Journal of Food Quality

Journal of Food Quality ISSN 1745-4557

TEXTURAL AND SENSORY CHARACTERISTICS OF RICE CHIFFON CAKE FORMULATED WITH SUGAR ALCOHOLS INSTEAD OF SUCROSE

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Received for Publication May 20, 2013
Accepted for Publication January 23, 2014

10.1111/jfq.12083

ABSTRACT

We measured the stability and the sensory and textural properties of rice chiffon cake batter and cake prepared with various sugar alcohols in place of sucrose. Mannitol substitution increased batter stability by 30% that of sugar cake and specific volume, allowing greater air retention than that achieved with other polyols, as well as formation of networks with equal cells. Nevertheless, the 100% sensory score of mannitol-substituted cake was low because of dryness. In contrast, maltitol, sorbitol and xylitol had no effect on the textural properties of cake batter and baked products. The sweetness and overall acceptability of chiffon cakes prepared with maltitol, sorbitol and xylitol, but not mannitol, were similar to those of sugar-added rice chiffon cake. In conclusion, maltitol, sorbitol and xylitol can be used to prepare low-calorie, gluten-free rice chiffon cake without affecting its quality.

PRACTICAL APPLICATIONS

Previous studies have reported rice flour substitutions of 0–100% in products such as sponge cake, yellow layer cake, butter cake and chiffon cake. The use of sugar alcohols (polyols) as bulking agents for low-calorie baked products has been tested previously. In this study, maltitol, sorbitol and xylitol could replace sucrose in rice chiffon cake with no significant changes in batter stability or baking and sensory properties. However, mannitol had an unfavorable impact on textural and sensory qualities, although it increased batter stability and loaf volume of the baked cake.

INTRODUCTION

Rice flour-based bakery products have become popular for their health-promoting properties, such as ease of digestion, hypoallergenic nature and bland taste. The baking industry has worked to create re-designed and innovative products using various grains and calorie-reduced ingredients to satisfy consumer demand. Natural gluten-free rice can be ideal for patients suffering from celiac disease and chronic diarrhea (Hartsook 1984). Substitution of wheat with rice flour in cakes and muffins reportedly does not affect the textural and sensory properties of these products (Kim *et al.* 1994; Dilek *et al.* 2007; Sari *et al.* 2008). Rice proteins are devoid of the elastic and plastic properties, a characteristic of wheat gluten (gliadin + glutenin), which are essential for preparing bread and other baked products (Lumdubwong and Seib 2000; Sivaramakrishnan *et al.* 2004). Most rice proteins are very hydrophobic and resist swelling in water at neutral pH (Baik *et al.* 2008); therefore, rice flour is thought to produce inconsistencies in baked products such as chiffon cakes, which are very light. However, we have previously prepared good-quality gluten-free chiffon cakes using rice flour (Kim and Shin 2009).

Chiffon cakes are categorized as unshortened or relatively low-fat cakes (Lin *et al.* 2003; Kim and Shin 2009) and have a unique structure and texture due to air bubbles dispersed in an egg yolk–vegetable oil emulsion by carefully folding the emulsion into egg white foam. The resultant batter is composed of a complex dispersion containing numerous air bubbles and dispersed fat globules in the same continuous phase. However, owing to their low saturated fat content (vegetable oil instead of butter) (Nutrition.com 2012), chiffon cakes are considered a healthier choice than traditional butter cakes, although the other principal ingredient, sucrose, is associated with lipogenesis and obesity (Ngo and Taranto 1986; Psimouli and Oreopoulou 2012). Many studies have explored the use of sugar alcohols (polyols) as bulking agents for low-calorie baked goods (Frye and Setser 1991; Attia *et al.* 1993; Baeva *et al.* 2000; Hicsasamaz *et al.* 2003; Lin *et al.* 2003; Hiroaki 2005; Dilek *et al.* 2007; Adisak 2009; Kim and Shin 2009; Samuel *et al.* 2010).

Sugar can tenderize cakes by restricting gluten formation and retarding starch retrogradation and can contribute to cake volume (Ronda *et al.* 2005). Sugar adds viscosity to the solution and stabilizes the emulsion and foam system in the cake batter by increasing the interfacial density among the dispersed droplets. However, reduction or substitution of sugar in baked products has become a priority owing to consumer demands for dietetic and diabetic alternatives (Lombardo *et al.* 1996). Polyols have been promoted as sugar substitutes because of their low glycemic index and because they generate reduced insulin response, which make them suitable sweeteners for diabetics and for use in low-carbohydrate diets. The caloric value proposed by the EC (European Commission) for all polyols is 2.4 kcal/g (Deis 1994), whereas the Federation of American Societies for Experimental Biology reported values ranging from 1.6 to 3.0 kcal/g (Billaux *et al.* 1991). The caloric values for the sugar alcohols used in this study (1.4–2.6 kcal/g) were lower than that of sucrose (4 kcal/g). In addition, polyols have other advantages for human health: (1) they are non-cariogenic, as they are poorly metabolized by oral microbes (Daniel 1994); and (2) they are only partially metabolized and require less insulin for their metabolism than does sucrose (Finer 1991; Wennerholm *et al.* 1991).

We investigated the effects of sucrose replacement with different sugar alcohols on cake batter stability using the light scattering method; cake structure and sensory qualities such as color, flavor and taste were also examined.

MATERIALS AND METHODS

Materials

Rice flour was purchased from Rizen Co., Ansung, Korea; the flour was sifted through 200 mesh prior to use. In our previous studies (Kim and Shin 2009), proximate composition analysis of rice flour sifted through a 200 mesh revealed higher protein (6.6 ± 0.0) and ash content (0.3 ± 0.0), but lower moisture (8.5 ± 0.2), fat (0.5 ± 0.0) and carbohydrate content (84.1), than wheat flour. Eggs, sugar, grape seed oil (CJ Co., Seoul, Korea) and baking powder (Jenico, Nord, France) were purchased from local markets. Sugar alcohols, such as sorbitol (D-sorbitol) maltitol (Maltisorb P35), xylitol (Xylisorb 60) and mannitol (Mannitol 60), were kindly provided by Roquette (Roquette Korea, Seoul, Korea). The batter was prepared using a Braun multi-mixer (model 4642, Braun, Madrid, Spain).

