore was to evaluate the integration of apple, pea and wheat fiber in muffin batters of similar viscosity (further denoted as iso-viscous batters), and to examine the effects of sugar replacement by rebaudioside A (RebA) and these fibers on batter characteristics and product properties.

2. Materials and methods

2.1. Analysis of fiber composition

Moisture content of wheat (WF 600-30), apple (AF 401-30) and pea (EF 100) fiber (JRS Rettenmaier, Rosenberg, Germany) was determined by drying in an oven at 103 °C to constant mass. Fat content was analyzed by Soxhlet extraction, protein by the Kjeldahl procedure (conversion factor 6.25). Ash was determined gravimetrically (5 h, 550 °C) in a muffle furnace. Carbohydrates were calculated by difference.

2.2. Water binding capacity (WBC)

The determination of fiber WBC was based on centrifugation (Chen, Piva, & Labuza, 1984). 4 g fiber was mixed with 40 g water and kept at room temperature for 30 min. Samples were centrifuged at 2000 g for 10 min, and the supernatant was decanted and weighed. Supernatant dry matter, giving the amount of fiber that remains in the aqueous phase, was determined using an MA 30 moisture analyzer (Sartorius, Göttingen, Germany) at 95 °C. WBC refers to the amount of water bound per gram dry fiber that remained in the centrifugation sediment.

2.3. Muffin formulation and preparation

The reference recipe comprised 200.0 g wheat flour, 120.0 g sucrose, 10.0 g baking powder, 15.0 g skim milk powder, 15.0 g whole egg powder mixed with 45.0 g water, 2.4 g salt, 80.0 g canola oil and 120.0 g water. Reduced sugar muffins were prepared by replacing 30, 60 or 100% sucrose with a combination of fiber, water and steviol glycosides. Apple fiber (AF), wheat fiber (WF) or pea fiber (PF) and water were incorporated to achieve batters iso-viscous to the reference. RebA was added to ensure iso-sweetness that has been determined previously (Zahn et al., 2013). To replace 36.0 g (=30%) sucrose, 0.14 g RebA and 35.86 g water–fiber-mixture were added; to replace 60% it were 0.28 g and 71.72 g, respectively. For full replacement, 0.48 g RebA and 119.52 g water–fiber-mixture were used and analyzed solely for WF since it gave the best product characteristics and batter processibility among the fibers. Batter preparation was performed as described previously (Zahn, Pepke, & Rohm, 2010), and the fiber was added with the dry ingredients. Finally, 43 ± 0.1 g batter were filled in paper cups, placed in a muffin baking tray and baked at 200 °C top heat and 180 °C bottom heat for 24 min (MIWE condo, Arnstein, Germany). Products from each recipe were produced, baked and analyzed in two independent batches.

2.4. Rheological analysis

Rotational and oscillatory measurements of muffin batters, separately produced without baking powder, were performed with a Physica MCR 300 rheometer (Anton Paar, Germany) equipped with a 50 mm plate-plate-geometry. After preparation, each batter was kept at 25 °C for 1 h and loaded to the geometry. The gap was adjusted to 1.025 mm as trimming position to carefully remove excess batter and, after batter relaxation for 10 min, finally adjusted to 1 mm. Experiments were performed from two batches in duplicate.

2.4.1. Flow properties

Apparent viscosity η_a was measured at 25 °C as a function of shear rate ($0.1 \le \dot{\gamma} \le 100\ s^{-1}$). Recipe development to create iso-viscous batters was carried out by adapting the water level. η_a of the reference (22.7 Pa s at $\dot{\gamma} = 10\ s^{-1}$) was the basis for an iterative approach to adjust viscosity of fiber-containing batter. For each fiber, 30% or 60% (100% for WF only) sucrose was replaced with a mixture of water and fiber. The fiber/water ratio was adjusted until η_a at $10\ s^{-1}$ did not differ significantly from reference η_a. The batter flow curves were power-law fitted

$$\eta_a = k \cdot \dot{\gamma}^{n-1} \quad (1)$$

where k (Pa s^n) refers to the viscosity factor, and n is the flow behavior index.

2.4.2. Viscoelastic properties

All oscillatory measurements were performed in the linear viscoelastic region at a strain of $\gamma = 0.0005$. The gap was covered with vaseline oil to prevent dehydration. A frequency sweep was performed at 25 °C were f decreased logarithmically from 10 to 0.1 Hz. A subsequent temperature sweep from 25 to 100 °C was conducted at f = 1 Hz and a heating rate of 5 K min^{-1}, previously determined as approximate heating rate in the center of a muffin during baking. After holding at 100 °C for 10 min, a final frequency sweep was performed ($10 \ge f \ge 0.1$ Hz).

2.5. Product characteristics

Maximum height and average diameter of ten muffins were measured using a digital caliper. After weighing, relative baking loss was calculated. Volume was determined in triplicate using the canola seed displacement method. Water activity of milled muffins was measured in triplicate with a thermoconstanter (Novasina, Lachen, Switzerland, Germany) at 25 °C. Crumb texture was analyzed using a XT2i Texture Analyzer (Stable Micro Systems, Surrey, UK). After storing the muffins in polythene bags at room temperature for 1 d, cylinders (d = 22.5 mm) were cut from the crumb of five muffins from each batch (28 mm length). Using an acrylic plate (d = 40 mm), crumb cylinders were compressed to 50% height at 1 mm/s, decompressed and compressed again; off-time between compressions was 5 s. Crumb firmness was the peak force during first compression, and cohesiveness refers to the ratio of areas under the 2nd to the 1st compression cycle in force–time diagrams (Zahn et al., 2013).

A Luci 100 spectral colorimeter (D65 Xenon lamp, 10° standard observer; Hach Lange, Düsseldorf, Germany) was used to measure crumb and crust color from three muffins in triplicate. The measurement was based on the CIE-Lab color space, and lightness L*, chroma C* and hue angle h_{ab} were further considered as color descriptors (Rohm & Jaros, 1996).