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Mixture design applied for the partial replacement of fat with fibre in sucrose-free chocolates

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ABSTRACT

Chocolate is a food gender with very specific rheological and sensory characteristics, which poses a challenge to the development of functional formulations due to the impact that the addition of various ingredients have on the product. The goal of this study was to develop sucrose-free chocolate formulations employing a mixture design to add fibres as partial substitutes for cocoa butter. The effects of the combination of different contents of inulin, β-glucan concentrate and cocoa butter on Casson plastic viscosity, Casson shear stress and the sensory characteristics of chocolate were investigated. An increase from 0 to 10 g/100 g chocolate in the inulin and the β-glucan concentrate contents, with the corresponding reduction in the amount of cocoa butter made the final product more viscous and more resistant to flow. The effects were more pronounced for β-glucan. The substitution of up to 50% of the formulation cocoa butter resulted in products with good acceptance. The least accepted product, with a mean score of 6.4 in a scale from 0 to 10 had the maximum concentration of β-glucan (10 g/100 g). The descriptive analysis of the Flash profile of this sample characterized it as more adherent and adhesive, with a non-characteristic chocolate taste.

1. Introduction

The unique taste and texture of chocolate result mainly from the combination of cocoa solids, sugar and cocoa butter. The high caloric value of traditional formulations leads consumers who seek a more balanced diet to avoid it. The first modification of chocolate recipes for nutritional ends was the elimination of sucrose. At present, the sucrose-free chocolate market is not restricted to diabetic patients anymore.

The efforts to control weight and maintain health have led conscious consumers to seek eating solutions to reduce the risk of diseases (Lim, Inglett, & Lee, 2010). Reducing the fat content in the diet may reduce the energy intake and contribute to the prevention of obesity. This is even more important in foods that are not part of the basic diet, including indulgent foods, such as chocolate (Norton, Fryer, & Parkinson, 2012).

Sucrose-free chocolates can be successfully produced. Researchers have characterized the rheological behavior and the texture of sucrose-free chocolate (Shah, Jones, & Vasiljevic, 2010; Vissotto, Gomes, & Batista, 2005) and investigated the influence of different body agents on the rheological and/or sensory characteristics of chocolate without saccharose and with reduction in calories (Gomes, Vissotto, Fadini, Faria, & Luiz, 2007; Melo, Bolini, & Efraim, 2009).

The extensive use of inulin in the food industry is based on its nutritional and technological properties (Aidoo, Afoakwa, & Dewettinck, 2014). Because it is fermented by bifidobacteria in the colon, inulin has a prebiotic effect on the organism (Bemiller & Huber, 2007). It plays the function of dietary fibres and may substitute fats and sugars without affecting the texture of foods, leading to products with a more balanced nutritional composition (Frank, 2002). Its use as a body agent in sucrose-free chocolates was studied by some researchers, which reported its effects in rheological, physical (Aidoo et al., 2014; Gomes et al., 2007; Shah et al., 2010), and sensory properties (Gomes et al., 2007; Shah et al., 2010) of chocolates.

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β-glucan efficaciously reduces the level of cholesterol, contributing to the control of blood glucose and reducing the risk of colon cancer (Lim et al., 2010). As it is a high-molecular weight polymer, it is used in the food industry due to its high capacity to retain water and for its thickening, jellifying and emulsifying properties (Lee, Warner, & Inglett, 2005). Lee, Biresaw, Kinney, and Inglett (2009) used a 30 g/100 g β-glucan concentrate in chocolates as a partial substitute of cocoa butter and found that for over 10 g/100 g substitution the viscosity of chocolates increased and yielded too soft products, decreasing hardness from 40 to 28 N. However, the samples were not submitted to sensory evaluation and no conclusion can be drawn on their acceptance.

Although inulin is recognized as efficient fat replacer for use in chocolate, its association with β-glucan could constitute a way to obtain similar calorie reduction carrying fibres with different functional action. The objective of this study was to develop sucrose-free chocolate formulations containing β-glucan concentrate and inulin as partial substitutes of cocoa butter using a constrained mixture design. The impact of these ingredients on the rheological and sensory characteristics and acceptance of the product was evaluated.

