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Effects of polyols and nondigestible oligosaccharides on the quality of sugar-free sponge cakes

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Abstract

Interest in nutrition is driving consumer demands for less fat, sugar, and calories. In most foods, however, the removal or reduction of ingredients causes readily detectable losses in appearance, texture and mouthfeel. In this work seven bulking agents (maltitol, mannitol, xylitol, sorbitol, isomaltose, oligofructose and polydextrose) were used to totally replace sucrose in sponge cakes. The effect of this substitution on cake quality was determined by measuring texture, colour and volume after baking under controlled conditions. These parameters were established instrumentally and by sensory evaluation. Best results were obtained with xylitol and maltitol, leading to sponge cakes more similar to the control one – manufactured with sucrose – and with the highest acceptance level in sensory evaluations. Lower quality sponge cakes were those elaborated with mannitol.

Keywords: Sponge cake; Bulking agent; Maltitol; Mannitol; Xylitol; Sorbitol; Isomaltose; Oligofructose; Polydextrose; Physical properties; Sensory evaluation

1. Introduction

The food industry is being challenged to redesign traditional foods for optimal nutritional value, in response to some population sectors with particular nutritional necessities, and making them as tasty or better than the original. One way to achieve a healthy food product is to reduce or to omit some of the calorie-laden ingredients – especially sugar and fat – since, at present, obesity is frequently cited as a serious health problem. At the same time there is a constant demand for dietetic foods suitable for diabetics, that may have the same calorie-value being also sucrose-free since this sugar cannot be metabolised without insulin.

Sucrose is a principal ingredient in sponge cakes, and its role extends beyond providing energy and sweetness. In consequence, it cannot be substituted only by intense sweeteners. It acts as a tenderiser by retarding and restricting gluten formation, increasing the temperatures of egg protein denaturation and starch gelatinization, and contributing to bulk and volume (Kulp, Lorenz, & Stone, 1991; Ngo & Taranto, 1986; Shukla, 1995; Spies & Hoseney, 1982). Therefore, the reduction of sucrose levels in a cake system affects structural and sensory properties (Frye & Setser, 1991). It is, thus, necessary to investigate the substitution of traditional and nutritional sweeteners to generate healthier foods but maintaining, at the same time, original colour, texture and flavour (Altschul, 1993). Bulking agents, which replace the nonsweet functional characteristics of sucrose, can be used as alternatives to sucrose in bakery products (Beereboom, 1979; Deis, 1993; Giese, 1993), but none of them seems to possess all of sucrose's properties. In general, a combination of bulking agents seems to give better results.

Hess and Setser (1983) tested layer cakes sweetened with aspartame, and found that its combination with low levels of fructose led to cakes more tender, more uniform and with higher overall eating quality than the non-bulking aspartame layer cakes. Other authors have studied the replacement of sucrose in sponge cakes by

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some polyols and/or polydextrose, with or without non-nutritive sweeteners. Frye and Setser (1991) achieved a successful textural optimization of sponge cakes, replacing sucrose by bulking agents, but found that polydextrose – included in the optimized formula – had some bitter or astringent aftertaste and mouth-drying effect. Attia, Shehata, and Askar (1993) proposed a formula involving fructose, polydextrose, and non-nutritive sweeteners, which led to sponge cakes with similar acceptability to that of sugar cake with a 40% reduction in calories. Baeva, Panchev, and Terzieva (2000) studied the effect of total replacement of sucrose by microencapsulated aspartame and bulking agents, such as sorbitol, wheat starch, and wheat germ, on physical and textural sensory characteristics of sponge cakes. Substantial differences among sugar-free cakes and the control one were found.

Pateras, Howells, and Rosenthal (1994) studied the effect of sucrose replacement by polydextrose on foam characteristics of cake batters. Polydextrose caused an increase in the mean size of air bubbles, and introduced a larger variation in bubble size distribution in the cake batter. Hicsasmaz, Yazgan, Bozoglu, and Katnas (2003) found the same increase in the mean bubble size and showed that polydextrose was capable of imitating the sucrose cake batter in terms of bubble size distribution. Also, they found that increase in polydextrose resulted in a significant decrease in cake height and a sensible change in the lightness and in the crumb colour hue.

