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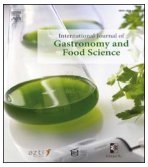

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The combined effects of Stevia and sucralose as sugar substitute and inulin as fat mimetic on the physicochemical properties of sugar-free reduced-fat dairy dessert

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Abstract

The aim of this study was to examine the influence of Stevia (St) and sucralose (Su) as a sugar substitute and inulin as a fat mimetic on starch-based model dairy desserts on it's physicochemical properties, since the substitution of sucrose (S) and fats modifies their sensory and textural properties. A mixed experimental design was used to study the effects of single, binary and tertiary combinations of sucralose and Stevia on the dessert properties. Our results suggest that sugar can be replaced by the combination of Stevia and sucralose and that fat can be partially replaced by inulin to improve the properties of the final product. Results showed that the flow behavior and viscoelastic parameters varied among samples, obtaining the highest values of viscosity and consistency factor (K) for the samples 100%St and 50%St+50%Su. The combination of 50% St+50%Su presented the highest sensorial acceptability, and there was no statistically significant difference with the control 100%S ($P > 0.05$). The addition of inulin to the fat-reduced dessert sweetened with the combination of 50%St+50%Su decreased the syneresis, and as a consequence, stability increased. The syneresis of this sample kept a constant value during storage and it was significantly lower than the control sample, 100%S ($P < 0.05$). The samples with inulin presented an increase in the consistency, confirming the effect of the polysaccharide as fat replacer. The sensory analysis showed a higher acceptability of the sample 50%St+50%Su+2.5%I compared to a reduced fat commercial sample. In this work, we have developed a formulation with sugar-free and reduced-fat content sweetened with combinations of St and Su using inulin as a fat substitute, with improved sensory and physical properties.

Keywords: Sugar-free dairy dessert; Reduced fat dairy dessert; Stevia; Inulin; Texture

Introduction

Nowadays the demand for low-calorie products increases for many different reasons, such as nutrition, health, and weight control. Accordingly, there is an increasing interest for the development of food formulations for diseases such as diabetes or nutrition-associated diseases caused by an excessive energy intake, or by a dietary-fiber intake below recommendation (Mohamed et al., 2006; Zahn et al., 2013). Dairy desserts are high calorie products with high fat and sucrose contents and are the most common used dairy products worldwide. Sucrose has a high glycemic index and for this reason diabetic people should not consume large quantities of typical dairy desserts and need appropriates sucrose substitutes (Martínez-Cervera et al., 2014). The sweeteners used as sugar substitutes must mimic the sensory and functional properties of sucrose with no aftertaste or non-sweet side tastes. In addition, they must be chemically stable, nontoxic, and economically feasible. Commercially available sweeteners do not combine all these characteristics. However, these limitations of individual sweeteners can be overcome by using them in blends. Sweetener blends provide flavor profiles that are more similar to sucrose taste. The attributes of off-flavor, bitter, or sweet after-taste are

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minimized in a blend of two or more sweeteners (Porto Cardoso and Andre Bolini, 2007). The sugar replacement in starch-based dessert formulations generates a negative effect due to syneresis increase. Carrageenan is a hydrocolloid with affinity for calcium-rich casein, which can be used to prevent syneresis in starch-based desserts formulated without sugar (Iop et al., 1999).

Stevia is used as a dietary supplement and low-calorie sweetener. The major sweetener components of the Stevia leaves are Stevioside, Rebaudioside A, Rebaudioside C and Dulcoside A, which are 200–300 times sweeter than sucrose (Erkucuk et al., 2009). Stevia has been used as a sweetener in dairy products such as yogurt and ice cream (Guggisberg et al., 2011; Ozdemir et al., 2015; Pon et al., 2015). Another interesting sweetener used as a sugar substitute is Sucralose. Sucralose is an artificial sweetener, has a taste profile very similar to sugar, and has no unpleasant aftertaste, an undesirable trait found in many other sweeteners. Sucralose is a highly intense sweetener that is 600 times sweeter than sugar (Shankar et al., 2013). Sucralose and Stevia are promising alternatives as sweeteners in dairy desserts manufacture, as they are stable and able to retain its sweetness when subject to high heat and acidity. These sweeteners are safe for diabetic patients because do not raise blood sugar levels and insulin resistance (Shankar et al., 2013; Tadhani et al., 2007).

The structure of a starch-based dairy dessert has been identified as a network of fat globules dispersed in a viscous aqueous phase. Therefore, the development of low fat desserts with a desirable texture represent a challenge for food technology due to the fact that the fat globule network would either be disrupted or absent and this could seriously impact on the final texture of the product (Aime et al., 2001). Different works have studied compounds that acts like fats, called fat substitutes, and its effect on the sensory properties of products (Bayarri et al., 2010; Douglas Goff, 2002; Romanchik Cerpovicz et al., 2006). Inulin is a linear non-digestible polysaccharide which acts as a fiber with beneficial effects on health as a prebiotic (Bayarri et al., 2010; Solowiej et al., 2015). Besides, it can be used as a low-calorie sweetener, fat substitute or texture modifier (González et al., 2009; Arcia et al., 2011; Bayarri et al., 2010; Morais et al., 2014). Recent studies investigated the effect of inulin addition in the rheological and sensory properties of dairy desserts. Torres et al. (2010) investigated the rheology changes during the storage of starch-based dairy desserts containing long-chain inulin. Furthermore, Bayarri et al. (2010) studied the influence of the long-chain inulin addition on the rheological behavior and sensory properties of low-fat semi-solid dairy desserts. However, few studies have investigated inulin addition in sugar-free reduced-fat dairy desserts.

Product optimization can be achieved with statistical techniques, such as experimental designs that are used to minimize the number of experiments in the process of product optimization. The mixture experimental design are useful for food products that require more than one ingredient that the sum of the different levels or proportions of all components are always one or 100% (Iop et al., 1999).