Preparation of Rice Chiffon Cake with Sugar Alcohols

The formulas for rice chiffon cakes with different levels of sugar alcohols are shown in Table 1. Sugar was replaced with 0, 25, 50, 75 and 100% (w/w) of each sugar alcohol. Cakes were prepared as follows: egg yolk and sugar were poured into a mixing bowl and mixed for 1 min at speed 2 (20,000 rpm), using a hand mixer (Braun multi-mixer, model 4642, Braun). Grape seed oil and water were added drop by drop into a mixing bowl and mixed for 1 min at speed 2 (20,000 rpm). After thorough mixing, rice flour and baking powder were sifted into this mixture and were softly mixed by hand until a smooth texture was attained. In a separate bowl, the egg whites were beaten for 3 min at speed 3 (30,000 rpm). The whipped egg white was folded into the flour–liquid mixture using a rubber spatula. The cake batter was immediately poured into chiffon cake pans (diameter of 18 × 9 × 11 cm) and baked at 160C for 40 min in a pre-heated oven.

Batter Stability

The dynamic phase properties of the cake batter were evaluated as described previously (Kim and Shin 2009). Briefly, 50 mL of batter samples was placed in capped vials and scanned using a Turbiscan (Turbiscan Lab Expert, Formulaction, L'Union, France) at intervals of 2 min for 1 h; data were automatically calculated as transmitted or backscattered light flux as a percentage of standards as a function of sample height. Creaming stabilities were plotted

TABLE 1. FORMULAS FOR RICE CHIFFON CAKES

		(Unit: g)				
		0%§	25%	50%	75%	100%
Flour	Rice flour†	90	90	90	90	90
	Baking powder	4	4	4	4	4
Emulsion	Egg yolk	50	50	50	50	50
	Sugar	45	33.75	22.5	11.25	0
	Sugar alcohol‡	0	11.25	22.5	33.75	45
	Grape seed oil	60	60	60	60	60
	Water	60	60	60	60	60
Foam	Egg white	115	115	115	115	115
	Sugar	60	45	30	15	0
	Sugar alcohol	0	15	30	45	60
Total weight		484	484	484	484	484

† Rice flour size: 200 mesh.
‡ Sugar alcohol: sorbitol, maltitol, xylitol, mannitol.
§ Control sample: Chiffon cake prepared with rice flour and sugar.

as a function of time. The operating principles of Turbiscan are as follows. Dispersion is contained in a cylindrical glass cell. The light source is an electroluminescent diode in the near infrared ($\lambda = 880$ nm). Two synchronous optical sensors receive light transmitted through the sample (180° from the incident light, transmission sensor) and light backscattered by the sample (45° from the incident radiation, backscattering detector). Turbiscan measures the backscattering and transmission intensities versus sample height to detect particle size changes (coalescence, flocculation) and phase separation (sedimentation, creaming) (Formulaction Smart Scientific Analysis 2009).

Baking Test

Specific gravity was measured as the ratio of the weight of a volume of cake batter to the weight of an equal volume of distilled water at room temperature (Lee and Hoseney 1982). Specific loaf volume was determined by rapeseed displacement as follows. First, an empty bowl was filled with rapeseed and the volume (V1) was measured using a graduated cylinder. Then, the bowl with the chiffon cake was filled with rapeseed, and the volume (V2) was measured as described before (Hardeep and Cristina 2004).

The enthalpy of a homogeneous system is defined as follows:

$$H = E + pV \tag{1}$$

where H is the enthalpy of the system (enthalpy of polyols); E is the internal energy of the system (water, fat, sugar and so on); p is the pressure of the system (baked controls); and V is the volume of the system (specific volume of samples).

In other words, $(H - E)/p = V$ was represented by equations. If our values of E and p were regarded as equivalent, the change in enthalpy would be proportionate to the increase in the volume of the cake sample.

Instrumental Texture Properties and Cake Color

Textural profiles were analyzed using a TA-XT2i texture analyzer (Stable Microsystems, Surry, U.K.). A 50-mm compression probe was used to compress the midsection of each cake to 80% its size (test time: 2.0 mm/s and compressed twice). The size of the prepared sample was $1.5 \times 1.5 \times 1.5$ cm. Each sample was compressed twice to produce two compression curves (A1 and A2), with the second compression following immediately after the upper plate returned to the sample's original height. The load cell (25 kg) was calibrated using a 5-kg weight.

Texture profile was used to determine instrumental adhesiveness, springiness, cohesiveness and chewiness of the cake samples. TPA determinations were made 3×3 times for each cake. Color was determined by the Hunter Lab Colorimeter model. Crust and crumb color were evaluated using a chroma meter (CP-400, Minolta Co., Osaka, Japan) with a 50-mm (diameter) measuring tube. L, a and b values denote white–black, red–green and yellow–blue, respectively. Color determination tests were performed 9×4 times in each cake. Crumb or crust color was checked at 9 points on each cake, and every point was measured four times.

Sensory Evaluation

Chiffon cakes formulated with 75% sugar alcohol replacement were selected for presensory evaluation. Intake of all polyol-containing cakes, except the mannitol-substituted cake, was 25–30 g/day. The mannitol-containing cake was consumed at 10 g/day. The panel sampled cakes with five different substitutions at the same time. Past an optimum intake level, stomach ache, emesis and diarrhea may occur; therefore, the 75% substituted cakes were used in this evaluation. A panel of 100 individuals, randomly recruited from the Department of Food and Nutrition (Hanyang University, Seoul, Korea), evaluated the sensory properties of the cakes and scored crust and crumb color, flavor, loaf volume, air cell size, sweetness, moistness, stickiness and overall acceptability on hedonic scales. The samples were randomized and coded with a 3-digit number. The panelists were instructed to rinse their mouths with water before tasting each sample.