This work includes the first systematic study of the separate effect of seven bulking agents on the quality of sugar-free sponge cakes, assessed by means of sensory evaluation and physical measurements of texture, colour, and specific volume. Several polyols – maltitol, mannitol, xylitol, sorbitol, isomaltose – and two oligosaccharides – polydextrose and oligofructose – were tested as bulking agents. The last two were chosen by their added nutritional interest as substances with functional effects similar to soluble dietary fibre (Gómez, Ronda, Blanco, Caballero, & Apesteguía, 2003; Roberfroid & Slavin, 2000).

2. Materials and methods

2.1. Materials

Wheat flour (72% extraction), sucrose (commercial grade), butter, and fresh whole eggs were purchased from the local market, mannitol (*mannitol 60*), sorbitol (*neosorb P60*), xylitol (*xilisorb 300*) and maltitol (*maltisorb P200*) from Roquette Laisa, SA, Spain, oligofructose (*Raftilose P-95*) from Orafti Active Food Ingredients, Belgium, isomaltose (*Isomalt PF*) from Ebro Agrícolas S.L., Spain and polydextrose (*Litesse*) from Danisco Ingredients S.A. Spain. The emulsifier (*Super Mixo T500)*, and the baking powder (*Slow T500*) used were purchased from Puratos, SA, Spain.

Table 1
Cake formulations

Ingredients	Control (g)	Sugar-free cake (g)
Eggs	450	450
Flour	240	240
Sugar	240	–
Bulking agent	–	240
Emulsifier	20	20
Baking powder	8	8
Butter	200	200

2.2. Cake preparation

Formulations used for the sponge cakes are given in Table 1. Dietetic cakes were prepared by total substitution of sucrose by one of the following bulking agents: Mannitol, sorbitol, xylitol, maltitol, isomaltose, polydextrose, and oligofructose. A sponge cake elaborated with sucrose was used as control cake.

A single-bowl mixing procedure was used. Eggs, emulsifier and bulking agent tested – or sucrose in the control cake – were mixed, during 14 min at speed eight, using a Kitchen-Aid Professional mixer (K45SS). After that, the flour, together with the baking powder and the butter, were added and mixed. 350 g of cake batter were placed into a 200 mm diameter and 45 mm height, metallic, lard-coated pan, and baked for 33 min at 185°C. Eight cakes of each batter were baked, and each formulation was prepared in duplicate.

2.3. Evaluation of cake quality

2.3.1. Sample preparation

Cake quality attributes were evaluated after cooling during 3 h at (25 ± 2) °C. For crust and crumb attribute determinations, whole cakes were halved along the height. The upper half cake was used for crust evaluation and the lower one for crumb cake evaluation. Four cakes from the same batter were destined for physical measurements, and the other four, for sensory evaluation, by placing them on coded white plastic plates, covered with plastic wrap to prevent drying. Sensory evaluation took place during 4–8 h after cooling.

2.3.2. Physical measurements of sponge cakes

The volume of the cake was determined by seed displacement (Chopin, SA, Francia). The cake was weighed after removal from the pan and the specific volume was calculated by the ratio volume to weight.

Colour was measured using a Minolta spectrophotometer CN-508i (Minolta, Co. LTD, Japan). Tristimulus values were automatically calculated from the spectrum by means of a computer programme. Results were expressed in the CIE $L^*a^*b^*$ colour space and were obtained using the D65 standard illuminant, and the 2° standard observer (CIE 1931). Colour determinations were made 9 × 5 times in each cake: Crumb or crust cake colour was checked at nine different points on each cake and every point was measured five times. The nine points were positioned in the centre of the cake and in the centre of eight imaginary sectors in which it was divided along the diameter.

Crumb firmness was measured using a TA-XT2 texture analyser (Stable Microsystems, Surrey, UK) provided with the software "*Texture Expert*". An Aluminium 25 mm diameter cylindrical probe was used in a "*holding until time*" compression test. The probe speed during the test was 2 mm/s and the compression distance 10 mm. The peak force was measured in grammes.

In cake texture determinations, the crust was removed, and for each cake interior crumb was sliced into four (40 × 40× 20) mm samples to be measured.

Averaged results of two cakes elaborated with the same formula but different batter are presented in all physical measurements.

2.3.3. Sensory evaluation

Intensity and hedonic sensory evaluations of sponge cakes were carried out with two different panels in different sessions. Intensity sensory tests were conducted by fifteen panellists that had been trained in sensory evaluation, and had previous specific experience in the evaluation of reduced-calorie cakes. Panellists were oriented to the product in ten 45 min training sessions.