2. Material and methods

2.1. Material

The ingredients used to prepare the formulations were: cocoa liquor (Barry Callebaut, Extrema, BR); cocoa butter (Barry Callebaut, Ilhéus, BR); skimmed milk powder (Tangará Foods, Vila Velha, BR); extra fine sugar (Glaçúcar, União, Piedade, BR); maltitol (ECIL Ingredientes, São Paulo, BR); stevia high intensity edulcorant (Enliten™, Corn Products, Mogi Guaçu, BR); soy lecithin (Solae do Brasil Ltda, Barueri, BR); polyglycerol polyricinoleate – PGPR (Danisco Brasil Ltda, Pirapozinho, BR); inulin (Orafti® GR, Beneo, Oreye, BE); and β-glucan concentrate (Barley Balance™, PolyCell Technologies, Crookston, USA, with 38 g/100 g dietary fibre, being 27 g/100 g β-glucan and 11 g/100 g insoluble fibre).

2.2. Experimental design

Simplex-centroid design was used with a three-component mixture, with lower and upper limit restrictions and central points (Statistica, 2011). The studied variables were: inulin (0–50 g/100 g), β-glucan concentrate (0–50 g/100 g) and cocoa butter (50–100 g/100 g). The ternary mixture component ratios (actual concentrations and as pseudocomponents) are given in Table 1.

The levels of variation of each component were determined in preliminary tests. In the conching stage of the chocolate production, we observed that the cocoa butter reduction had to be limited to 50 g/100 g so that the mixture of all chocolate ingredients could be processed. Therefore, so were the maximum limits of each of the two other components (50 g/100 g). The design consisted of eight formulations, one being a repetition of the central point in order to verify the standardization of the process by calculation of the experimental error. The samples were identified by the letters CB, IN or BG representing cocoa butter, inulin or β-glucan, respectively, followed by numbers showing the concentration of the added fibre in the chocolate formulation, as is showed in Table 2. In all formulations, the sucrose used in traditional chocolate was replaced with the same concentration (34 g/100 g) of a mixture of maltitol with 0.04 g/100 g (of the total formulation weight) of high intensity edulcorant. These amounts and those of the other ingredients, cocoa liquor (30 g/100 g), milk powder (15.5 g/100 g), lecithin (0.3 g/100 g), and PGPR (0.2 g/100 g), were kept constant. A standard formulation produced with sucrose and without fibre addition was included in the experiment for external control and comparison with the sugar-free chocolate formulations.

Table 1
Experimental design for ternary mixtures of inulin, β-glucan concentrate and cocoa butter in real proportions and in pseudocomponents.

Formulation	Component proportions in the ternary mixture					
	Real concentrations (g/100 g)			Pseudocomponents[a]		
	Inulin	β-glucan concentrate	Cocoa butter	Inulin (X_1)	β-glucan concentrate (X_2)	Cocoa butter (X_3)
CB	0.0	0.0	100.0	0.000	0.000	1.000
IN10	50.0	0.0	50.0	1.000	0.000	0.000
BG10	0.0	50.0	50.0	0.000	1.000	0.000
BG5	0.0	25.0	75.0	0.000	0.500	0.500
IN5	25.0	0.0	75.0	0.500	0.000	0.500
BG5 + IN5	25.0	25.0	50.0	0.500	0.500	0.000
BG3.2 + IN3.2	16.6	16.6	66.8	0.333	0.333	0.333
BG3.2 + IN3.2	16.6	16.6	66.8	0.333	0.333	0.333

CB = cocoa butter IN = inulin BG = β-glucan. The numbers in the samples codes represent the concentration of the added fibre in the chocolate formulation.
[a] Calculated with equations: $X_1 = (C_{inulin} - 0.00)/0.50$; $X_2 = (C_{\beta\text{-glucan}} - 0.00)/0.50$, $X_3 = (C_{CB} - 0.50)/00.5$.

2.3. Chocolate production

Cocoa liquor was mixed to the powder ingredients of each formulation (milk powder, sucrose, maltitol + edulcorant, inulin and β-glucan concentrate) and with 2/3 of the corresponding cocoa butter in a planetary mixer (PPA-P, Inco S. A., Avaré, BR) at 40 °C for 10 min.

Grinding to 17–23 μm particle size was carried out in a three-cylinder pilot mill (Draiswerke GmbH, Mannhein, D). Particle size was determined with a digital micrometer (Mitutoyo Sul Americana Ltda, Suzano, BR).

Conching was performed in a planetary mixer at 60 °C for 14 h. The emulsifiers and the remaining cocoa butter were incorporated in the beginning of this stage.