The aim of this work was evaluate the effect of sucrose replacement by single sweeteners and blends of sweeteners in reduced fat dairy dessert, using a mixture design, and investigate possible synergistic effects. Furthermore, the effect of inulin as fat substitutes in reduced fat dairy desserts, and its influence on the textural and sensory properties were studied.

Material and methods

Raw materials and sample preparation

The materials used in the manufacture of sugar-free reduced-fat dairy dessert were: reconstituted skim milk powder 82% (w/v); bitter cocoa 3.2% (w/w); vanilla flavor 0.095% (w/w); chocolate flavor 0.6% (w/w); κ-carrageenan (Sigma Aldrich) 0.02% (w/w); gelatin 0.02% (w/w); potassium sorbate 0.05% (w/w); sodium triphosphate 0.15% (w/w); modified starch (Matharch M 25) 4.75% (w/w); milk cream 5% (w/w); sucrose (Ledesma) 6% (w/w). Dairy desserts were sweetened using different combinations of sucrose (S) and the sugar replacements sucralose (Su, Sucaryl) and Stevia (St, Dulri) using a mixture experimental design. The samples with the best sensorial and physical properties were selected to perform the test with inulin addition at 1% and 2.5% (w/w), (Table 1).

Samples were prepared in batches of 1250 mL as follows: Skimmed milk was prepared two hours advance by dissolving milk powder (14%, w/w) in water and storing under refrigeration (5 ± 2 °C). The following ingredients were added and mixed under constant stirring for 10 min at room temperature (20 ± 2 °C): cream, starch, bitter cocoa, carrageenan, gelatin, sodium triphosphate. The mixture was placed in a container and pasteurized in a water bath at 98 ± 1 °C and stirred for 10 min with a propeller stirrer at 200 rpm. When the product temperature reached 85 °C, it was held for a further 10 min. The evaporated water during de process was replaced gravimetrically by sterile water and then the mix was stirred at

Table 1
Samples tested using an experimental mixture design with combination of the following sweeteners: x_1 = sucrose, x_2 = Stevia and x_3 = sucralose, with and without inulin addition.

Test	*Sweeteners combination (Experimental design)*			*Inulin concentration (%, w/w)*	*Sample*
	x_1	x_2	x_3		
1	1	0	0	0	100%S
2	0	1	0	0	100%St
3	0	0	1	0	100%Su
4	0.5	0.5	0	0	50%S+50%St
5	0.5	0	0.5	0	50%S+50%Su
6	0	0.5	0.5	0	50%St+50%Su
7	0	0.5	0.5	1.0	50%S+50% St+1%I
8	0	0.5	0.5	2.5	50%S+50% St+2.5%I

85 °C for 5 more min. Then inulin and the colorant was added and the sample was cooled until it reached about 60 °C under constant stirring and the remaining ingredients were added: the combination of sweeteners selected (sucrose, Stevia y/o sucralose) and the flavoring (vanilla and chocolate). First, the mix was cooled until it reached about 40 °C under constant stirring and then was placed into a cold-water bath and cooled without agitation until it reached a room temperature. The sample was transferred to pre-cooled sterilized flasks (110 ± 1 °C for 2 h) and stored (5 ± 2 °C) for 24 h before being evaluated. The addition of inulin was performed simultaneously with the colorant.

Chemical measurements

The shelf life of the product storage at 5 ± 2 °C was followed through pH and total titratable acidity (TTA) measurements by titration with 0.01 N NaOH (g 100 g^{-1} acetic acid; AOAC, 1995). The measurements of the samples were performed every day over a period of 30 days.

Syneresis

Syneresis was measured by a centrifugation test using a Rolco 2070 centrifuge (USA). Centrifuge tubes were partially filled with hot samples and stored at 5 ± 1 °C for 24 h before the study starts. Then samples were centrifuged at 3500 rpm for 30 min. After centrifugation the free water was separated, weighed and expressed as percentage of the total amount of water present in each sample (Verbeken et al., 2006). Syneresis values were recorded every 5 days over a period of 20 days.

Rheological measurements

Rheological experiments were performed with a programmable Brookfield DV-III + Viscometer (Brookfield, USA) equipped with a concentric cylinder geometry. Measured were performed every 5 days during a period 20 days at a sample temperature of 10 ± 1 °C and at different shear rates (0.25–12.50 s^{-1}). The rheological behavior of the fluid was characterized by means of Power-Law:

$$\eta = K\gamma^{n-1} \quad (1)$$

where η: apparent viscosity of the fluid (Pa s); γ: shear rate (s^{-1}); K: flow consistency index (Pa s^n); n: flow behavior index (< 1 for pseudoplastics or shear-thinning fluids).

Optical microscopy

Samples were placed in glass slides with a cover slip and observed at a magnification of 40x with an optical microscope (Arcano XSZ1008N). Images were acquired using a digital camera and was analyzed with the Image-Pro Plus 6.0 (Media Cybernetics Inc, Bethesda,USA) software.

Texture profile analysis (TPA)

TPA was determined in quintuplicate samples after 1, 10 and 20 days of refrigerated storage, with a TMS-TOUCH texture analyzer (Food Technology Corporation, USA). A double penetration test were performed at a penetration rate of 100 mm/min and a distance of 10 mm, corresponding to one-third of the height of the samples, using a cylindrical probe with a diameter of 10 mm. Dairy desserts at 40 °C were poured into sterilized glass containers and closed to prevent dehydration and were maintained over refrigeration by 20 days. The samples were analyzed periodically every 10 days. For every day of analysis a new sample was used to avoid contaminations that could alter the properties of the product and affect the results. The total work for penetration, represented by the surface under the deformation curve, was defined as the gel strength or consistency (Depypere et al., 2009; Szwajgier and Gustaw, 2015). Hardness (N) of samples was evaluated as the peak compression force during penetration. Adhesiveness (N s) was determined as the negative area under the curve when the probe was pulled out of the sample. The fracture point (N) was assessed as the penetration depth of the probe at gel fracture (Arltoft et al., 2008; BahramParvar et al., 2013).