Hedonic sensory tests were conducted by 60 untrained panellists consisting of Agricultural Engineering College staff and students.

A one to nine rating scale was used for evaluating the intensity of flavour, sweetness, aftertaste, manual and mouth firmness, and uniformity in outward appearance of sugar-free cakes in comparison to the control one. In different cake samples and sessions, the same attributes were also evaluated on a hedonic scale, together with an overall acceptability test. In this context, nine meant extreme intensity or satisfaction, and one, extreme low intensity or dissatisfaction. The control cake was used as reference and was positioned on the middle of the scale, except in the overall acceptability evaluation, where the control sponge cake was presented simultaneously with the rest of samples and was evaluated in random order among panellists. Thus, figures obtained in the present work have to be taken in relative terms, except in the overall acceptability study.

For determining outward appearance whole cakes were presented to panellists. This attribute evaluated the crust uniformity. Texture, flavour, taste, and aftertaste evaluations were carried out in 2.54 cm/cube/cake crumb samples.

2.3.4. Statistical analysis

Data obtained were analysed using standard statistical packages for Windows™. Significance of differences between control and treated samples was evaluated using Duncan's multiple range test at the 5% level.

3. Results and discussion

3.1. Colour

Sponge cakes manufactured with bulking agents different from sucrose were in general lighter than sucrose cakes. As can be seen in Fig. 1 crust lightness (L^*) values of free-sugar cakes were always notably higher – up to 25% – than control cake, with the exception of oligofructose cakes. When this bulking agent was used, the resulting cake was darker than the control as confirmed by its L^* value, 18% lower than the control one. This was especially detected in crust, where Maillard reaction take place due to the higher temperatures attained. Crumb lightness was not so affected by sucrose substitution. Polydextrose led to the darkest cake crumb, showing a 10% decrease in lightness with respect to the control.

In Fig. 2, the colour hues of crumb and crust cakes are shown in a^*–b^* diagrams. The line that determines all colours with the same hue as the control cake – *iso-hue line* – is presented on the diagram too. The highest difference in crust hue was obtained with oligofructose, which led to a remarkable deviation 20° from yellow to red with respect to the control cake crust hue. This fact was associated with the increase in chromatic parameter a^* simultaneously with the decrease in parameter b^*. The isomaltose cakes also showed a significant difference of crust hue in relation to the control one, although slighter than oligofructose 7° and in the opposite sense. The rest of the bulking agents had no significant effect on crust or crumb colour hue.

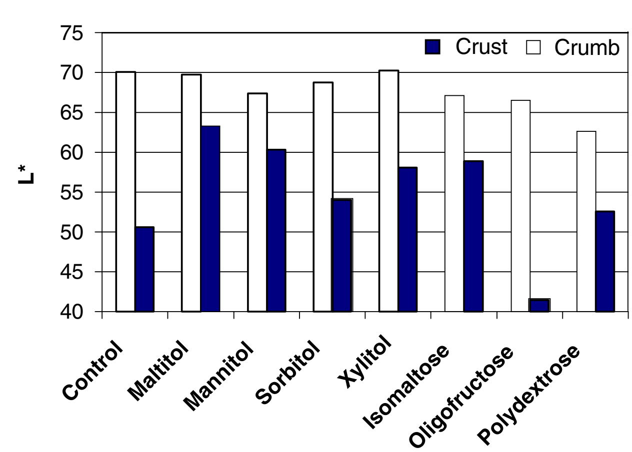

Fig. 1. Lightness of crumb and crust of sponge cakes elaborated with different bulking agents and with sucrose (control).