Statistical Analysis

All preparations and determinations were carried out in triplicate, and the results were expressed as mean ± standard deviation (except the sensory evaluation). All data were analyzed using the Statistical Package for the Social Sciences (SPSS) 14.0 (SPSS, Inc., Chicago, IL). Analysis of variance with Duncan's multiple comparison test was performed, and significant differences were determined at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Sugar Alcohols and Batter Stability

Regular section analysis from 0 to 20 mm differentiated the backscattering flux (%) profiles of all samples (Fig. 1). Typical coalescent processes occurred with the use of sugar and sugar alcohols. Major destabilization phenomena that affect dispersion homogeneity include particle migration (creaming, sedimentation), particle size variation and particle aggregation (coalescence). Specifically, the coalescent processing of the batter significantly differed with the amount of sugar alcohol (mannitol sample) ($P < 0.05$).

Mannitol substitution significantly increased batter stability by 30% in a concentration-dependent manner

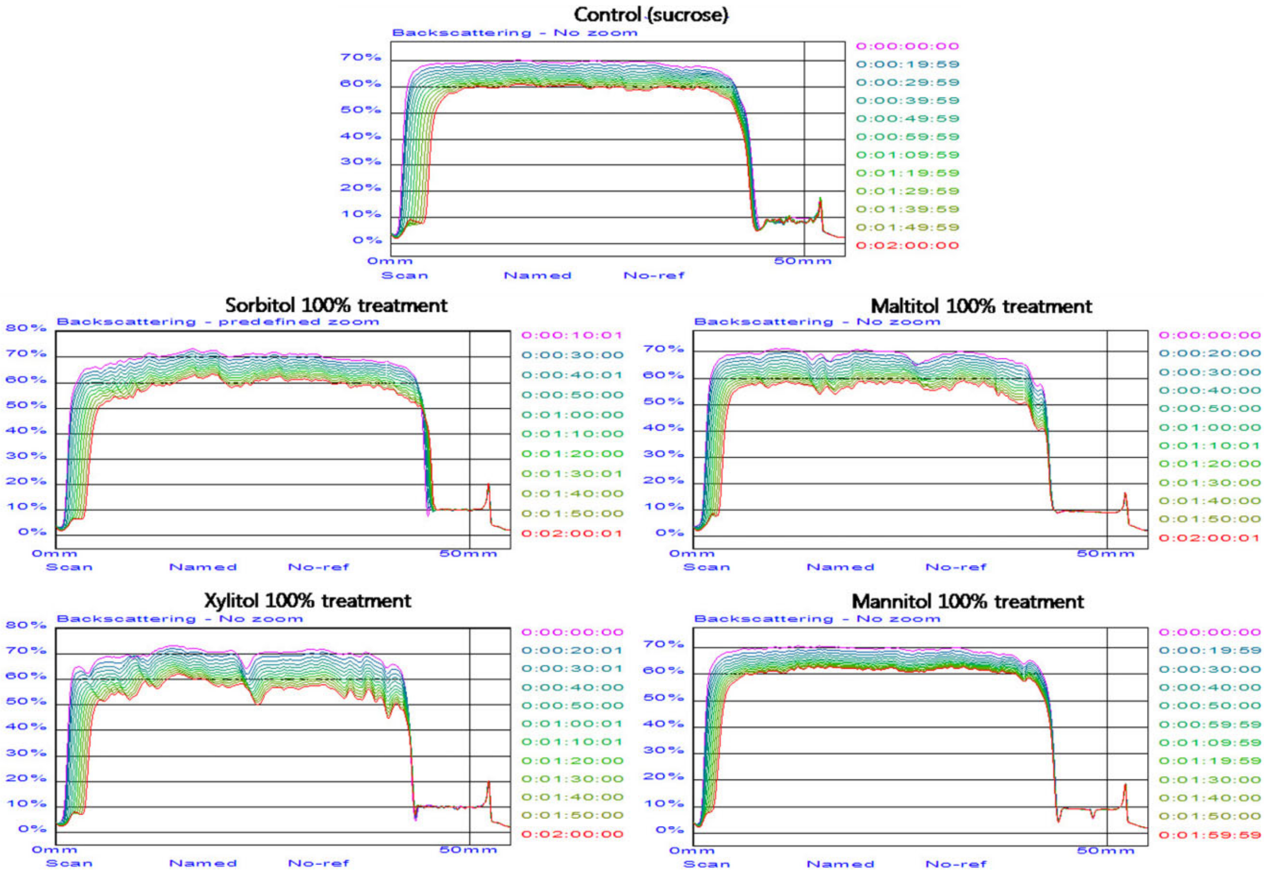

FIG. 1. BATTER STABILITY (%) AT VARYING SUGAR ALCOHOL LEVELS

(25–100%). The increased batter stability and increased specific loaf volume obtained with mannitol substitution might be related to the decrease in batter viscosity or foam size.

Total replacement of sucrose with sorbitol or xylitol slightly reduced batter stability ($P > 0.05$). Sugar alcohols are low-calorie sugar substitutes, distinguished from other saccharides by their reduced aldehyde and ketone functions (Hiroaki 2005; Formulaction Smart Scientific Analysis 2009). Moreover, sugar alcohols have high chemical stability, high affinity to water and low capacity for crystallization and the Maillard reaction (Hiroaki 2005). According to Peteras *et al.* (1994) and Hicsasamaz *et al.* (2003), polydextrose increased mean air bubble size and introduced a larger variation in bubble size distribution in the cake batter. The choice between reducing the sugar content and substituting the sugar can be difficult, depending on the food matrix because sugar, apart from sweetening, tenderizes products by facilitating the incorporation of air in the batter (Paton *et al.* 1981; Kocer *et al.* 2007). Cake quality is strongly associated with its aerated structure, which is achieved by the incorporation of air during mixing as well as by the development of bubbles during baking. A batter with low stability will fail to entrap or retain sufficient air during mixing and baking, producing a cake with decreased volume. Thus, batter stability is an important factor in the aeration of the final product because it determines not only initial air bubble incorporation but also the air-holding capacity of the batter during baking. Our results showed that polyols (with the exception of mannitol) do not affect the stability of rice chiffon cake batter.