Sensory analysis

Fifty-two semi-trained panelists of 20–50 years, regular consumers of this type of dessert were selected. Samples were presented in disposable plastic cups, coded with 3 digit numbers, after the 48 h storage at 5 °C. Samples with different combinations of sucrose, Stevia and sucralose were evaluated for overall acceptability using a 5-point unipolar scales of liking, the panelists scored on a scale of 1 (no dislike) to 5 (like extremely) for flavor, color and texture. Samples were considered acceptable if their mean scores for overall acceptability were above 3 (Ayar et al., 2009; Iop et al., 1999). Besides, a sensory evaluation was carried out by thirty semi-trained panelists, both male and female, for the preferred sample, selected in terms of sensory and physicochemical analysis against a commercial sample (Ser, La Serenisima, Mastellone Hnos S.A.). It was evaluated for overall acceptability and the parameters flavor, color and texture using 5-point unipolar scales of liking, the panelists scored on a scale of 1 (no dislike) to 5 (like extremely).

Experimental design

The influence of the saccharide combinations as sweetening agents in properties of dairy desserts was studied using a three-component simplex-centroid mixture design. The variables in the sweetener mixture were: sucrose (x_1), sucralose (x_2) and Stevia (x_3). Proportions of the variables in the mixture were calculated in % and the sum was equivalent to 100%. Sweeteners concentration was selected based on its equivalent in sweetness to sucrose (1 g de Stevia ≡ 15 g de Sucrose; 1 g de Sucralose ≡ 7.5 g de Sucrose).

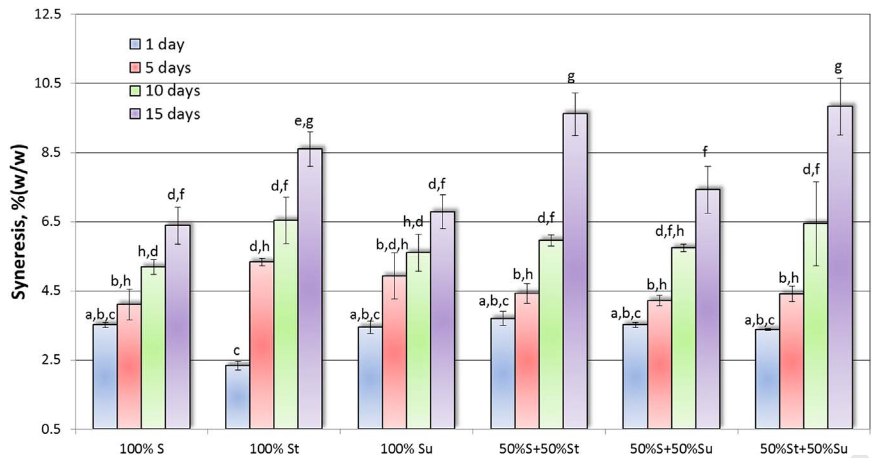

Fig. 1. Syneresis of dairy desserts during time containing different blends of sweeteners: Sucrose (S), Sucralose (Su) and Stevia (St). Different superscript letters denote differences ($P<0.05$) between the mean. Means of each sample represented as a bar with equal superscripts are not significantly different ($P>0.05$) by the Tukey's test.

The response surface methodology (RSM) is an optimization approach which allows though a mathematical fit of the experimental results identify the conditions that yield the best properties from a small number of experiments (Erkucuk et al., 2009). Three factor simplex-centroid designs are important since it permits the evaluation and validation of special cubic models (Ferreira et al., 2007).

Mixture models have the following mathematical expression:

$$y=\sum_{i}^{q} b_i x_i+\sum_{i\neq j}^{q}\sum_{i}^{q} b_{ij}x_i x_j+\sum_{i\neq j}^{q}\sum_{j\neq k}^{q}\sum_{k}^{q} b_{ijk}x_i x_j x_k+\ldots, \qquad (2)$$

The experimental results for viscosity, syneresis and sensorial, were applied to obtain the regression models or the special cubic model for a ternary system, in function of the proportions of each ingredient (x_1 = sucrose and x_2 = Stevia and x_3 = sucralose in sweetness equivalent to sucrose) present in the formulations (Table 1). The special cubic model for a ternary system is:

$$y=b_1x_1+b_2x_2+b_3x_3+b_{12}x_1x_2+b_{13}x_1x_3+b_{23}x_2x_3 + b_{123}x_1x_2x_3 \qquad (3)$$

where y is the dependent variable or estimated response, b´s are the parameter obtains for the prediction model and x_i are the independent variables. The first three terms represents the linear model, which is only valid in absence of interaction effects between components. The next three terms represent synergic or antagonistic binary interaction effects for all possible pairs of components. The last term represents a ternary interaction effect and is usually important for systems having maximum or minimum values in the interior of the concentration triangle (Ferreira et al., 2007).

The saccharides mixtures were analyzed experimentally by employing a simplex-centroid design to obtain data for modeling. Triangular contour plots were constructed for the response of samples made with different combinations of sweeteners obtained from the regression equations generated with the syneresis, sensorial and apparent viscosity at 20 and 5 days storage. The statistical analysis was performed using Statistical 8 software.

Statistical analysis

Results are expressed as means with standard deviations of analysis performed in triplicate. One-way analysis of variance and Tukey's test were used to establish the significance of differences among mean values at $P<0.05$. The statistical analyses were performed using GraphPad InStat Software Inc.

Results and discussion

Shelf life time related to the pH, TTA and syneresis of dairy desserts

The values of pH and TTA (total titratable acidity) of dairy dessert samples after five days of storage at 5 ± 1 °C did not vary ($P<0.05$), and no significant difference was found between the tested samples. The average values found were pH = 6.60 ± 0.01 and TTA = 0.127 ± 0.01% (w/w). However, all samples showed a statistically significant increase in the TTA values (0.140 ± 0.02%, w/w) and a statistically significant decrease in the pH values (6.20 ± 0.03) after 25 days of storage at 5 ± 1 °C ($P<0.05$). The same behavior was observed for a tested commercial sample.