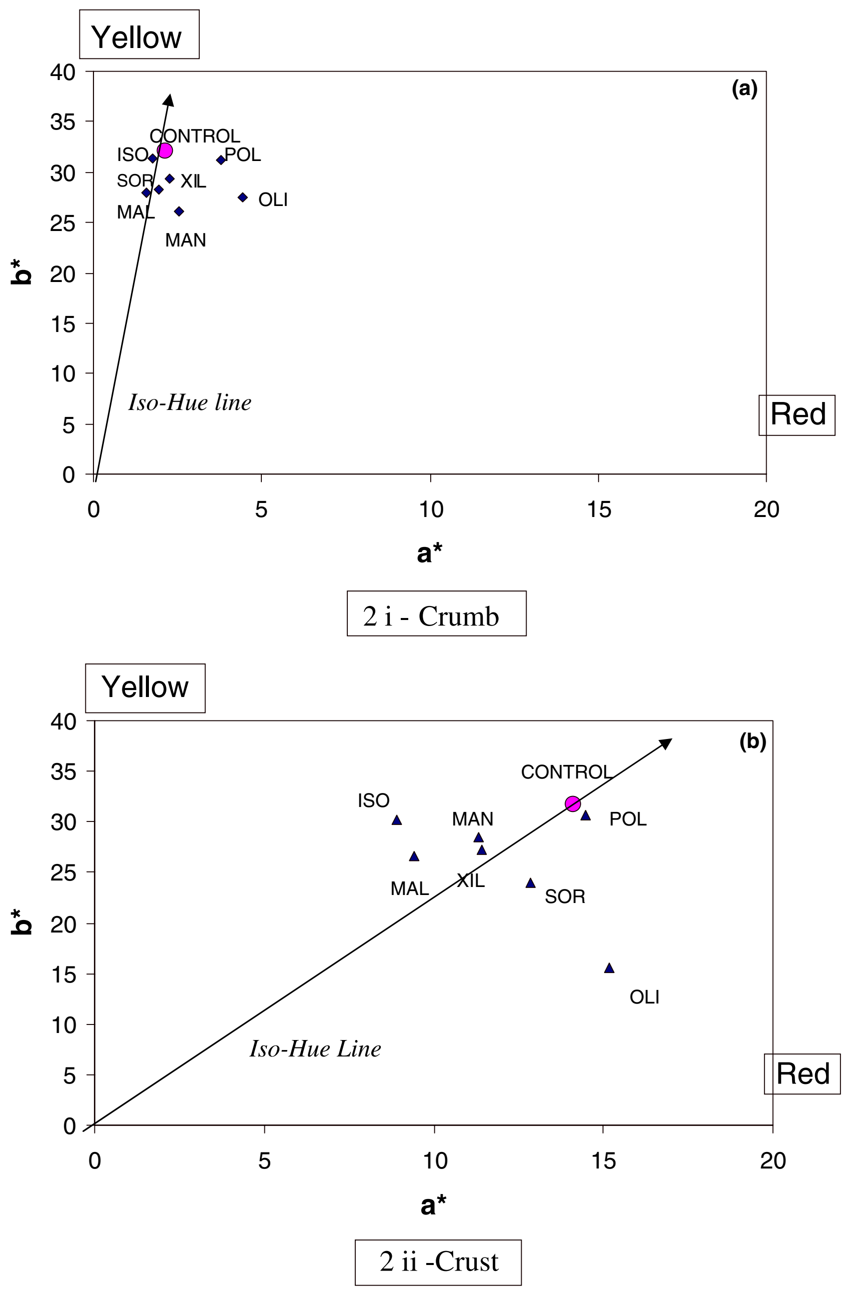

Fig. 2. Localisation in the plane a^*b^* of chromatic coordinates of crumb (2i) and crust (2ii) of sponge cakes elaborated with sugar (control) or with different bulking agents: MAL (maltitol), MAN (mannitol), XIL (xylitol), SOR (sorbitol), ISO (Isomaltose), OLI (oligofructose), POL (polydextrose). Iso-hue line specify colours with the same hue than control.

Differences detected in the colour of cakes, especially crust lightness, can be related to the fact that sugar alcohols do not undergo Maillard reactions (Bennion & Bamford, 1997; Lin, Hwang, & Yeh, 2003) while oligofructose and polydextrose are able to promote browning reactions as a result of thermal degradation.

3.2. Specific volume

Sugar-free cakes showed always specific volumes lower than sugary ones (Fig. 3). However, while xylitol, sorbitol and oligofructose cakes showed density values close to the control ones, mannitol cakes had specific volumes notably lower than the control (33%). This fact was associated with the higher crumb firmness measured on fresh sponge cakes manufactured with mannitol.