Traditional tempering on a marble surface at 18 °C was performed. The initial mass temperature was 50 °C and the mass was frequently revolved with spatulas for a fast heat exchange until the temperature fell to 27 °C. Next, the process efficiency was assessed with a tempermeter (E5, Sollich, Bad Salzuflen, D) and then, the chocolate was kept in a double boiler at 30 °C so that any unstable crystals melted and the product remained at the ideal molding temperature.

The tempered mass was molded in acetate molds (2.3 × 2.8 × 1.5 cm) forming round 10 g pieces for sensory evaluation and bars in rectangular polyethylene molds (8.5 × 2.5 × 0.7 cm) for

Table 2
Proportions (g/100 g) of ingredients in chocolate formulations. Cocoa liquor, skim milk powder, soy lecithin and PGPR were constant.

Formulation[a]	Sucrose	Maltitol + edulcorant	Cocoa butter	β-glucan concentrate	Inulin
CB	–	34	20	–	–
IN10	–	34	10	–	10
BG10	–	34	10	10	–
BG5	–	34	15	5	–
IN5	–	34	15	–	5
BG5 + IN5	–	34	10	5	5
BG3.2 + IN3.2	–	34	13.6	3.2	3.2
BG3.2 + IN3.2	–	34	13.6	3.2	3.2
Control	34	–	20	–	–

[a] CB = cocoa butter IN = inulin BG = β-glucan. The numbers in the samples codes represent the concentration of the added fibre in the chocolate formulation.

Table 3
Nutritional values of the formulations for 100 g of chocolate.

	Caloric value (kcal)	Carbohydrates (g)	Proteins (g)	Total fats (g)	Saturated fat (g)	Dietary fibre (g)	Inulin (g)	β-glucan (g)	Sodium (mg)
CB	480	25.2	8.0	29.2	4.3	3.7	–	–	84
IN10	404	35.6	8.0	19.2	2.8	13.7	10.0	–	84
BG10	424	49.2	9.6	19.2	2.8	7.7	–	3.0	84
BG5	452	37.2	8.8	24.0	3.5	5.7	–	1.3	84
IN5	440	30.2	8.0	24.0	3.5	8.7	5.0	–	84
BG5 + IN5	416	42.4	8.8	18.0	2.8	10.7	5.0	1.3	84
BG3.2 + IN3.2	432	36.4	8.0	22.0	3.3	8.1	3.2	0.9	84
Control	544	59.2	8.0	29.2	4.3	3.7	–	–	84

CB = cocoa butter IN = inulin BG = β-glucan. The numbers in the samples codes represent the concentration of the added fibre in the chocolate formulation.

rheological tests. The molds were agitated on a vibrating table (JAF Inox, Tambaú, BR) for the removal of air bubbles and placed in a cooling tunnel (Siaht, Jundiaí, BR) programmed for temperature variation every 11 min up to 11 °C until the product solidified.

The chocolate pieces were demolded and wrapped with aluminum foil and kept at 20 °C for 5 days for instrumental analysis and for 60 days for sensory evaluation.

2.4. Composition and caloric value estimation

The formulation compositions were theoretically estimated using nutritional data provided by the ingredient and additive makers. The caloric value was calculated using the factors 4 kcal/g for carbohydrates and 9 kcal/g for total fats. For maltitol and stevioside, the factor 2.4 kcal/g was used, and for inulin, 1 kcal/g (ANVISA, 2005; EC, 1990).

2.5. Rheological properties

The samples were melted in glass jars with lids in an oven at 45 °C.A programmable rheometer (RVDVIII, Brookfield Engineering Lab. Inc., Stoughton, USA) with an adapter for small samples and a spindle (S15) was used. A thermostatic bath (TC-150, Brookfield Engineering Lab. Inc., Stoughton, USA) was coupled to the adaptor to keep the product temperature constant at 40 °C. The spindle rotation velocity range (5–100 rpm), established by Vissotto et al. (1999), was used in assays of 3 s^{-1} to 240 s^{-1}, totaling 11 measurement points of shear rate (γ) and shear stress (τ). The flow curve obtained in this procedure was adjusted to the Casson mathematical model (Eq. (1)), considering the configuration of the used viscosimeter as recommended by Beckett (2009).

$$\sqrt{\tau_{ca}} = \sqrt{\tau_0} + \sqrt{\eta_{ca}} \cdot \sqrt{\gamma} \quad (1)$$

where: τ_{ca} is Casson shear stress, τ_o is yield stress and η_{ca} is Casson plastic viscosity.