As it is expected, Fig. 1 shows an increase of syneresis values of the tested samples during fifteen days of storage. This may be due to the reorganization of starch molecules or retrogradation during cold storage of starch-based systems that may result in a release of water or syneresis increase (Verbeken et al., 2006). As shown in Fig. 1, the full or partial sugar replacement by Stevia (100%St, 50%S+50%St, 50% St+50%St) increased syneresis during the storage. This increase becomes statistically significant after 15 days of storage. This may be due to changes in the structure and stability of the gels, which could modify the textural properties and acceptability of the product. However, the replacement of

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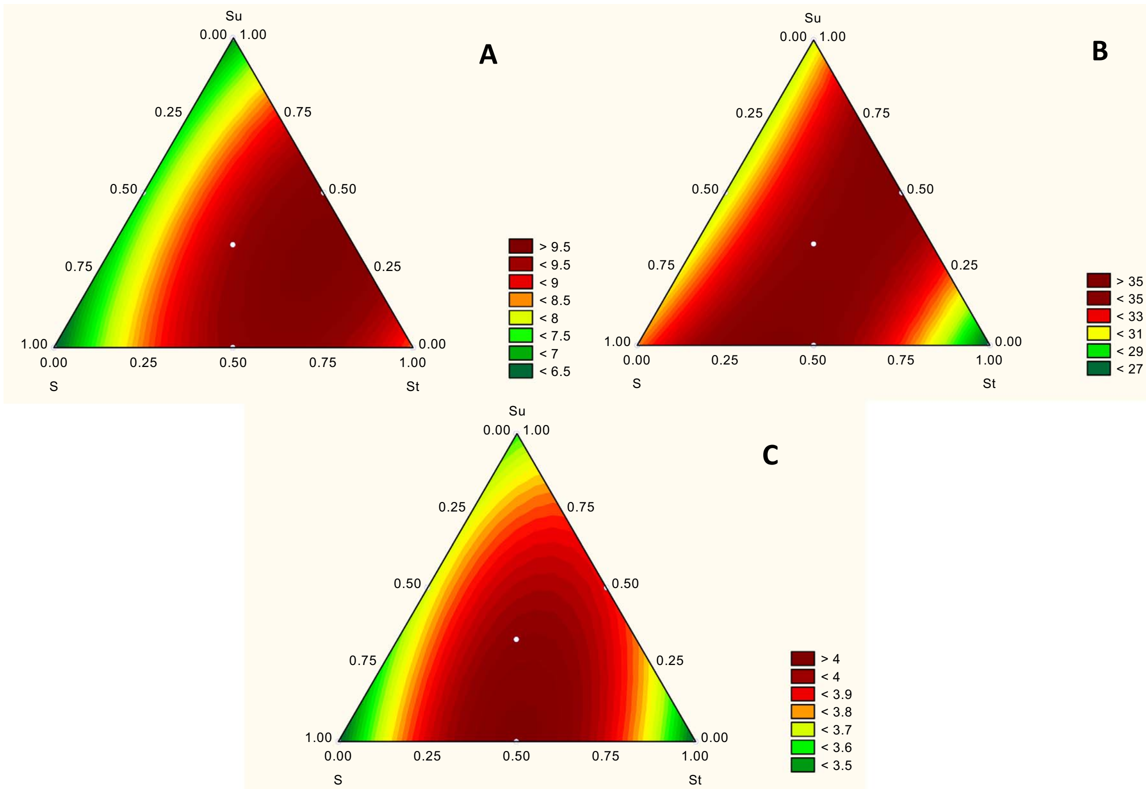

Fig. 2. Contour plot for (A) syneresis after 15 days of storage, (B) viscosity (shear rate of 0.25 s^{-1}), (C) acceptability of dairy desserts containing different blends of sweeteners: Sucrose (S), Sucralose (Su) and Stevia (St).

sucrose with 100%Su significantly improved the stability of this gel, with no significant difference with the control sample during the storage period studied.

From the syneresis data after 15 days of storage (T = 5 ± 1 °C), expressed as the percentage of free water after centrifugation, was obtained the following special cubic model, where only the statistically significant terms were considered ($P < 0.05$):

$$y = 6.39x_1 + 8.60x_2 + 6.79x_3 + 8.44x_1x_2 + 2.82x_1x_3 + 8.52x_2x_3 \quad (4)$$

The model adequately fits the data with $P < 0.05$, a 95% confidence limit and $R^2 = 0.998$. By comparing the experimental with theoretical values, an average relative error of 5% was obtained. The terms that contain Stevia as sweetener (100%St, 50%St+50%S, 50%St+50%Su) contributed to the model more than the other factors.

From the model of the system (Eq. (4)), the response surface graph for the syneresis of the dairy dessert was generated, as shown in Fig. 2A. The highest values were observed in the right-hand side of the graph which corresponds to the combination of sweeteners and Stevia. Previous studies performed by Wattanachant et al. (2003) revealed that starch retrogradation is responsible for the syneresis of starch pastes and gels when held for long storage periods.

The influence of inulin addition to sugar-free samples at 1% and 2.5% (w/v) was studied, and the results were compared with a control sample. The syneresis studies performed after 24 h of storage revealed that inulin addition (2.5%, w/v) increases the syneresis values of the 100%St and 100%S samples from 2.34 ± 0.09% (w/w) to 4.12 ± 0.20% (w/w), and 100%S from 3.52 ± 0.05% (w/w) to 4.41 ± 0.03% (w/w). The increase of inulin concentration did not generate statistically significant differences in the syneresis values of the samples formulated with 100%Su (3.61 ± 0.14%, w/w) and 50% St+50%Su (3.44 ± 0.07%, w/w). The 100%Su and 50% St+50%Su samples with inulin addition at 1% and 2.5% (w/w) did not present significant differences as compared to the control sample (100%S) without inulin addition.