The decrease in sugar-free cake expansion seems to have two main causes: Decrease in batter stability during the heating stage – related to batter viscosity decrease and foam bubble size increase – and changes in the thermosetting mechanism, due to different interactions among the bulking agent used and starch and

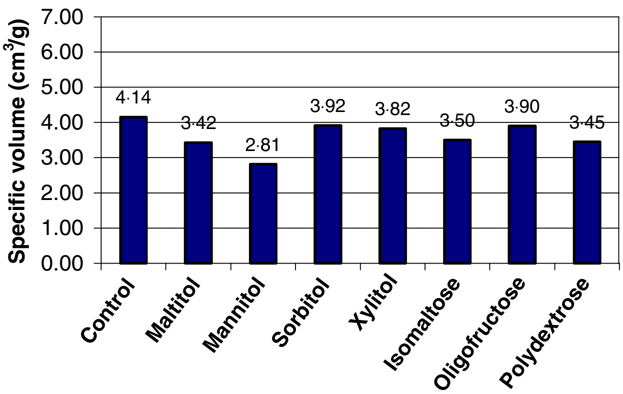

Fig. 3. Specific volume of fresh sponge cakes elaborated with different bulking agents and sucrose (control).

proteins of the batter that affect starch gelatinization and protein denaturation temperatures. A decrease in any of these temperatures is expected to cause a premature thermosetting of protein or starch matrix, which will start at the crust due to direct contact with the heating medium. This, then, lowers the heat transfer rate, and produces a vapour pressure build-up, causing inadequate expansion of individual bubbles (Hicsasmaz et al., 2003; Stauffer, 1990).

3.3. Firmness

The effect of total substitution of sugar, by bulking agents, on crumb firmness of sponge cake is shown in Fig. 4. In general, sugar-free fresh cakes had significantly softer crumb textures than the control. Pieces prepared with xylitol produced the highest firmness decrease (nearly 50%). Only fresh cakes made with mannitol showed a marked increase in firmness, which was related to the high density of these cakes as suggested above.

The crumb firmness evolution during a storage period of 4 days showed the different and important effects on cake lifetime of the different bulking agents tested. As can be seen in Fig. 4, isomaltose showed a great effect in delaying cake hardening during the period studied. When oligofructose, polydextrose or mannitol were used, however, crumb firmness increased notably, showing, at the fourth day, a hardening effect between 33% and 49% with respect to those of the control. Sorbitol, maltitol, and xylitol cakes, though, showed textural properties very close to the control ones. These effects are mainly associated with the differences in water binding capacities – related to water loss facilities during storage – of the different bulking agents tested, and with their interactions with starch, that would affect the starch retrogradation.

Results obtained with textural measurements of fresh cakes were corroborated by sensory evaluation as explained in the following section. The excellent behaviour of isomaltose cakes during storage could not be confirmed because sensory tests were only realized on fresh cakes.

3.4. Sensory evaluation

Averaged results of sensory evaluation attributes of sugar-free sponge cakes are summarised in Table 2. As can be seen, polydextrose and oligofructose led to the highest flavour intensity sponge cakes, while mannitol cakes were the least flavoured. In spite of this, the hedonic panel did not find any significant difference in preference with regard to this attribute. In relation to sweetness, the sponge cakes elaborated with xylitol were the closest to the control one, followed by those made