Sugar Alcohols and Baking Properties

The specific gravity of the cake batter and the specific loaf volume of the chiffon cake formulated with sugar and sugar alcohols are shown in Table 2. Cake appearances are shown in Fig. 2. Sugar alcohol substitution slightly increased the specific gravity of the cake batter; however, there were no significant differences among the batters prepared using different sugar alcohols.

In our previous study, a decrease in specific gravity increased specific loaf volume (Kim and Shin 2009). Polyol

TABLE 2. BAKING PROPERTIES OF RICE CHIFFON CAKES WITH DIFFERENT SUGAR ALCOHOL CONTENTS

	Blend (%)	Sorbitol	Maltitol	Xylitol	Mannitol
Specific loaf volume (mL/g)	0†	457.79 ± 46.15^a			
	25	500.76 ± 58.48^a	512.95 ± 45.53^a	477.41 ± 45.36^a	506.07 ± 60.35^a
	50	493.28 ± 65.76^a	517.52 ± 40.75^a	491.44 ± 64.16^a	551.36 ± 48.26^a
	75	507.61 ± 63.72^a	529.12 ± 26.28^a	483.55 ± 55.30^a	625.72 ± 29.97^a
	100	501.49 ± 89.01^a	514.76 ± 60.79^a	505.20 ± 36.69^a	667.58 ± 31.93^b

Values are expressed as mean ± standard deviation. Values within a column with different superscripts significantly differ at $P < 0.05$ by Duncan's multiple range tests.

† Control sample: Chiffon cake prepared with rice flour and sugar.

substitution (except substitution with mannitol) did not significantly affect specific gravity or specific loaf volumes. Although the specific gravity of the batter formulated with mannitol was the same, the specific loaf volume of the baked cakes was highest with 100% mannitol substitution. These results suggest that cake batter containing mannitol retains more air, which results in the formation of tunnels with equal air cells in the baked product. These properties were associated with the decreased adhesiveness and chewiness of fresh rice chiffon cakes containing mannitol. Lombardo *et al.* (1996) found that mannitol-containing cakes had notably higher specific volumes than the control, cakes prepared using other polyols (maltitol, sorbitol, xylitol, isomaltose, oligofructose and polydextrose) and cakes prepared using other digestible oligosaccharides. In contrast, Ronda *et al.* (2005) reported that sugar alcohol negatively affected the quality of sponge cakes because the specific volume and sensory scores of sugar-free sponge cakes were lower than those of sugar-containing cakes; this was particularly true for mannitol-substituted cakes. These results are variably consistent with our results, in that the crust of cake containing mannitol had a hard, dry texture (Table 5). Furthermore, Ronda *et al.* (2005) reported that the enthalpy and heat capacity values were higher for mannitol than for other polyols (e.g., sorbitol, maltitol, xylitol, glucose and fructose). In general, enthalpy is a measure of the total energy of a thermodynamic system. This includes the internal energy, which is the energy required to create a system, and the amount of energy required to make room for it by displacing its environment and establishing its volume and pressure (Lian *et al.* 1982). This theory lends credence to our results. Although the chiffon cake is a