2.6. Sensory characterization and acceptance

The tests were conducted in individual cabinets illuminated with white light. The chocolate pieces were unwrapped and served at room temperature (20–24 °C) on three-digit numbered plastic plates. Mineral water at room temperature and diced peeled apple were served between sample servings.

The acceptance test was carried out with 59 panelists, 18 male and 41 female, a number higher than the 52 recommended by Hough et al. (2006) for these assessment conditions. The panelists were aged between 18 and 40 years old, had undergraduate or graduate education (92%) and 79% of them consumed chocolate daily or weekly. An 11-point hybrid hedonic scale with verbal terms for the extremes, 0, strongly disliked, and 10, strongly liked, was used (Villanueva, Petenate, & Silva, 2005). Eight samples were presented for evaluation in two sessions to avoid panelist sensory fatigue.

In the descriptive test, the Flash Profile technique (Dairou & Sieffermann, 2002) was applied individually to 18 panelists, 2 male and 16 female, in a single session following the procedure described by Terhaag and Benassi (2010). This number of panelists is greater than those reported for the same method with jams (Dairou & Sieffermann, 2002) and milk derivatives (Delarue & Sieffermann, 2004). Formulations BC (without fibres), IN10 (maximum replacement of BC with inulin) and BG10 (maximum replacement of BC with β-glucan) (Table 2), were chosen to this test due to their differences in composition and their implications for acceptance and rheological characteristics (Table 4). The samples were presented simultaneously and the panelists were asked to report the perceived similarities and differences. Next, sample evaluation cards and the panelist list of definitions of attributes were prepared. The samples were simultaneously presented again and the panelist ranked the samples in increasing order of intensity of attributes.

Table 4
Rheological properties and acceptance of chocolate formulations.

Formulation	Inulin[a]	β-glucan concentrate[a]	Cocoa butter[a]	Casson plastic viscosity (Pa s)[b]	Casson shear stress (Pa)[b]	Sensory acceptance[b,c]
CB	0.0	0.0	20.0	2.19 ± 0.04	0.26 ± 0.20	7.97 ± 1.11
IN10	10.0	0.0	10.0	6.30 ± 0.07	4.26 ± 0.33	7.74 ± 1.44
BG10	0.0	10.0	10.0	11.58 ± 1.72	22.92 ± 3.99	6.44 ± 2.03
BG5	0.0	5.0	15.0	4.33 ± 0.05	1.44 ± 0.02	7.54 ± 1.55
IN5	5.0	0.0	15.0	2.89 ± 0.11	0.29 ± 0.32	8.16 ± 1.43
BG5 + IN5	5.0	5.0	10.0	9.55 ± 0.23	11.40 ± 0.55	7.14 ± 1.67
BG3.2 + IN3.2	3.2	3.2	13.6	5.65 ± 0.05	0.68 ± 0.03	8.11 ± 1.11
BG3.2 + IN3.2	3.2	3.2	13.6	5.47 ± 0.03	0.60 ± 0.04	–
Control	0.0	0.0	20.0	3.32 ± 0.11	1.44 ± 0.84	8.29 ± 1.03

CB = cocoa butter IN = inulin BG = β-glucan. The numbers in the samples samples codes represent the concentration of the added fibre in the chocolate formulation.
[a] Contents in chocolate formulation (g/100 g).
[b] Mean ± standard deviation of replicates ($n = 3$).
[c] 0 = strongly disliked until 10 = strongly liked.

2.7. Statistical analysis

Mathematical models based on Scheffé's canonic model were fitted to the rheological and sensory acceptance results. Analysis of variance (ANOVA) at 5% significance level (F test) was performed to find the adjusted determination coefficient (adjusted R^2). To study the significance of individual effects on the variable response, the independent variables were adjusted to a 5% significance level ($p \leq 0.05$). Data analysis and graph plotting were performed using software Statistica version 10.0 (Statistica, 2011).

The descriptive sensory results were submitted to Generalized Procrustes Analysis using the Senstools Version 2.3.28 software (OP & P Product Research, 1998).

3. Results and discussion

3.1. Composition and caloric value estimation

Table 3 gives the estimated composition and caloric value of the sucrose-free and control chocolate formulations.

The Control formulation had composition and caloric value (544 kcal/100 g) similar to that of commercial milk chocolate. Similar caloric values (ranging from 540 to 574 kcal/100 g) were reported by Gomes et al. (2007) and Shah et al. (2010), which demonstrates that the basic formulation used is similar to commercial formulations.

