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Optimization of inulin and polydextrose mixtures as sucrose replacers during sugar-free chocolate manufacture – Rheological, microstructure and physical quality characteristics

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ABSTRACT

Inulin and polydextrose have in recent times form basic ingredients in the manufacture of many sugar-free products. However, the applicability and suitability of inulin and polydextrose mixtures as sucrose replacers during manufacture of sugar-free chocolate is yet to be fully understood. This work investigated optimum conditions as well as influences of inulin and polydextrose mixtures as sucrose replacers on rheological properties, microstructure and physical qualities during manufacture of sugar-free chocolate. Increasing inulin concentrations with simultaneous reduction in polydextrose resulted in consistent increases in the Casson plastic viscosity while that led to decreases in Casson yield stress. Chocolate formulated with 100% polydextrose revealed large crystals with dense smaller particles and minimal inter-particle spaces compared to large crystals with more void spaces in chocolates formulated with 100% inulin. Chocolate formulation consisting of 75.3594% polydextrose and 24.6406% inulin was found as the optimum concentrations producing the most acceptable rheological and physical quality characteristics.

1. Introduction

The applicability and suitability of inulin and polydextrose as bulking agents in sugar-free chocolate manufacture have been reviewed (Aidoo et al., 2013). Polydextrose and inulin are considered as fibres that do not only increase the bulk consistence of food and its rapid movement through the gastrointestinal, but also helps in preventing constipation and possible colon and rectal cancer. Polydextrose, a randomly linked polymer of glucose has similar technological properties as sucrose except for sweetness and inulin is a polymer of various lengths comprising of fructose molecules linked together and ending with a glucose molecule (Burdock and Flamm, 1999; Afoakwa et al., 2007a; Beckett, 2009).

Polydextrose, as a commercial available preparation, is produced by the condensation of a melt which consists of approximately 89% D-glucose, 10% sorbitol and 1% citric acid on a weight basis (Colliopoulos et al., 1986). The average degree of polymerization (DP) of polydextrose is ~12 (weight average molecular weight of ~2000), although the range of molecular weight is 162 to about 20,000 (Craig et al., 1998; Aidoo et al., 2013). Polydextrose has been successfully incorporated into a wide range of foods including baked goods, beverages, confectionery and frozen desserts and is known to provide the bulk and appropriate textural and mouthfeel qualities which are usually associated with sugar and fat while lacking the sweet taste and caloric value connected with those conventional food ingredients (Lauridsen, 2004).

Inulin is a mixture of oligo- and polysaccharides, which are composed of fructose units connected by β-(2–1) links. The extensive use of inulin in the food industry is based on its nutritional and technological properties. Inulin is of interest for the development of healthy products because it simultaneously responds to a variety of consumer demands: it is fibre-enriched, prebiotic, low fat, and low sugar. As a dietary fibre, inulin passes through the digestive tract largely undigested. In the colon it acts as a prebiotic because it is selectively fermented by the beneficial flora, stimulates their growth, and reinforces its action against putrefactive microorganisms (Roberfroid et al., 1998). Inulin can be highly branched or linear depending on the source. The more branched the polymers, the more soluble they will become (up to 230 g in 100 g of water), but at the same time offering slightly less viscosity than the linear ones.

Inulin and polydextrose have often formed the basis for most researches for use as bulking agents in the production of sugar-free chocolates (Farzanmehr and Abbasi, 2009; Shah et al., 2010; Palazzo et al., 2011). Farzanmehr and Abbasi (2009) evaluated the effects of inulin, polydextrose and maltodextrin as bulking

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agents on rheological characteristics of prebiotic milk chocolate formulations and concluded that inulin and polydextrose can be used in various ratios and owing to their noticeable effects can improve chocolate properties even at very low ratios. Shah et al. (2010) replaced sucrose with inulin (HP, HPX and GR) with different degree of polymerization and polydextrose as bulking agents in the development of sugar-free milk chocolates and recommended inulin HP (high degree of polymerization) as suitable for sucrose free chocolate formulations. Palazzo et al. (2011) replaced sucrose with polydextrose and erythritol as bulking agents in new diet chocolate formulations. Findings from these previous researches show that substituting sucrose with these polymers as bulking agents could lead to production of low-calorie chocolate but, the influences of inulin and polydextrose on the rheology and functionality in dark chocolate manufacture has not been fully elucidated.

The simplex lattice mixture design is a useful tool for finding optimum levels of ingredients in product formulations and has been successfully used to identify the best combination of ingredients in many food processing applications (Rößle et al., 2011; Arcia et al., 2011; Farzanmehr and Abbasi, 2009). This work was therefore aimed at investigating the optimum conditions as well as influences of inulin and polydextrose mixtures as sucrose replacers on the rheological properties, microstructure and physical qualities during manufacture of sugar-free chocolate.