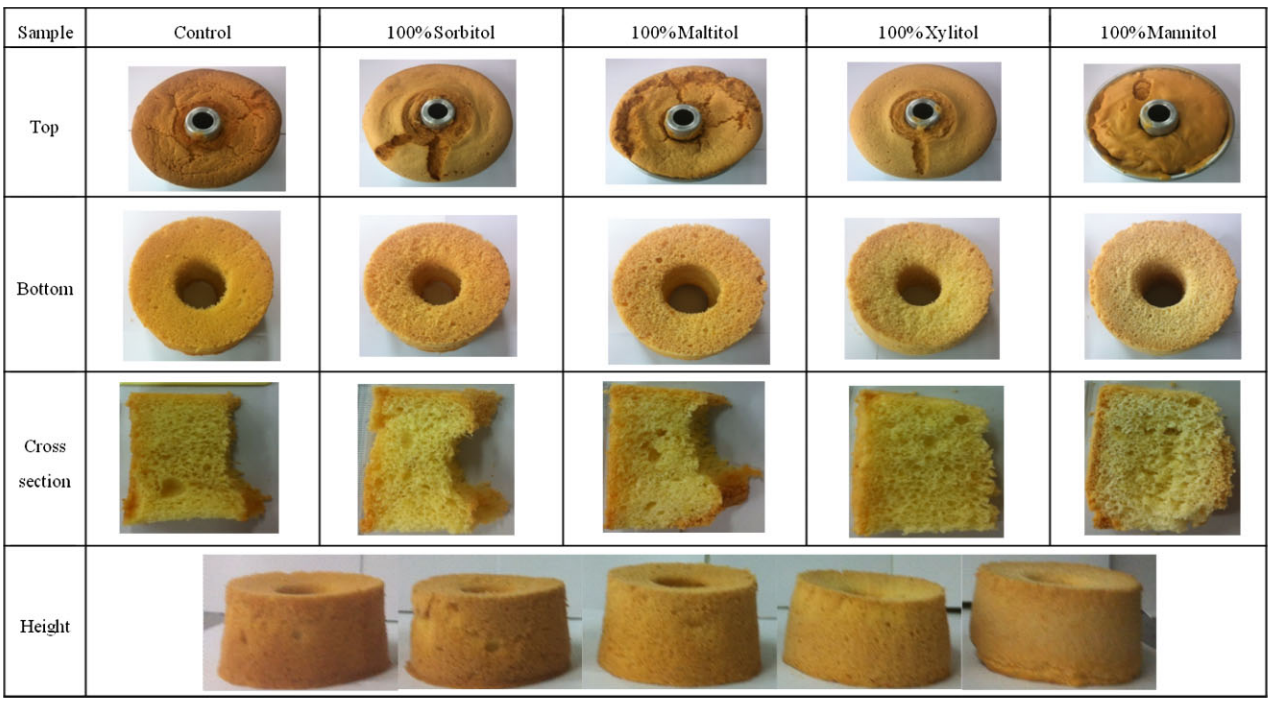

FIG. 2. RICE CHIFFON CAKES WITH DIFFERENT SUGAR ALCOHOLS

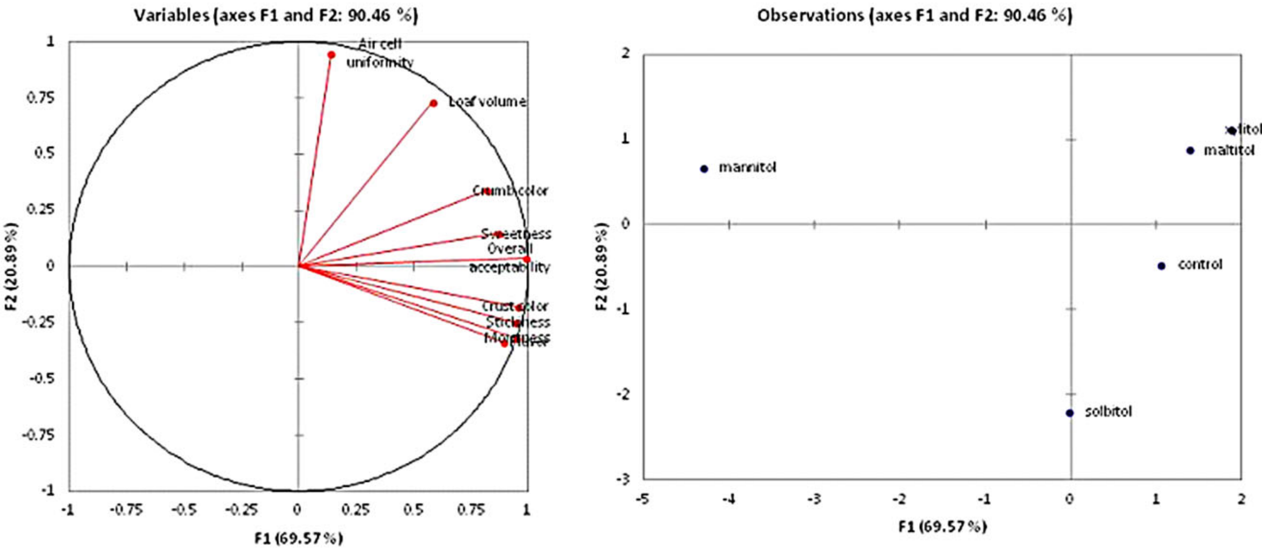

FIG. 3. PRINCIPAL ANALYSIS OF RICE CHIFFON CAKES PREPARED WITH DIFFERENT SUGAR ALCOHOLS

complex system, it is significantly affected by the sugar or sugar alcohol content in the meringue. Therefore, the specific loaf volume of the 100% mannitol cake was higher than that of other samples. This property also influenced the sensory evaluation results ($P < 0.05$), as shown in Fig. 3. The sensory scores for mannitol cakes were the lowest of all tested cakes. Thus, our results suggest that different polyols (sorbitol, maltitol, xylitol and mannitol) may produce different effects on cake volume during preparation, thereby by altering volume estimates.

Sugar Alcohols and Instrumental Texture Properties

Previous studies showed that fresh sugar-free cakes have significantly softer crumb textures than controls (Hess and Setser 1983). However, the textural measurements in this study suggest that all the sugar alcohol substitutions produced hardness and gumminess (data not shown) values similar to that of the control cake. Table 3 shows that sugar alcohol substitutions yielded no significant differences in textural properties, including hardness and gumminess. In the mannitol treatment, adhesiveness, springiness, cohesiveness and chewiness profiles were significantly different. Cakes containing 75 and 100% mannitol were significantly less chewy than the control. Complete mannitol substitution reduced adhesiveness, springiness, cohesiveness and chewiness of crumb, which is consistent with the observed sensory properties of dryness and softness. These effects can be attributed to the differences in the water-binding capacities of the different bulking agents and to their interactions with starch, which would affect starch retrogradation, as described by Lombardo *et al.* (1996). In preliminary studies, the water content of sugar alcohol cakes was similar to that of the controls (data not shown). The dryness of mannitol-substituted cake can be attributed to the higher enthalpy of mannitol, which would increase the amount of energy required for baking. We conclude that the dry texture of mannitol cake was due to this thermodynamic principle.

