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Effects of sucrose reduction on the structural characteristics of sponge cake[1]

Efeitos da redução de açúcar nas características estruturais de bolos tipo esponja

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ABSTRACT - The consumption of reduced-calorie cakes has been increasing, however this has presented challenges to be overcome concerning the formation of their structure when the sucrose is substituted by alternative sweeteners, gums or thickening agents. The present study evaluated the internal characteristics of cakes with a reduction in sucrose, and the effects of its substitution on starch gelatinisation. Starting with a pre-established formulation, the sucrose was gradually substituted by a 1.0% mixture of sucralose in a 1.5% xanthan gum solution. In the substituted cake mix, the apparent viscosity and its thermal properties were evaluated using differential scanning calorimetry (DSC). Specific volume (SV) and cell count (CC) were evaluated in the cakes. As the sucrose content decreased (52.17 to 10.00%), the specific volume (1.94 to 0.7 mL/g), cell count (36.2 to 4.0 cell/cm²) and the apparent viscosity of the batter (337.56 to 631.40 cP) were also reduced. The results showed that substituting the sucrose contributed greatly to the formation of defects in the cake structure (holes). From the data obtained, and thermograms of standard cake batters and those with a reduction in sucrose, it can be concluded that sucralose reduced the temperature of starch gelatinisation, speeding the process and causing compaction of the cake structure during baking, favouring the formation of bubbles throughout the batter.

Key words: Low calorie. Sucralose. Xanthan gum.

RESUMO - O consumo de bolos com redução calórica vem crescendo, mas tem apresentado desafios a serem superados na formação da sua estrutura quando o açúcar é substituído por adoçantes alternativos, gomas ou espessantes. O presente trabalho avaliou as características internas de bolos com redução de açúcar e os efeitos da sua substituição na gelatinização do amido. A partir de uma formulação pré-estabelecida, a sacarose foi gradualmente substituída, por uma mistura de sucralose (1.0%) em solução goma xantana (1.5%).Na massa dos bolos substituídos,foram avaliadas , a viscosidade aparente e suas propriedades térmicas por meio de calorimetria diferencial exploratória (DSC) e nos bolos, seus volumes específicos e a contagem de células(CC)). À medida que o teor de sacarose diminuiu (52.17-10,00%) foram reduzidos o volume específico (1.94-0.7 mL/g), a contagem de células (36.2-4.0 cel/cm²) do bolo e a viscosidade aparente da massa (631.40-337.56 cP). Os resultados obtidos demonstraram que a substituição do açúcar contribuiu acentuadamente para a formação de defeitos na estrutura do bolo (buracos). A partir dos dados encontrados e dos termogramas das massas dos bolos padrão e com redução de sacarose, pudemos concluir que a presença de sucralose reduziu a temperatura de gelatinização do amido, acelerando esse processo e causando uma compactação da estrutura durante o assamento, favorecendo a coalescência das bolhas dispersas na massa.

Palavras-chave: Bolos. Sucralose. Gomas.

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INTRODUCTION

Highly popular around the world, cakes have a high sugar content in their recipes (MANISHA; SOWMYA; INDRANI, 2012). However, the increasing rate of high-calorie foods rich in sugar has been a matter of great concern to the public health programs of some countries in order to prevent diabetes and hypertension in the population (CARRILLO *et al*., 2012). In addition, because of the high glycemic index of cakes, people that suffer from diabetes are not able to eat large amounts of ordinary cake (MARTÍNEZ-CERVERA; SALVADOR; SÁNZ, 2014).

In general, food products with the total or partial replacement of sucrose have their quality impaired (texture, volume and appearance); mainly sponge cakes, where defects (holes) can be seen in their internal structure (MANISHA; SOWMYA; INDRANI, 2012; PAREYT *et al*., 2009) due to the diffusion of gas from small to larger bubbles (HICSASMAZ *et al*., 2003).

Some studies into low-sucrose cakes have been undertaken, and all report structural defects (FRYE; SETSER, 1991; HICSASMAZ *et al*., 2003). Sucrose plays a key role in the cake; it helps good incorporation of the air, so creating a more viscous and stable sponge (PATON; LAROCQUE; HOLME, 1981). In addition, sucrose can retard gelatinisation of the starch during baking (KULP; LORENZ; STONE, 1991; NGO; TARANTO, 1986; SHUKLA, 1995; SPIES; HOSENEY, 1982), allowing better expansion of the bubbles due to the pressure generated by carbon dioxide and water vapour before the cake sets (KIM; SETSER, 1992; KIM; WALKER, 1992). In order to compensate for the reduction of sucrose in low calorie cakes, some alternatives have been employed incorporating the use of different sweeteners, such as encapsulated aspartame, acesulfame K (WETZEL; WEESE; BELL, 1997), polyols and polydextrose (EDWARDS, 2000; KAMEL; RASPER, 1988). Although these sweeteners can make up for sucrose in sensory evaluations to an extent, they are unable to change the structure in the same way as sucrose. Replacing sucrose with polyols such as xylitol, results in acceptable organoleptic properties, but also in an undesirable colouration (RONDA *et al*., 2005). Further, polyols can cause such abdominal discomfort as bloating, cramps or diarrhoea (EMBUSCADO, 2006). In another report (KOCER *et al*., 2007), polydextrose presented desirable results, but the amount of substitution possible in this case is low (22 %), and at higher levels of substitution, the structure can collapse (PATERAS; HOWELLS; ROSENTHAL, 1994). The present work was developed considering these problems and the lack of studies into the substitution of sucrose by xanthan gum and sucralose.