2. Materials and methods

2.1. Materials

2.1.1. Raw materials

Ghanaian cocoa liquor (containing 53.77% fat as cocoa butter) was obtained from Cargill Cocoa Processing Company, Accra, Ghana. Cocoa butter was obtained from Belcolade, Erembodegem, Belgium. Sucrose and soy lecithin were obtained from Barry Callebaut, Weize, Belgium. Polydextrose (Litesse Two) and inulin-HP were respectively obtained from Danisco, Holland and BENEO Orafti, Belgium.

2.1.2. Experimental design and sample preparation

Chocolate samples were prepared according to ingredients (Table 1) formulated from the design matrix (Table 2). The ingredients were weighed and mixed in Vema mixer (Vema BM 30/20, Vemaconstruct, NV Machinery Verhoest, Izegem Belgium). The mixed ingredients were refined using a 3-roll refiner (Exakt SOS Apperatebau GmbH & Co. KG, Norderstedt, Germany) to 28–30 μm. Seven hundred (700) grams of refined chocolate was placed in a Stephan Mixer (STEPHAN Food Service Equipment GmbH, Hameln, Deutschland) and dry conched at 65 °C for 10 min. Lecithin and cocoa butter were added after dry conching and this was followed by wet conching at 50 °C for 15 min. The resulting molten chocolate obtained was kept in sealed plastic containers at ambient temperature (20–22 °C) for further analysis. A reference chocolate sample was prepared using sucrose.

Samples for hardness measurements were incubated at 52 °C for 4 h for melting prior to tempering. The molten chocolate was tempered using a Selmi One Continuous Chocolate temper machine (SelmiSrl, Santa Vittoria d'Alba (CN), Italy) and precrystallisation was measured using Aasted Makrovert Chocometer (Aasted-Makrovert Aps, Farum, Denmark) to ensure the chocolate has temper value (slope) of 0 ± 0.25 Temper Unit (TU). The tempered chocolate was then moulded using plastic moulds of dimension 102 mm length, 23 mm breadth, and 8 mm height, and allowed to cool in a refrigerator (11 °C) for 1 h before de-moulding. The moulded finished chocolates were packed onto plastic trays and conditioned at ambient temperature (20 ± 2 °C) for 2 weeks before analyzed.

Table 1
Formulations used in dark chocolate formulation.

Material	Composition (%)
Cocoa mass	40
Cocoa butter	11.6
Inulin	0–48 (Table 2)
Polydextrose	0–48 (Table 2)
Lecithin	0.4

Table 2
Experimental design of two components in dark chocolate formulation.

Formulation	Inulin (%)	Polydextrose (%)
1	25	75
2	50	50
3	75	25
4	100	0
5	0	100
6	50	50
7	100	0
8	25	75
9	75	25
10	0	100
11	0	0
12	0	0

2.2. Analytical methods

2.2.1. Rheological properties

Rheological properties of the molten chocolates were studied using an AR2000ex stress-controlled rheometer (TA Instruments, New Castle, Delaware, USA) with concentric cylinder system (cup and bob). Chocolates samples were prepared by heating in an oven at 52 °C for an hour for melting. Approximately 20 g of molten chocolate samples were weighed into the cup and measurements were performed using the ICA (2000) official method for chocolate. Samples were pre-sheared at 5 s^{-1} at 40 °C before starting the measurement cycle. Shear stress was measured as a function of increasing shear rate from 2 s^{-1} to 50 s^{-1} (ramp up), holding at 50 s^{-1} for 60 s, then decreasing from 50 s^{-1} to 2 s^{-1} (ramp down). The data were fitted to the Casson model and the Casson yield stress and Casson viscosity were deduced from the results. Mean values from 3 replicate measurements and standard deviations were calculated.

2.2.2. Moisture

The Karl-Fisher titration method (ICA 26, 1988) was used to determine moisture content of samples. Chocolate samples were heated for at least an hour in an oven at 60 °C to melt before measurements were conducted. Mean values from 3 replicate measurements and standard deviations were calculated.

2.2.3. Particle size distribution (PSD)

The particle sizes were measured using a Malvern MasterSizer equipped with a 300 RF lens to measure particles in a range of 0.05–900 μm. Approximately 0.5 g of molten chocolate was mixed with 10 ml of isopropanol and placed in an oven at 60 °C for approximately 1 h shaking vigorously to aid dissolution. Drops of the dissolved chocolate was dispersed in isopropanol at ambient temperature (20 ± 2 °C) until an obscuration greater than 10 was obtained. The sample was continually shaken during measurement to ensure particles were independently dispersed. Size distribution was quantified as the relative volume of particles in size bands presented as size distribution curves. Mean values of the largest