Sugar Alcohols and Color Values

The colors of rice chiffon cakes prepared using polyols were compared with those of sucrose cake (Table 4). "L" (lightness) values for sugar alcohol-substituted cakes (crust) were not significantly higher than that of the control cake ($P < 0.05$). However, crust lightness was significantly higher in the mannitol cake samples than in the other samples. When mannitol was used, the resulting cake was darker than the control. This was particularly true for the crust, where the Maillard reaction occurs owing to the high temperatures attained. The L value of crumb color did not significantly differ between formulations. Crumb redness ("a" value) of 100% sorbitol-, 100% maltitol-, all xylitol-substituted cakes and of 50 or 100% mannitol-substituted cakes was significantly lower than that of sugar-containing cakes. Lin *et al.* (2003) reported that the color of cakes prepared with 75 and 100% erythritol became lighter, less red and less yellow compared with controls; there was no significant increase in crust color when using 25 and 50% erythritol relative to that of cakes prepared using a 100% sucrose formulation. Because of their thermal stability, polyols are degraded at high temperatures attained in the crust, allowing them to react with amino acids through

TABLE 3. TEXTURE OF RICE CHIFFON CAKE WITH DIFFERENT SUGAR ALCOHOL CONTENTS

	Blend (%)	Adhesiveness (g)	Springiness	Cohesiveness	Chewiness (g)
Control	0†	–64.84 ± 19.14[a]	0.61 ± 0.13[a]	0.53 ± 0.04[a]	295.38 ± 72.18[a]
Sorbitol	25	–59.87 ± 7.16[a]	0.53 ± 0.10[a]	0.53 ± 0.02[a]	248.87 ± 56.05[a]
	50	–78.92 ± 19.89[a]	0.59 ± 0.17[a]	0.51 ± 0.04[a]	286.93 ± 101.73[a]
	75	–80.88 ± 13.02[a]	0.58 ± 0.16[a]	0.50 ± 0.04[a]	244.08 ± 74.35[a]
	100	–87.24 ± 21.50[a]	0.55 ± 0.11[a]	0.51 ± 0.03[a]	255.64 ± 65.20[a]
Control	0†	–64.84 ± 19.14[a]	0.61 ± 0.13[a]	0.53 ± 0.04[a]	295.38 ± 72.18[a]
Maltitol	25	–71.41 ± 18.52[a]	0.63 ± 0.12[a]	0.55 ± 0.02[a]	345.63 ± 82.65[a]
	50	–54.02 ± 22.21[a]	0.55 ± 0.06[a]	0.54 ± 0.01[a]	267.34 ± 51.57[a]
	75	–71.79 ± 14.91[a]	0.64 ± 0.12[a]	0.54 ± 0.03[a]	363.55 ± 104.43[a]
	100	–73.83 ± 11.02[a]	0.64 ± 0.11[a]	0.53 ± 0.02[a]	329.17 ± 62.38[a]
Control	0†	–64.84 ± 19.14[a]	0.61 ± 0.13[a]	0.53 ± 0.04[a]	295.38 ± 72.18[a]
Xylitol	25	–86.06 ± 17.58[a]	0.66 ± 0.12[a]	0.54 ± 0.05[a]	375.33 ± 88.37[a]
	50	–56.95 ± 29.10[a]	0.61 ± 0.10[a]	0.54 ± 0.04[a]	340.73 ± 94.62[a]
	75	–87.51 ± 32.82[a]	0.62 ± 0.12[a]	0.49 ± 0.02[a]	276.34 ± 72.25[a]
	100	–71.44 ± 16.34[a]	0.56 ± 0.08[a]	0.54 ± 0.04[a]	287.76 ± 57.38[a]
Control	0†	–64.84 ± 19.14[a]	0.61 ± 0.13[a]	0.53 ± 0.04[a]	295.38 ± 72.18[a]
Mannitol	25	–83.89 ± 12.09[a]	0.69 ± 0.09[a]	0.53 ± 0.03[a]	323.66 ± 49.98[a]
	50	–53.8 ± 37.29[a]	0.43 ± 0.08[a]	0.49 ± 0.06[a]	210.38 ± 77.86[a]
	75	–50.08 ± 28.03[a]	0.42 ± 0.10[a]	0.49 ± 0.05[a]	153.12 ± 41.65[b]
	100	–3.69 ± 4.34[b]	0.25 ± 0.03[b]	0.45 ± 0.03[b]	98.78 ± 21.04[c]

Values are expressed as mean ± standard deviation. Values within a column with different superscripts are significantly different from each other at $P < 0.05$ by Duncan's multiple range tests.
† Control sample: Chiffon cake with added rice flour and sugar.

the Maillard reaction (Adisak 2009). The difference in crust lightness could be attributed to the fact that polyols do not promote the Maillard reaction because they lack the aldehyde group.

Sugar Alcohols and Sensory Properties

The sensory evaluation results for the sample cakes are shown in Table 5. There was no difference in the sensory