The study of syneresis conducted during 15 days resulted in a different pattern for the sample 50%St+50%Su with the incorporation of inulin at 2.5% (w/w). An increase in syneresis in the first 5 days ($P < 0.001$) from 3.03 ± 0.21% (w/w) to 5.05 ± 0.32% (w/w) was observed. From this day, a gradual decrease in time was produced (day ten = 4.69 ± 0.29%, w/w), until a significantly lower value than that of the first day ($P < 0.01$) was reached at day twenty (1.40 ± 0.35%, w/w). This effect is probably due to the gelling properties of inulin that improve product consistency through increased water-binding capacity (Buriti et al., 2010). Furthermore, inulin could generate structural changes in the sample matrix. In previous studies, Tárrega et al. (2011) concluded that there were changes in the physical properties of dairy desserts with inulin incorporation. They also found that these changes depended on dessert composition and began to manifest after

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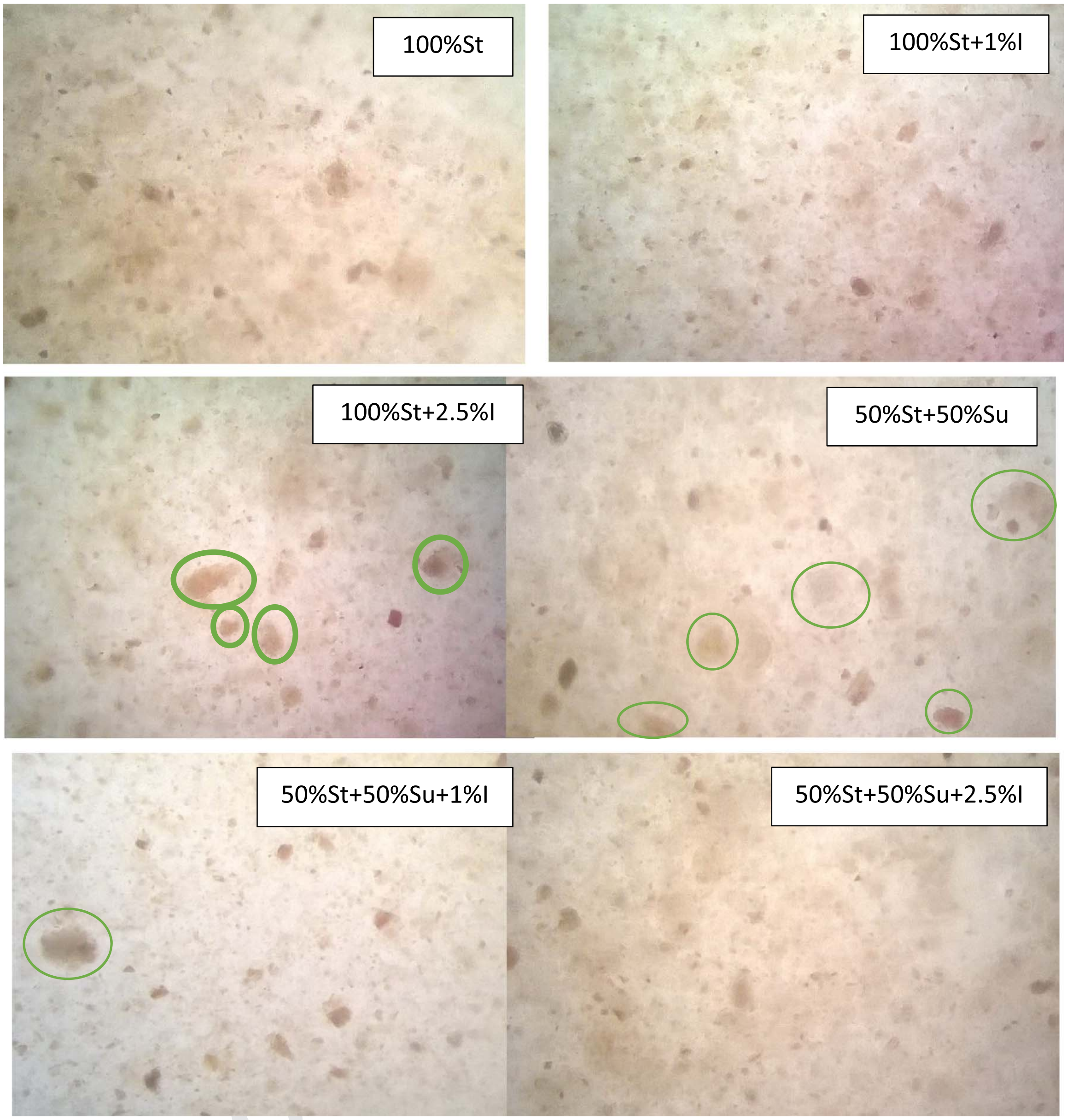

Fig. 3. Micrograph images of the samples 100%St y 50%St+50%Su with different concentrations of inulin 0–2.5%, w/w).

3–6 days of storage. Buriti et al. (2010) found that the incorporation of inulin as fat replacement in refrigerated mousses affected texture during storage. However, Guven et al. (2005) reported that the addition of inulin as substitute of milk fat in yoghurts did not affect texture during 15 days of storage at 4 °C. Therefore, the changes on the physical properties of the samples during storage due to inulin addition may depend on the matrix composition. This confirms our results, in which only the 50%St+50%Su sample presented a significant difference in the syneresis during storage. Torres et al. (2010) postulated that dairy desserts with inulin presented rheological properties that markedly varied in time, which indicated a change in the system structure during storage. Additionally, they found that these changes were higher in skimmed-milk samples.