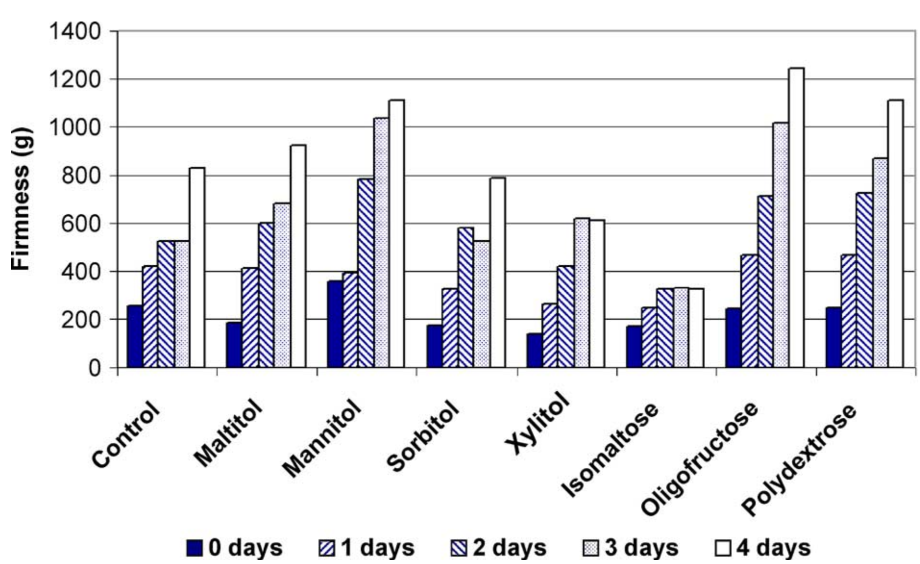

Fig. 4. Effect of bulking agent used on crumb firmness of fresh sponge cake (0 days storage) and its evolution after 1–4 days of storage.

with maltitol or sorbitol. Cakes elaborated with oligofructose and polydextrose were least sweet. These results agree with the sweetener power of polyols and oligosacarides (Altschul, 1993).

With regard to aftertaste, the cake most appreciated, even more than the control, was the xylitol sponge cake, followed by the maltitol one. The low score achieved by oligofructose and polydextrose sponge cakes is remarkable.

Texture sensory evaluation was in good agreement with instrumental measurements (Fig. 5). Depending on the bulking agent used, significant differences in sponge cake texture – manual and mouth firmness – were obtained. In spite of this, the hedonic panel did not show any significant difference in preference with regard to that attribute. Only mannitol sponge cakes had significant lower score than the rest on the hedonic scale.

Sponge cakes elaborated with mannitol, isomaltose and sorbitol have the least uniform crust surface. The rest of the bulking agents tested led to sponge cakes more uniform than the sucrose one.

Fig. 6 shows averaged sensory scores for the overall acceptability of sponge cakes elaborated with the different bulking agents tested. Those prepared with xylitol were closest to the control cake, and more appreciated by panellists than the rest of sugar-free cakes. It can be seen in Fig. 6 that it is also possible to obtain suitable sponge cakes using maltitol as a substitute for sucrose.

Panellists assigned the lowest score in overall acceptability to mannitol cakes, followed by oligofructose and polydextrose ones. The poor sensory scores given to the oligofructose and polydextrose cakes were mainly related to taste and aftertaste. This agrees with sensory

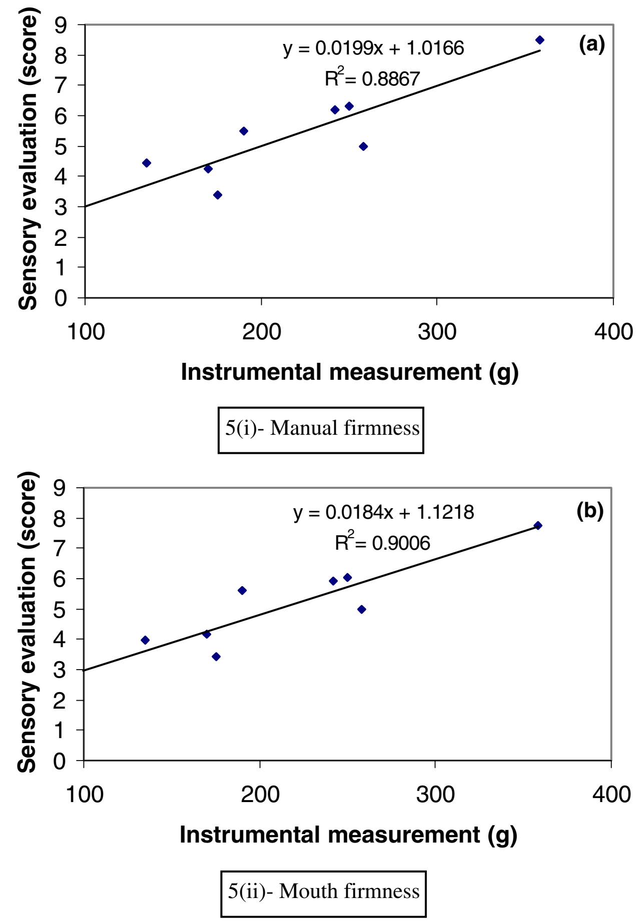

Fig. 5. (i) Manual firmness. (ii) Mouth firmness obtained by sensory analysis versus firmness values obtained with the texturometer.