Brazilian legislation allows the use of the term light for food with a reduction of at least 25% in the caloric value, sugar or fat contents (Brasil, 1998). In Europe, the minimum reduction is 30% (EC, 2006). The American regulations do not set a minimum percent reduction for food to be considered light, as long as the nutrient percent reduction in relation to the reference food is informed (FDA, 2009).

The sucrose-free formulations that we developed had caloric reductions of 12–26% in relation to the control. Formulation IN10 had the greatest reduction (26%), which makes it "light" in calories both in Brazil and in the United States, but not in the European Union.

The total fat reduction varied from 18 to 38%, with formulations IN10 and BG10 having a reduction of 34% and formulation BG + IN5 of 38%, being light for fats in Brazil, in the United States and in the European Union. These formulations had the lowest cocoa butter content and consequently, lowest total fats as well.

Formulations Control, and BG5 can be classified as fibre sources (content ≥ 3.0 g fibre/100 g of solid food) and formulations IN10, BG10, IN5, BG + IN5 and BG + IN3,2, as high fibre (content ≥ 6.0 g fibre/100 g solid food), pursuant to the Brazilian, American and European regulations (Brasil, 1998; EC, 2006; FDA, 2009).

Brazilian and American legislations allow the use of functional and health claims on the labels of food products that are sources of dietary fibres. Brazilian legislation also allows specific claims for inulin, fructooligosaccharides, β-glucan and lactulose, and in the United States, for β-glucan (Brasil, 2005; FDA, 2009).

In agreement with these legislations, formulations IN10, IN5, BG + IN5 and BGIN3,2 may be claimed to be healthy because of the use of inulin, with only formulation BG0 containing the required amount of β-glucan. The reason is that while inulin can be added as a pure ingredient, β-glucan corresponded only to 27.5% of the added concentrate. Improvement in the purification of β-glucan is essential for its use as an ingredient with lesser interference of the other formulation components.

3.2. Rheological properties

The rheological parameters studied, Casson plastic viscosity (η_{ca}) and Casson shear stress (τ_{ca}), are given in Table 4.

Plastic viscosity is defined as the amount of energy necessary to maintain a non-Newtonian fluid in movement, while the shear stress is the energy required to start flow, and is related to the interparticle interaction forces at rest (Afoakwa, Paterson, & Fowler, 2007).

Formulation BC, which differs from Control only in the substitution of sucrose with maltitol (Table 2), had lower η_{ca} and τ_{ca} than Control. Konar (2013) found that this substitution decreased the viscosity because maltitol is less crystalline. Crystallization is more effective and increases the interparticle forces in chocolate containing sucrose, which requires a greater force to maintain the flow, thus a greater τ_{ca}.

Plastic viscosity (η_{ca}) ranged from 2.19 to 11.58 Pa s and the shear stress (τ_{ca}) from 0.26 to 22.92 Pa, which agrees with the standards for traditional chocolate (1–20 Pa s and 0.5–20 Pa, respectively) proposed by Chevalley (1974).

These values are also similar to those found by Aidoo et al. (2014), Konar (2013), Gomes et al. (2007), Vissotto et al. (2005) in sucrose-free chocolate formulations ranging η_{ca} from 1.68 to 17.08 Pa s and τ_{ca} from 0,05–5.98 Pa.

The models fitted to the rheological properties are given in Table 5. The models were significant, had an adjusted $R^2 \geq 93\%$ and non-significant lack of fit, indicating their good predictive power. The analysis of variance of the polynomial regressions showed that inulin and β-glucan concentrate contributed significantly to the plastic viscosity model, while inulin and the β-glucan-cocoa butter interaction affected the shear stress.

The increase in the inulin content led to a significant increase in plastic viscosity (Fig. 1a). In a study that investigates sucrose substitution with inulin and polydextrose in chocolate, Aidoo et al. (2014) achieved the highest Casson viscosity by completely substituting sucrose with inulin. Shah et al. (2010), which measured chocolate viscosity at 55, 30, 27 and 12 °C, remarked that the chains formed by inulin might affect crystallization and the aggregation of chocolate particles and increase viscosity.

The concentration of β-glucan affected the two rheological parameters significantly. Its increase raised the viscosity and the shear stress (Fig. 1). Its low density (260 g/L) in relation to inulin (580 g/L) requires the addition of a larger volume for obtaining the same formulation proportion (w/w). A greater amount of β-glucan means more solid particles and a greater contact surface. It is important to point out that molding and removing air bubbles from formulation BG10 were difficult due to its high concentration of β-glucan (10 g/100 g). The solid particle content was over the standards proposed by Chevalley (1974), indicating that the amount of cocoa butter used was not sufficient to cover the solid particles and made

Table 5
Coefficients and analysis of variance of the models adjusted to the rheological parameters and sensory acceptance.