Flow behavior of dairy dessert

The Power-Law was used to model the apparent viscosity data of dairy dessert samples at increasing shear rate ($0.994 \leq R^2 \leq 1.000$). The results showed differences in the model parameters between the assayed samples. All samples exhibited a n value smaller than 1 ($0.20 < n < 0.27$), showing that samples had a pseudoplastic behavior. The formulations 100%St (0.27 ± 0.02), 100%Su (0.24 ± 0.01), 50%S+50%Su (0.25 ± 0.02), 33% S+33%St+33%Su (0.26 ± 0.01) showed no statistically significant differences in relation to the control sample (100%S, 0.25 ± 0.02). The samples 100%St (9.77 ± 0.45) and 33% S+33%St+33%Su (10.29 ± 0.36) presented the lowest values for the flow consistency index parameter. However, the other samples tested showed no statistical differences in relation to the control (100%S, 11.39 ± 0.31), ($P < 0.05$).

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From the experimental results of apparent viscosity at a shear rate of $0.25\ s^{-1}$ (Pa s), a special cubic model was obtained as a function of the proportions for each ingredient (Eq. (3)), where only the statistically significant terms were considered ($P < 0.05$):

$$y = 31.79x_1 + 26.73x_2 + 30.38x_3 + 23.39x_1x_2 + 26.05x_2x_3 \quad (5)$$

The model adequately fits the data, with $P < 0.05$, a 95% confidence limit and $R^2 = 1.000$. The individual sweeteners contributed to the model more than the other factors.

This model was used to generate the contour plot (fitted response) for the apparent viscosity at a shear rate of $0.25\ s^{-1}$ (Pa s), (Fig. 2B). Binary combinations of 50%Su+50%St and 50%S+50%St generated a higher viscosity. Viscosity decreases towards the corners of the graph, namely the samples with a single sweetener. This demonstrates that the combination of sucrose with Stevia, and sucralose with Stevia had a synergistic effect on the viscosity values, with higher values than the 100%S control sample ($P < 0.05$).

Optical microscopy

Fig. 3 shows the optical microscopy results. The 100%St sample with inulin at 2.5% (w/w) presented the formation of large aggregates with an average diameter of 33.4 ± 8.4 µm. These aggregates could be responsible for the increase in syneresis reported by the incorporation of inulin into the matrix. Similar results were found by Meyer et al. (2011), who studied skimmed-milk samples of dairy desserts with inulin showing some large particles or aggregates. On the other hand, the sample 50%St+50%Su without inulin presented aggregates of 36.6 ± 4.0 µm. However, by incorporating inulin at 2.5% (w/w) these large aggregates were no longer observed (Fig. 3). Therefore, the incorporation of inulin generated changes on the matrix that would justify the lower syneresis values previously found for this sample (50% St+50%Su + 2.5% I).

Evaluation of the texture profile

We compared the texture profile of sugar-free formulations suitable for diabetics (100% St, 100% Su and 50%St+50%Su) with the control sample 100% S (Table 2 and Table 3). In order to improve the textural and sensory properties of these reduced-fat desserts, the incorporation of inulin at 1% and 2.5% (w/w) to the samples 100%St, 100%Su and 50% St+50%Su was studied and compared with 100%S.

The instrumental texture profile parameters of dairy desserts derived from penetration tests showed that the increase of inulin concentration for the 100%S sample, did not affect the studied instrumental texture profile parameters. Similar results were found by Lobato et al. (2009), who analyzed the effects of interactions among milk, starch and inulin on the instrumental texture profile parameters of a dairy dessert without sugar replacement.

Table 2
Texture parameters of hardness and adhesiveness obtained from the texture profile analysis of the different samples of dairy desserts with inulin at 1.0% and 2.5% (w/w) after twenty days of refrigerated storage at 4 ± 1 °C.

Sample	Inulin (%, w/w)	Hardness (N)	Adhesiveness (N.s)
100% S	0	0.168 ± 0.011[a,b]	0.926 ± 0.121[a]
	1	0.164 ± 0.006[a,b]	0.800 ± 0.056[a]
	2.5	0.149 ± 0.007[b]	0.728 ± 0.083[a]
100% St	0	0.168 ± 0.011[a]	0.816 ± 0.081[a]
	1	0.197 ± 0.010[b]	0.760 ± 0.046[a]
	2.5	0.158 ± 0.010[b]	0.710 ± 0.094[a]
100% Su	0	0.141 ± 0.008[a,b]	0.806 ± 0.056[a]
	1	0.153 ± 0.011[a,b]	0.804 ± 0.065[a]
	2.5	0.142 ± 0.007[b]	0.831 ± 0.058[a]
50%St+50%Su	0	0.157 ± 0.007[a,b]	0.776 ± 0.062[a]
	1	0.145 ± 0.006[b]	0.671 ± 0.047[a]
	2.5	0.142 ± 0.003[b]	0.668 ± 0.044[a]

Different superscript letters in a column denote differences ($P < 0.05$) between the mean of the refrigerated dairy desserts.

The sugar-free samples (100%St, 100%Su and 50% St+50%Su) showed clear changes in the data collected from the different textural parameters studied, except for adhesiveness (Table 2). This parameter showed no significant differences between samples tested with and without addition of inulin in relation to the control sample 100%S ($P > 0.05$). Hardness is measured as the resistance of the dairy dessert to deformation when an external force is applied. Our results showed that the increase of inulin concentration had significant effects on instrumental texture, decreasing hardness of the sample 100%St from 0.168 ± 0.006 N to 0.158 ± 0.005 N ($P < 0.01$), (Table 2). However, no significant changes in this parameter for the samples 100%Su (0.145 ± 0.003 N) and 50%St+50%Su (0.148 ± 0.004 N) were found.