MATERIAL AND METHODS

Specific volume was measured by the seed displacement method, described in American Association of Cereal Chemists International (2000) for cake samples.

Slices of each cake formulation, 11.0 mm thick, were scanned, and a count made of the cells formed after baking, in a 5.0 x 5.0 cm square located in the centre of the slice being evaluated, as per an adjusted methodology of Wilderjans *et al*. (2008).

The basic formulation used for the sponge cake consisted of 39.36% sucrose, 25.25% wheat flour, 14.29% water, 11.86% egg, 7.27% hydrogenated fat, 1.72% powdered milk and 0.25% baking powder. Ten percent reductions in sucrose were made, substituting it with a mixture of 1.0% sucralose in a 1.5% solution of xanthan gum, as shown in Table 1, without modifying

Table 1 - Sucrose substitution by a sucralose + gum mixture in the basic formulation used to make sponge cakes

Formulation	Sucrose (g)	Sucralose + Gum (g)	Sucrose substitution (%)
Standard	650.00	0.00	0.00
1	585.00	65.00	10.00
2	526.50	123.00	19.00
3	473.85	176.15	27.10
4	426.47	223.54	34.39
5	383.82	266.18	40.95
6	345.44	304.56	46.86
7	310.89	339.11	52.17

the amounts of the other ingredients. The parameters measured were the range of starch gelatinisation, specific volume and cell count for the cakes, and the apparent viscosity of the batters.

The apparent viscosity of the batter was measured at 25.0 ºC, in a Brookfield model DVII+ viscometer linked to a Thermosel temperature control, using a number 28 spindle, at a rotation of 50 rpm and with a standardisation period of 20 minutes, as described by Ronda *et al*. (2011).

The temperature range for gelatinisation of the starch in the batter was determined with a differential scanning calorimeter (DSC), using 8.0 mg samples of sucrose-reduced cake batter in sealed aluminium capsules, taking as reference an empty sealed capsule, at a heating rate of 10 °C min^{-1} and a temperature range of 20-250 °C (WILDERJANS *et al*., 2008).

The data were analysed by Tukey's test ($p<0.05$), using the STATSOFT (2010) v 7.0 statistic software.

RESULTS AND DISCUSSION

Figure 1 shows the effects on the internal structure of cakes where the sucrose was substituted by a mixture of sucralose and xanthan gum. As the percentage of sucrose decreased from 52.17 to 0, a heterogeneous (amorphous) formation of cells could be seen, with a reduction in cell count from 51.8 to 4.0 units.

A similar effect has also been seen inside muffins, both with the gradual reduction in sucrose in the standard formulation, and with its gradual substitution by erythritol and xanthan gum (MARTÍNEZ-CERVERA *et al*., 2012). Similar results have been reported by Manisha, Sowmya and Indrani (2012). They verified changes in the internal structure of cakes where the sugar had been substituted by sorbitol, xanthan gum and polisorbate as an emulsifier, with gelatinised starch trapped in the protein matrix and a compacted internal structure caused by the increasing concentrations of xanthan gum.

In the present work, at a substitution level of 19.0%, macro bubbles began to form due to the agglomeration of small cells. There was also compaction of the internal structure, which had the appearance of concentrated gelatinised starch (darker areas), and was probably due to the effect of the increasing levels of sucralose lowering the temperature range for gelatinisation of the starch, as can be seen by the values for To (Table 2). Researchers have reported that the gelatinisation temperature can be affected by gum type (TUBARI *et al*., 2010).

Figure 1 - Effects of sucrose substitution on the structure of a standard cake at increasing levels of substitution with a mixture of 1.0% sucralose in a 1.5% solution of xanthan gum (CC - cell count; SL - level of sucrose substitution)