Coefficients[a]	Casson plastic viscosity (Pa s)*	Casson shear stress (Pa)*	Sensory acceptance
β_1	6.272*	2.517	7.779*
β_2	11.552*	22.153*	6.479*
β_3	2.162	−0.418	7.935*
β_{12}	2.980	–	–
β_{13}	−4.879	–	1.757
β_{23}	−9.679	−42.483*	1.877
Significance of the model (p)	0.0001	0.0001	0.0001
Lack of fit of the model	0.096	0.720	0.068
Adjusted R^2	0.992	0.934	0.821

*Significant at the level of $p < 0.05$, in the Tukey test.

[a] β_1, β_2, β_3 correspond to the effects of inulin, β-glucan concentrate and cocoa butter, respectively, in the model $y = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3$.

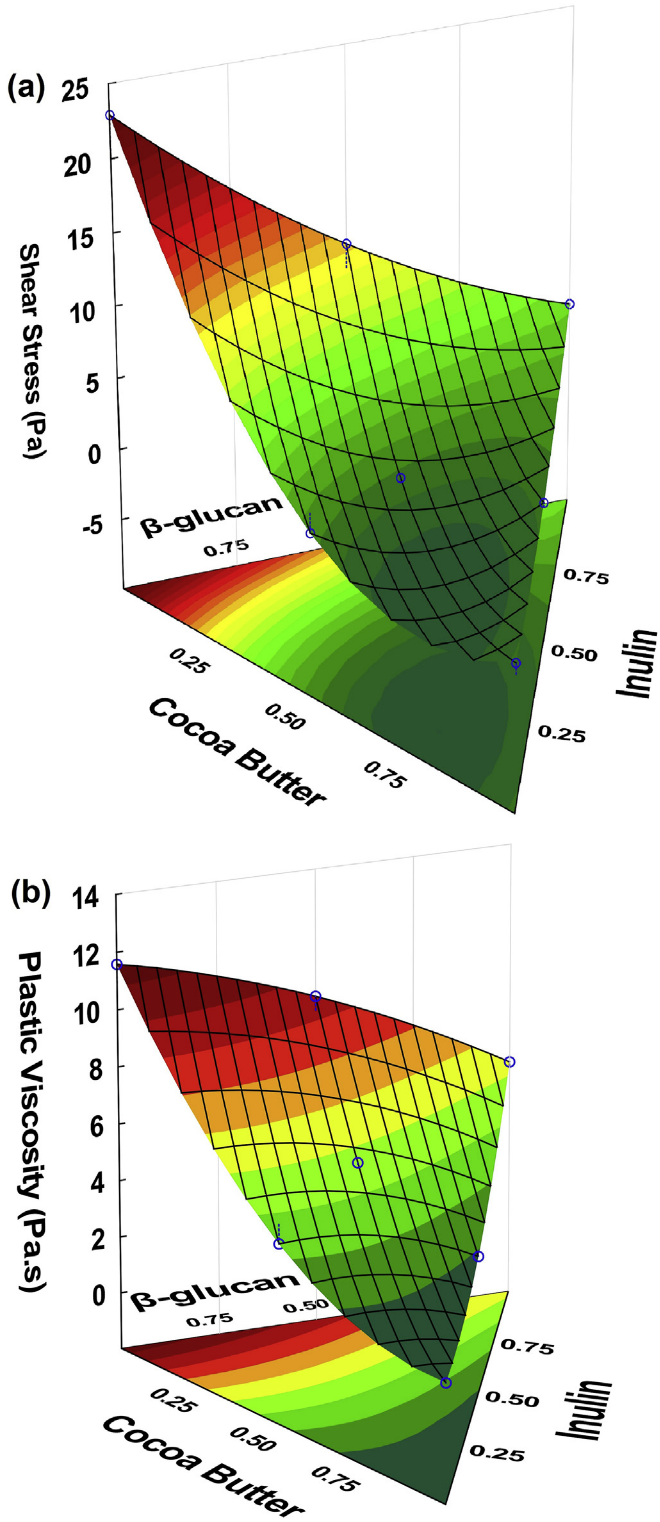

Fig. 1. Adjusted surfaces for the studied rheological properties (a) Casson shear stress and (b) Casson plastic viscosity of mixtures containing inulin, β-glucan concentrate and cocoa butter expressed as pseudocomponents. The experimental area is delimitated by the shown sample points.

processing slower and more difficult. We must also remark that the concentrate that we used contained other compounds besides β-glucan, such as carbohydrates (32 g/100 g) and proteins (17 g/100 g) which may have affected processing negatively.