Consistency or gel strength is defined as the work required to attain deformation indicating internal strength of bonds within the product (BahramParvar et al., 2007; Verbeken et al., 2004). Table 3 shows the results obtained for the parameter consistency of samples tested with addition of inulin. The samples tested without inulin addition presented no significant changes on the textural parameters during the study period of 20 days ($P > 0.05$). Table 3 shows a decrease in the consistency values, mainly after 20 days of storage, in accord with the observed increase in the syneresis values. Besides, according to our research, increased inulin content affected the texture of samples without sucrose during storage ($P < 0.05$). BahramParvar et al. (2007) found that consistency values had a good negative correlation with creaminess and smoothness. They found that the addition of κ-carrageenan on vanilla ice cream significantly decreased consistency and increased creaminess and smoothness values. The samples 100%St, 100%Su and 50%St+50%Su showed higher values of the consistency parameter over storage than their counterparts with inulin at 2.5% (w/w), being significantly lower after 20 days of storage (Table 3). Therefore, these samples with a sugar-free matrix may present an improved creaminess and smoothness, reaffirming the inulin effect as a mimic agent of full-fat products.

Table 3
Texture profile analysis of the samples of dairy desserts formulated with different combinations of sweeteners and inulin at 1.0% and 2.5% (w/w) during a refrigerated storage of twenty days.

Sample	Consistency (N.s) Time (days)			Fracture point (N) Time (days)			Cohesiveness Time (days)	
	1	10	20	1	10	20	1	10
100%S	$0.727 \pm 0.045^{a,b}$	$0.628 \pm 0.066^{b,c}$	$0.591 \pm 0.053^{b,c,d}$	$0.130 \pm 0.009^{b,c,d}$	$0.109 \pm 0.007^{a,b}$	$0.125 \pm 0.001^{a,b}$	$0.714 \pm 0.004^{d,e}$	$0.717 \pm 0.015^{d,e}$
100%S + 1%I	$0.610 \pm 0.009^{b,c}$	$0.592 \pm 0.013^{b,c}$	$0.608 \pm 0.049^{b,c}$	$0.116 \pm 0.009^{c,d}$	$0.125 \pm 0.007^{c,d}$	$0.130 \pm 0.003^{c,d}$	$0.721 \pm 0.019^{d,e}$	$0.725 \pm 0.020^{d,e}$
100%S + 2.5%I	$0.619 \pm 0.023^{b,c}$	$0.633 \pm 0.059^{b,c}$	$0.667 \pm 0.065^{b,c}$	0.104 ± 0.007^{d}	$0.113 \pm 0.012^{c,d}$	$0.123 \pm 0.006^{c,d}$	$0.693 \pm 0.028^{c,e}$	$0.635 \pm 0.044^{c,d}$
100%St	0.835 ± 0.031^{a}	0.859 ± 0.042^{a}	$0.701 \pm 0.040^{a,b}$	$0.162 \pm 0.013^{a,b}$	$0.166 \pm 0.007^{a,b}$	$0.142 \pm 0.009^{b,c}$	$0.609 \pm 0.024^{a,b,c}$	$0.576 \pm 0.009^{a,b,c}$
100St + 1%I	$0.680 \pm 0.030^{b,c}$	$0.684 \pm 0.031^{b,c}$	$0.562 \pm 0.035^{c,d}$	0.127 ± 0.006^{c}	$0.142 \pm 0.012^{b,c}$	0.115 ± 0.008^{d}	$0.639 \pm 0.014^{b,c}$	$0.613 \pm 0.022^{a,b,c}$
100St + 2.5%I	$0.688 \pm 0.028^{b,c}$	$0.554 \pm 0.035^{c,d}$	0.435 ± 0.028^{d}	$0.135 \pm 0.008^{b,c}$	0.108 ± 0.006^{d}	0.085 ± 0.004^{e}	$0.646 \pm 0.036^{c,d}$	0.741 ± 0.005^{e}
100%Su	$0.726 \pm 0.033^{a,b}$	$0.667 \pm 0.052^{b,c}$	$0.650 \pm 0.060^{b,c}$	$0.123 \pm 0.006^{c,d}$	$0.110 \pm 0.009^{c,d}$	$0.120 \pm 0.006^{c,d}$	$0.709 \pm 0.042^{c,d,e}$	$0.708 \pm 0.012^{d,e}$
100%Su+ 1%I	$0.721 \pm 0.036^{a,b}$	$0.593 \pm 0.050^{b,c}$	$0.562 \pm 0.090^{b,c}$	$0.120 \pm 0.005^{c,d}$	0.104 ± 0.007^{d}	$0.115 \pm 0.010^{c,d}$	$0.716 \pm 0.024^{d,e}$	$0.726 \pm 0.042^{d,e}$
100%Su + 2.5%I	$0.647 \pm 0.046^{b,c}$	$0.606 \pm 0.041^{b,c}$	0.501 ± 0.060^{c}	$0.123 \pm 0.018^{c,d}$	$0.113 \pm 0.012^{c,d}$	$0.120 \pm 0.003^{c,d}$	$0.708 \pm 0.029^{d,e}$	$0.726 \pm 0.025^{d,e}$
50%St+50%Su	$0.717 \pm 0.038^{a,b}$	$0.666 \pm 0.040^{b,c}$	$0.622 \pm 0.028^{b,c}$	$0.127 \pm 0.001^{c,d}$	$0.127 \pm 0.001^{c,d}$	$0.125 \pm 0.004^{c,d}$	$0.683 \pm 0.015^{c,d,e}$	$0.746 \pm 0.017^{d,e}$
50%St+50%Su+ 1%I	0.689 ± 0.033^{b}	$0.587 \pm 0.095^{b,c,d}$	0.419 ± 0.025^{d}	$0.132 \pm 0.007^{b,c,d}$	0.105 ± 0.013^{d}	0.105 ± 0.001^{d}	$0.692 \pm 0.022^{d,e}$	$0.710 \pm 0.011^{d,e}$
50%St+50%Su+ 2.5%I	$0.655 \pm 0.051^{b,c}$	$0.550 \pm 0.038^{c,d}$	0.439 ± 0.016^{d}	$0.118 \pm 0.006^{c,d}$	0.101 ± 0.004^{d}	0.105 ± 0.005^{d}	$0.718 \pm 0.019^{d,e}$	$0.737 \pm 0.015^{d,e}$

Different superscript letters in a row or a column denote differences ($P < 0.05$) between the mean of the refrigerated dairy desserts for a same texture parameter.