TABLE 4. COLOR OF RICE CHIFFON CAKE WITH DIFFERENT SUGAR ALCOHOL CONTENTS

		Crust			Crumb		
	Blend (%)	*L*	*a*	*b*	*L*	*a*	*b*
Control	0†	58.06 ± 0.91[a]	3.47 ± 0.73[a]	22.59 ± 0.52[a]	59.99 ± 3.61[a]	–1.84 ± 0.40[a]	20.24 ± 0.96[a]
Sorbitol	25	58.14 ± 1.68[a]	2.81 ± 1.75[a]	21.62 ± 1.41[a]	61.84 ± 2.11[a]	–2.80 ± 0.29[b]	19.44 ± 0.87[a]
	50	59.52 ± 1.91[a]	1.82 ± 1.88[a]	21.31 ± 1.43[a]	62.72 ± 2.02[a]	–2.71 ± 0.48[b]	19.96 ± 0.92[a]
	75	58.54 ± 2.16[a]	2.48 ± 0.99[a]	21.07 ± 1.15[a]	63.05 ± 2.95[a]	–3.02 ± 0.27[b]	19.29 ± 0.89[a]
	100	59.01 ± 3.09[a]	2.38 ± 1.75[a]	21.10 ± 0.46[a]	63.02 ± 1.76[a]	–3.38 ± 0.32[c]	18.78 ± 0.84[a]
Control	0†	58.06 ± 0.91[a]	3.47 ± 0.73[a]	22.59 ± 0.52[a]	59.99 ± 3.61[a]	–1.84 ± 0.40[a]	20.24 ± 0.96[a]
Maltitol	25	58.98 ± 1.67[a]	3.03 ± 1.26[a]	21.94 ± 1.20[a]	60.40 ± 1.73[a]	–2.30 ± 0.54[a]	19.12 ± 1.56[a]
	50	57.19 ± 0.78[a]	3.82 ± 0.84a	22.18 ± 0.58[a]	60.96 ± 1.08[a]	–2.32 ± 0.23[a]	19.32 ± 1.54[a]
	75	58.40 ± 1.49[a]	2.89 ± 0.91[a]	21.77 ± 0.71[a]	61.51 ± 1.98[a]	–2.58 ± 0.35[a]	19.08 ± 1.85[a]
	100	57.17 ± 1.78[a]	3.13 ± 1.08[a]	21.61 ± 1.01[a]	62.85 ± 2.17[a]	–2.84 ± 0.15[b]	19.36 ± 1.38[a]
Control	0†	58.06 ± 0.91[a]	3.47 ± 0.73[a]	22.59 ± 0.52[a]	59.99 ± 3.61[a]	–1.84 ± 0.40[a]	20.24 ± 0.96[a]
Xylitol	25	57.70 ± 1.45[a]	4.61 ± 0.86[a]	22.38 ± 0.37[a]	61.34 ± 1.69[a]	–2.65 ± 0.25[b]	18.91 ± 1.09[a]
	50	59.22 ± 1.51[a]	2.38 ± 1.88[a]	21.17 ± 1.16[a]	60.92 ± 2.02[a]	–3.17 ± 0.23[bc]	17.97 ± 0.82[a]
	75	60.09 ± 1.70[a]	1.11 ± 1.17[a]	20.77 ± 0.69[a]	62.46 ± 1.27[a]	–3.67 ± 0.36[cd]	18.78 ± 0.82[a]
	100	60.91 ± 2.59[a]	1.70 ± 1.20[a]	20.41 ± 0.74[b]	64.42 ± 2.40[a]	–3.97 ± 0.56[d]	17.88 ± 1.56[a]
Control	0†	58.06 ± 0.91[a]	3.47 ± 0.73[a]	22.59 ± 0.52[a]	59.99 ± 3.61[a]	–1.84 ± 0.40[a]	20.24 ± 0.96[a]
Mannitol	25	58.41 ± 1.25[a]	3.67 ± 1.30[a]	22.47 ± 0.97[a]	61.58 ± 2.78[a]	–2.57 ± 0.35[a]	19.23 ± 1.54[a]
	50	61.23 ± 8.24[a]	1.90 ± 4.12[a]	21.23 ± 1.28[a]	63.57 ± 4.86[a]	–3.54 ± 0.85[b]	18.18 ± 1.92[a]
	75	58.23 ± 5.17[a]	4.75 ± 1.78[a]	21.74 ± 0.85[a]	58.36 ± 2.68[a]	–2.50 ± 1.00[a]	16.96 ± 1.77[b]
	100	66.69 ± 1.60[b]	4.04 ± 0.33[a]	19.47 ± 0.44[b]	61.01 ± 3.33[a]	–3.22 ± 0.20[b]	16.15 ± 1.02[b]

Values are expressed as mean ± standard deviation. Values within a column with different superscripts significantly differ at $P < 0.05$ by Duncan's multiple range tests.
† Control sample: Chiffon cake prepared with rice flour and sugar.

TABLE 5. SENSORY EVALUATION OF RICE CHIFFON CAKES PREPARED WITH DIFFERENT SUGAR ALCOHOLS

Sample	Crust color	Crumb color	Loaf volume	Air cell uniformity	Flavor	Sweetness	Moistness	Stickiness	Overall acceptability
Control	5.3[a]	4.6[bc]	5.6[a]	4.4[ab]	5.3[a]	5.1[a]	6.4[a]	5.3[a]	5.5[a]
Sorbitol†	5.5[a]	4.9[b]	4.1[c]	4.1[b]	5.3[a]	4.1[b]	6.4[a]	5.3[a]	4.7[b]
Maltitol	5.8[a]	5.8[a]	5.5[a]	5.0[a]	5.5[a]	4.3[b]	6.1[a]	5.1[a]	5.6[a]
Xylitol	5.5[a]	6.4[a]	5.9[a]	4.9[a]	5.0[a]	5.2[a]	6.2[a]	5.8[a]	5.6[a]
Mannitol	3.7[b]	4.0[c]	4.7[b]	4.7[ab]	4.[2b]	3.2[c]	2.9[b]	4.0[b]	3.1[c]

Values within a column with different superscripts significantly differ at $P < 0.05$ by Duncan's multiple range tests.

† Sorbitol = sorbitol 75% treatment; maltitol = maltitol 75% treatment; xylitol = xylitol 75% treatment; mannitol = mannitol 75% treatment.

scores for crust color; the cake formulated with mannitol had the lowest score for crust color. Panelist scores are consistent with the Hunter *L*, *a* and *b* values shown in Tables 3 and 4; i.e., the crust became lighter, less red and less yellow as the mannitol content increased. The crumb color in xylitol cakes was the darkest. The loaf volume score was highest for the xylitol cakes (5.9) and lowest for the sorbitol cakes (4.1). There was no significant difference in the uniformity of air cells from that of the sugar cake. The flavor scores were 5.3 and 4.2 for the sugar and mannitol cakes, indicating that the flavor of the mannitol cake was significantly poorer than that of the sugar cake. This can be attributed to the lack of Maillard reaction during baking. The stickiness of the mannitol-substituted cakes was lowest. Cakes formulated with sorbitol, maltitol and mannitol had the lowest mean sweetness scores. The overall acceptability score of the xylitol (5.6) and maltitol (5.6) cakes was higher than that of the control (5.5). The sorbitol and mannitol received acceptability scores of 4.7 and 3.1, respectively. The sweetness of the mannitol cake was significantly less than that of cakes prepared using sorbitol, maltitol and xylitol, which is consistent with the sweetening power of the polyols. Moistness evaluation results were similar for all samples, except for mannitol cake. The moistness scores of the control and mannitol cakes were 6.4 and 2.9.