Lee et al. (2009) also reported an increase in plastic viscosity and shear stress of chocolate formulations starting at 10% substitution of β-glucan concentrate with cocoa butter.

The most important effect on the shear stress was the antagonistic interaction between β-glucan and cocoa butter. The increase in the shear stress with the increase in substitution of cocoa butter with β-glucan concentrate in formulations can also be attributed to the increase of solid particles in the product, as previously mentioned. Cocoa butter has an opposite effect; with the increase in the lipid phase of chocolate, the solid particles become more dispersed, which reduces the flow resistance and the interference in the crystallization process (Ziegler & Hogg, 2009).

3.3. Sensory characterization and acceptance

The mean acceptance scores ranged from 6.44 to 8.16 (Table 4). It is worth pointing out that all formulations received a score of 6 or higher in a scale from 0 to 10 and were considered accepted.

The mathematical model adjusted to the acceptance results is shown in Table 5. One can notice a significant contribution from the three independent variables.

The increase in the cocoa butter content improved the sensory acceptance (Fig. 2). This correlation is largely accepted in the production of chocolates, as cocoa butter determines the rheological properties, contributing to appropriate hardness, mouthfeel and deglutition (Beckett, 2009).

The increase of inulin content in the chocolate formulation up to 5 g/100 g (pseudocomponent values 0.5 for inulin, 0.5 for cocoa butter and 0.0 for β-glucan, Fig. 2) enhanced acceptance. Therefore, the chocolate containing 5 g/100 g inulin replacing the same amount of cocoa butter obtained the highest acceptance (8.4), similar to those of Control formulation (without fibres and with sucrose) (Table 2).

Gomes et al. (2007) and Shah et al. (2010) observed that the addition of inulin results in good acceptance of sucrose-free

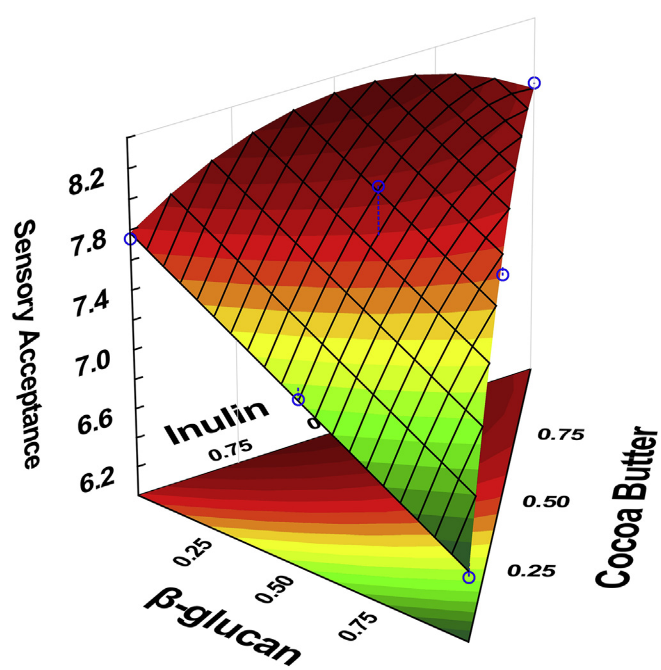

Fig. 2. Adjusted surface for sensory acceptance (hedonic scale from 0 = strongly disliked to 10 = strongly liked) of chocolates containing inulin, β-glucan concentrate and cocoa butter expressed as pseudocomponents. The experimental area is delimitated by the shown sample points.

chocolates. This may be related to a weaker effect of the addition of inulin when compared to those of the reduction in the cocoa butter content and the increase in β-glucan concentrate content, which decreased acceptance (Fig. 2).

The sensory impact of the addition of β-glucan concentrate has not been reported in the literature so far. However, the increase in the rheological parameters analyzed in this study correlated with the lower acceptance. Very viscous chocolate has an altered chewing melting rate, which affects the action of the taste receptors and decreases the sensory acceptance (Beckett, 2009).