Similar results were found by Arcia et al. (2011) and González Tomás et al. (2009) who studied inulin as fat substitute on low fat dairy dessert without sugar replacement. According to the results found by Arcia et al. (2010) inulin addition modifies the properties of dairy desserts, and these effects depend on concentration of inulin and sucrose. Previous studies performed by Meyer et al. (2011) showed that inulin addition at fat-free desserts modifies the texture, with a significant increase of creaminess. Prior studies indicate that inulin can modify the texture of food products, creating a different network structure (Arcia et al., 2010; Torres et al., 2010; Meyer et al., 2011). Our results suggest that the presence of sucrose, sucralose or Stevia solubilized in the continuous phase affected inulin ability to modify the matrix of dairy desserts. Therefore, inulin in these matrixes creates a new structure within the continuous phase responsible for decreasing the consistency.

Inulin addition at 2.5% (w/w) in the sample 100%St significantly increased the cohesiveness parameter; this change was more marked after 10 days of storage (Table 3). Similar results were found by Buriti et al. (2010), who studied inulin addition in refrigerated mousses, showed a significant increase of the cohesiveness values during storage ($P < 0.05$). Besides, the sample 100%St presented lowered cohesiveness values between the assayed samples during the studied days of storage ($P < 0.05$). This may be due to the presence of Stevia, which generated emulsion destabilization. Furthermore, this result agrees with the lower values found for the viscosity data.

The sample 100%St with inulin addition generated the decrease of the consistency values and the fracture point. This decrease can be related to the presence of large aggregates (Fig. 3) that probably generate a weakening of the starch network and an increase of syneresis. Similar results were found by Lobato et al. (2009), who analyzed the effect of inulin (medium chain length) in the texture profile parameters of a milk pudding formulation. Their results showed that an increase in concentration of inulin, which only affected the cohesiveness parameter.

The consistency of the free sugar samples 100%Su and 50% St+50%Su with increase of inulin concentration did not show statistical differences during storage and against the control sample (100%S).

Sensory analysis

From the experimental data of global acceptability obtained from the samples with different combinations of sweeteners without inulin addition was performed by the following special cubic model:

$$y = 3.40x_1 + 3.40x_2 + 3.60x_3 + 2.74x_1x_2 \qquad (6)$$

The binary combination of sweeteners contributes more to the model than the other terms of the equation, and the binary combination of sucrose and Stevia is only statistically significant one. The model adequately fits the data with $P < 0.05$, a 95% confidence limit and $R^2 = 0.997$.

Fig. 2C shows the contour plot obtained from the global acceptability. All samples presented scores higher than 3. The samples with one sweetener and the binary combination of 50%S + 50%Su showed the lowest acceptability, and the sweetener blends of 50%S + 50%St and 50%St + 50%Su presented the highest score ($P > 0.05$). These two samples had a higher acceptability than the control sample 100%S ($P < 0.05$). These formulations presented the highest viscosity values (Fig. 2B), and this increase may reduce sweetness perception in foods (Lethuaut et al., 2003), which allowed us to obtain samples with a profile more similar to sucrose. Besides, studies performed by Kersiene et al. (2008) demonstrated that a close relationship between the flavor release and the food matrix exists, such as the starch three-dimensional structure that is capable of the inclusion of various hydrophobic volatiles. Thus, the sensory properties of these formulations were improved with the addition of these combinations of sweeteners (50%S + 50%St and 50%St + 50%Su).

The formulation 50%St + 50%Su with inulin at 2.5% (w/w) with a sugar-free and fat-reduced content showed the best results in relation to all the parameters studied. Thus, it was selected to be evaluated by a semi-trained sensory panel against a commercial sample with a reduced sucrose and fat content. In this sensory analysis, different attributes like flavor, color, aroma and texture were evaluated. The results showed that no statistically significant difference was observed among all measured attributes except for texture ($P < 0.05$). The sample 50%St + 50%Su + 2.5%I (4.19 ± 0.16) was preferred over the commercial sample (3.19 ± 0.21) for the texture parameters. The sample 50%St + 50%Su + 2.5%I presented a higher acceptability than the commercial sample. This may be due to the inulin influence on sweet taste and on flavor intensity, suggesting a faster flavor release in these systems (Tárrega and Costell, 2006).

Conclusions

The replacement of sucrose with combinations of sucralose and Stevia using an experimental mix design was attained. Likewise, inulin addition as fat substitute was evaluated to improve the textural properties of reduced fat. The samples with the highest sensory acceptability were 50%St + 50%Su and 50%S + 50%St. The sugar-free sample 50%St + 50%Su was selected as optimal. It was observed that samples containing St, such as 100%St, 50%St + 50%Su and 50%S + 50%St presented the highest viscosity values. However, after 15 days of storage, the syneresis values were the highest of all the tested samples. These values were also observed to be significantly higher than those of the 100% S control sample. However, the addition of inulin at 2.5% (w/w) to the sample 50%St + 50%Su helped to stabilize the sample, since syneresis values decreased significantly over time. Besides, it was significantly lower than the control sample and it remained constant over the study time of 20 days (i.e. during the lifetime of the product). The sample with the sweetener combination of 50%St + 50%Su and inulin addition at 2.5% presented a decrease of textural consistency values. This decrease may be associated with a higher creaminess of the sample. Furthermore, a sensory analysis was performed between the sample 50%St + 50%Su + 2.5%I with a sugar-free and reduced-fat content and a commercial dairy dessert reduced in fat and sugar content. In this study, no statistically significant differences were found in the different sensory parameters evaluated, except for texture, being the sample 50%St + 50% Su + 2.5%I preferred over the commercial one. Therefore, it was possible to develop a dairy dessert formulation with a sugar-free and reduced-fat content, sweetened with a St and Su combinations, using inulin as fat substitute, with sensory and physical properties pleasant for the consumer.

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