Table 2
Sensory evaluation of sugar-free sponge cakes in comparison with the control one (sugar cake) which was taken as reference and arbitrarily positioned in the middle of a 1–9 scale

	Maltitol	Mannitol	Sorbitol	Xylitol	Isomaltose	Oligofructose	Polydextrose
Flavour							
Intensity	4.31b	2.14a	4.20b	3.92b	3.81b	6.48c	6.23c
Hedonic scale	4.80a	3.24a	4.47a	4.69a	4.41a	4.24a	4.32a
Taste							
Sweetness	4.32cd	2.99ab	3.66bc	4.82d	2.99ab	2.44a	2.86a
Hedonic scale	4.54cd	2.87ab	3.87bc	5.15d	2.93ab	2.37a	2.28a
Aftertaste							
Intensity	4.66ab	3.05a	4.10ab	5.46b	3.27a	5.21b	5.32b
Hedonic scale	4.59bc	3.09a	3.92ab	5.66c	3.59ab	2.70a	2.85a
Texture							
Manual firmness	5.49bc	8.49d	3.38a	4.43ab	4.26ab	6.21c	6.32c
Mouth firmness	5.60b	7.76c	3.43a	3.99a	4.15a	5.93b	6.02b
Hedonic scale	4.47b	2.24a	4.36b	4.70b	4.30b	4.19b	4.35b
Appearance							
Uniformity	5.27bc	3.10a	4.44ab	6.99d	3.22a	6.27cd	6.20cd
Hedonic Scale	4.90bc	3.32a	4.21ab	5.99c	3.93ab	4.05ab	4.16ab

Values under five mean lower intensity or satisfaction than control and over five mean higher intensity or satisfaction in the attributes studied.

The values presented are the averages obtained from four cakes prepared with the same formula in two batters. Values in the same file with the same letter are not significantly different at $P = 0.05$.

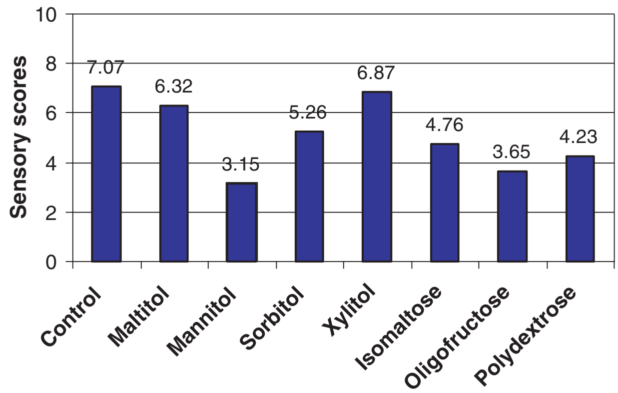

Fig. 6. Sensory scores for overall acceptability of sponge cakes elaborated with different bulking agents and sucrose (control). The control cake was evaluated in a random order among panellists.

evaluation attributes already mentioned (Table 2) and it shows the great contribution of these two attributes to the overall acceptability. The lack of sweetness and a bitter aftertaste were the most common descriptive information given by panellists.

4. Conclusion

Replacement of sucrose in the elaboration of sponge cakes to give products of very similar characteristics and with good consumer acceptance can be achieved.

Among the seven bulking agents tested, xylitol was the best substitute since the sponge cakes elaborated with it gave sensory evaluations scores – especially hedonic ones – very similar to those of sugar cake, even surpassing it in some attributes such as taste, aftertaste, and outward appearance. The only handicap of this bulking agent, apart from its high price, is its inability to cause Maillard reactions. As a consequence, sponge cakes are paler than those manufactured with sucrose or other bulking agents, which are able to promote these browning reactions, directly or as consequence of thermal degradation. In this sense, in spite of the bad results obtained in general with oligofructose and polydextrose, addition of small amounts of these oligosaccharides to correct the excessively clear colour of sugar-free cakes elaborated with polyols could be interesting. Furthermore, these compounds hold much promise as functional ingredients in nutraceutical products.

Maltitol was also considered as a viable alternative to sucrose although it led to lower scored cakes than those elaborated with xylitol. On the contrary, mannitol proved to be the worse substitute of sucrose among all the bulking agents tested.

Further work to optimise the final formula testing different combinations of xylitol, maltitol, polydextrose and/or oligofructose, is underway. The convenience of adding non-nutritive sweeteners is also to be established.

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