Formulations CB, IN10 and CB10 were selected for descriptive analysis due to their differences in compositions and their implications for acceptance and rheological characteristics (Table 4).

In the consensus configuration of the samples (Fig. 3), the total explained variance was 89%.The first dimension (D1) was responsible for 64% of the variance and was associated mainly with characteristics of chocolate and texture attributes (Fig. 3, Table 1S). A positive correlation was observed with the attributes chocolate flavor and sweet taste and a negative correlation with bitter taste, bitter aftertaste, non-characteristic flavor of chocolate, oat/flour flavor and aftertaste. As to the texture attributes, D1 correlated positively with softness and melting and negatively with adherence, adhesiveness and hardness.

The second dimension (D2) explained 25% of the variance and correlated negatively with brown color.

Formulation CB, without the addition of fibres, and which had the greatest acceptance among the three samples compared in this test (Table 4), was placed in a high right position in the graph. It can be described as having the most intense aroma, flavor and texture attributes characteristic of chocolate (chocolate aroma, chocolate flavor, sweet taste, chocolate aftertaste, softness and melting) and more intense brown color (Fig. 3, Table 1S).

Formulation IN10, with 10 g/100 g inulin and intermediate acceptance (Table 4), was placed in the lower right quadrant, being characterized by lower intensity of characteristic chocolate attributes in relation to Formulation 1, and was characterized by its difference in dimension 2, with a bitter taste and less intense brown color attribute (Fig. 3, Table 1S).

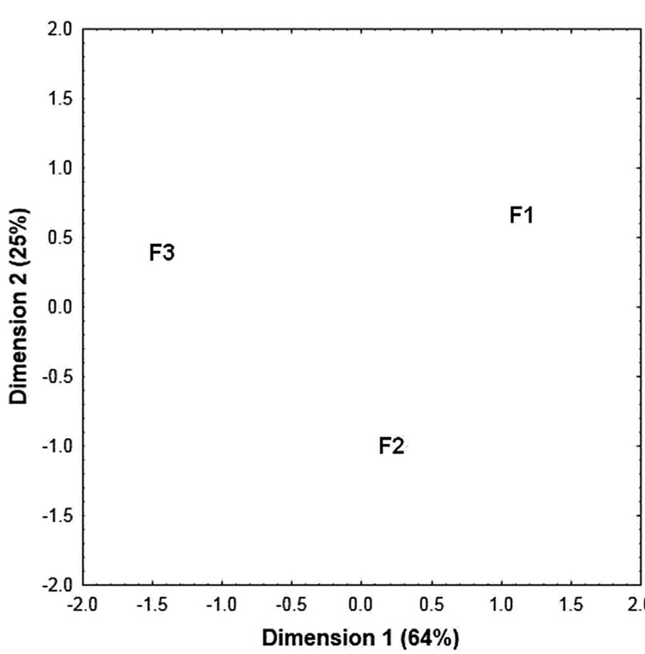

Fig. 3. Consensus configuration for descriptive sensory analysis of formulations (CB, IN10 and BG10) for dimensions D1 and D2.

Formulation BG10, with 10 g/100 g β-glucan concentrate and smaller acceptance (Table 4), was placed in the upper left quadrant and was described as having more intense non-characteristic chocolate attributes, such as bitter taste, non-characteristic chocolate flavor, oat/flour flavor, bitter aftertaste, oat/flour aftertaste, adherence and adhesivity (Fig. 3, Table 1S).

The association of sensory results (descriptive and acceptance) and rheological characteristics showed that the addition of 10 g/100 g β-glucan concentrate produces major changes in chocolate sensory characteristics, with a negative impact on its acceptance.

4. Conclusions

Formulations of sucrose-free chocolates with up to 50 g/100 g substitution of cocoa butter with inulin and/or β-glucan concentrate promoting a substantial reduction in calories contents (17–26%) were successfully produced. Some of them may make health claims associated with the inulin or β-glucan contents.

The substitution of 25 g/100 g of the total weigh of cocoa butter with an equal amount of inulin resulted in a dietetic chocolate (sucrose-free) with acceptance similar to that of standard chocolate (with sucrose).

The maximum β-glucan concentrate content tested (10 g/100 g of chocolate) had a negative impact on the rheological and sensory characteristics, with adhesivity and stronger non-characteristic chocolate flavor parameters. These attributes were responsible for a lower acceptance in relation to other formulations (average score lower than 7, on a scale from 0 to 10).

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.lwt.2014.08.047.

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