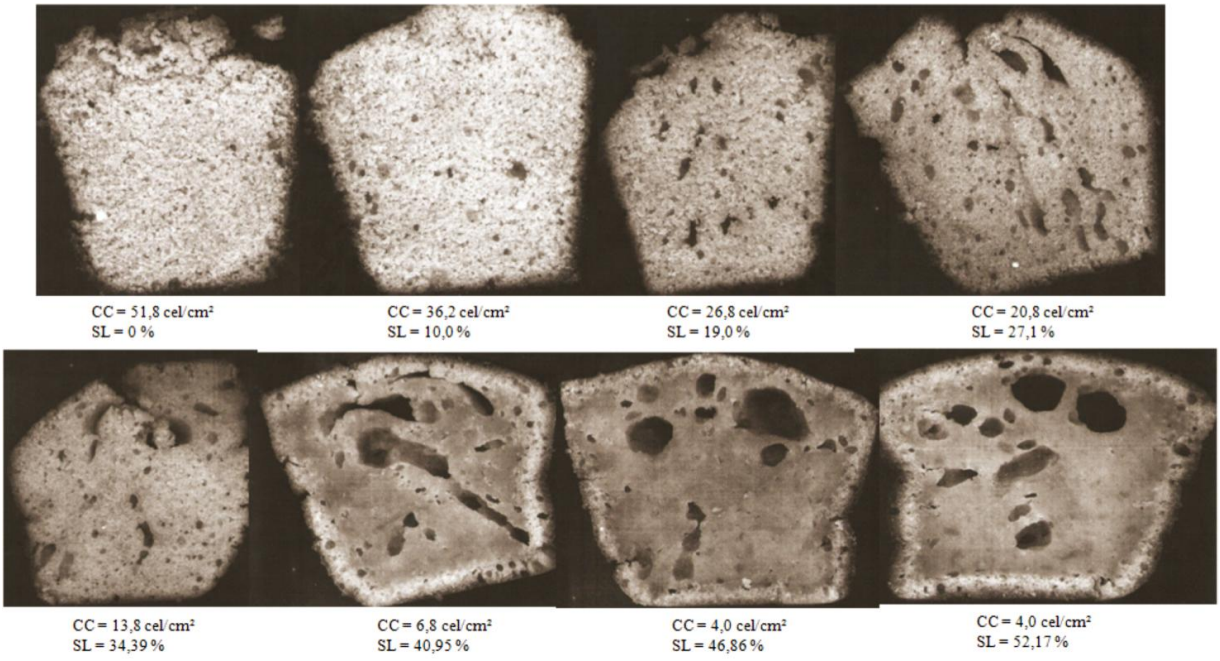

Table 2 - Onset (To), peak (Tp) and recovery (Tr) temperatures and enthalpies (ΔH), in the standard cake batter and with 19.0% (formulation 2) and 34.39% (formulation 4) of sucrose substitution

Sample	To (°C)	Tp (°C)	Tr (°C)	ΔH (J/g)
Standard	75.20	109.20	127.20	373.60
Formulation 2	70.20	102.90	117.00	406.10
Formulation 4	58.00	85.60	72.60	255.30

Determinations performed in triplicate

According to the literature (HOSENEY, 1994; MANISHA; SOWMYA; INDRANI, 2012), several solutes can interact with starch to lower or reduce the temperature range for gelatinisation. When the start of gelatinisation in the cake batter occurs at a lower temperature (around 75.0 ºC), gel formation takes place first and protein denaturation, responsible for the formation of the cake structure, second. Therefore, if gelatinisation occurs at a lower temperature than usual in the batter, it causes the air bubbles to coalesce. With the rise in temperature, the coalesced bubbles increase in volume, resulting in macro bubbles. The starch gel formed earlier during the first stage of heating appears to hamper release of the macro bubbles, due to the formation of a gel barrier which reduces or inhibits permeation (micro channels through which the incorporated air can escape).

Sucrose gives the batter a high viscosity value (Table 3), and its gradual replacement by sucralose and xanthan gum, was not enough to maintain stability of the air bubbles in the dough. Although the substituted batters displayed significant values for viscosity, they were still very low compared to the standard batter. The values for the specific volume of the cakes were also inferior to the standard batter.

Ronda *et al*. (2005) also found a reduction in specific volume in cakes with no sucrose, compared to the standard batter (with sucrose), when using maltitol, manitol, xylitol, sorbitol, isomaltose, oligofructose and polydextrose as bulking agents to completely replace the sucrose in cakes. Similarly, Manisha, Sowmya and Indrani (2012) observed a decrease in the viscosity of the cake batter at different levels of sucrose substitution by sorbitol.

Table 3 - Apparent viscosity of the batters, and specific volume of the cakes, from formulations with substitution of the sucrose

Formulation	Sucrose (g)	Sucralose + Gum (g)	Level of sucrose substitution (%)	Specific volume(*) (mL/g)	Viscosity at 50 rpm(*) (cP)
Standard	650.00	0.00	0.00	2.47 a ± 0.04	4327.50 a ± 5.19
1	585.00	65.00	10.00	1.94 b ± 0.89	631.40 f ± 10.89
2	526.50	123.00	19.00	1.59 c ± 0.54	1855.70 b ± 32.06
3	473.85	176.15	27.10	0.81 e ± 0.22	1193.50 e ± 14.06
4	426.47	223.54	34.39	0.70 e ± 0.18	1260.88 d ± 23.84
5	383.82	266.18	40.95	1.20 d ± 0.14	1270.50 d ± 22.67
6	345.44	304.56	46.86	1.16 d ± 0.09	1399.48 c ± 13.15

n = 3 ;(*) mean ± standard deviation. Values in any one column with the same letter do not differ significantly at $p \leq 0.05$

CONCLUSION

As the sucrose content was gradually substituted in the standard cake formulation by xanthan gum and sucralose, there was a corresponding decrease in the viscosity of the batter, the specific volume and the formation of cells in the cake, showing that the sucrose plays an important role in the development of the batter, and in the uniform formation of the internal structure of light or diet cakes.

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