In addition, the principal analysis of sensory evaluation with the sample cakes is shown in Fig. 3. The first principal component (PC1) explained 69.57% of the variation in the data, and the second principal component (PC2) explained 20.89% of the variation, giving a total explained variance of 90.46% for a two-component model. These first two components were used in Fig. 1 to give a sufficient visual overview of the relationship between samples and descriptors. The samples on the left of the PC1 axis (Fig. 3) are mainly influenced by descriptors for crust color, stickiness, moistness and flavor. PC2 is mostly described by negative sensory attributes. The sample mannitol stands apart from the other samples along the PC2 axis. The samples on the right of PC1 are mostly described by descriptors for the crust color, crumb color, loaf volume, air cell uniformity, flavor, sweetness, moistness, stickiness and overall acceptability. On the left side of PC1 is the sample mannitol. In Table 5, many significant differences in taste and flavor can be seen between the four samples (control, sorbitol, maltitol and xylitol) and the mannitol sample, which are the farthest to the right on PC1 (Fig. 3).

The panelists assigned the lowest overall acceptability score to the mannitol cake, followed by the sorbitol cake. The poor sensory scores of the mannitol cake were mainly due to moistness and crust color. This shows the great contribution of these attributes to overall acceptability. Lombardo *et al.* (1996) tested sugar-free sponge cakes containing polyols; the best results were obtained with xylitol and maltitol, which yielded sponge cakes more similar to the control and with the highest acceptance scores. They also reported that panelists assigned the lowest overall acceptability scores to mannitol cakes. Our results indicate that low-calorie rice chiffon cakes could be produced using 75% maltitol and xylitol without significant deterioration of the physicochemical properties, batter properties or cake quality.

CONCLUSIONS

Sugar has been replaced with polyols in rice chiffon cakes to produce product with characteristics similar to that of sugar-containing cakes and good consumer acceptance. Among the four bulking agents tested, xylitol was found to be the best substitute, yielding sensory evaluation scores similar to those of sugar cake, even surpassing it for attributes such as moistness, sweetness and overall appearance. The only handicap of this bulking agent, apart from its high price, is its inability to participate in Maillard reactions. The caloric content of 0, 25, 50, 75 and 100% sugar-alcohol cakes are 186.9, 182.1, 176.9, 172.4 and 167.6 kcal/piece, respectively (estimated by raw materials used for each cake). A partial replacement of sugar alcohol (maltitol, sorbitol, xylitol and mannitol) for sucrose in chiffon cakes may produce a lower calorie cake. Previously, the effect of total replacement of wheat flour by rice flour, such as 200-mesh rice, on the physical and sensory characteristics of chiffon cakes has been studies. Substantial very similar among gluten-free cakes and the control one were found. These results suggest that sugar can be completely replaced by sugar alcohols in rice chiffon cakes without affecting its quality. Sugar alcohols (maltitol, sorbitol, xylitol and mannitol) have been approved as safe by the Food and Drug Administration and could therefore be used as natural sweeteners in food products.

ACKNOWLEDGMENTS

This study was supported by Roquette (Roquette Korea, Seoul, Korea) and Leonontech (Leonontech Korea, Gyeonggi-do, Korea).

REFERENCES

ADISAK, A. 2009. Quality of reduced-fat chiffon cakes prepared with erythritol-sucralose as replacement for sugar. Pak. J. Nutr. *8*, 1383–1386.

ATTIA, E.A., SHEHATA, H.A. and ASKAR, A. 1993. An alternative formula for the sweetening of reduced-calorie cakes. Food Chem. *48*, 169–172.

BAEVA, M.R., PANCHEV, I.N. and TERZIEVA, V.V. 2000. Comparative study of texture of normal and energy reduced sponge cakes. Nahrung *44*, 242–246.

BAIK, C.S., PARK, Y.S. and CHANG, H.G. 2008. Physico-chemical properties of wheat flour supplemented with black rice flour. Food Eng. Program *12*, 49–57.

BILLAUX, M.S., FLOURIE, B., JACQUEMIN, C. and MESSING, B. 1991. Sugar alcohols. In *Handbook of Sweeteners* (S. Marie and J.R. Piggott, eds.) pp. 72–103, The Blackie Publishing Group, New York, NY.

DANIEL, M.B. 1994. *The Evaluation of the Energy of Certain Sugar Alcohols Used as Food Ingredients*, pp. 20–90, LSRO (Life Sciences Research Office), Bethesda, MD.

DEIS, R.C. 1994. Adding bulk without adding sucrose. Cereal Food World *39*, 93–97.

DILEK, K., ZEYNEP, H., ALEV, B. and SINAN, K. 2007. Bubble and pore formation of the high-ratio cake formulation with polydextrose as a sugar- and fat-replacer. J. Food Eng. *78*, 953–964.

FINER, N. 1991. Sweeteners and metabolic disorders. In *Handbook of Sweeteners* (S. Marie and J.R. Piggott, eds.) pp. 225–247, The Blackie Publishing Group, New York, NY.

FORMULACTION SMART SCIENTIFIC ANALYSIS. 2009. Application note. http://www.formulaction.com/index.html (accessed October 20, 2009).

FRYE, A.M. and SETSER, C.S. 1991. Optimising texture of reduced calorie sponge cakes. Cereal Chem. *69*, 338–343.

HARDEEP, S.G. and CRISTINA, M.R. 2004. Improvement of the breadmaking quality of rice flour by glucose oxidase. Food Res Int. *37*, 75–81.

HARTSOOK, E.T. 1984. Celiac sprue: Sensitivity to gliadin. Cereal Food World. *29*, 157–158.

HESS, D.A. and SETSER, C.S. 1983. Alternative system for sweetening layer cakes using aspartame with and without fructose. Cereal Chem. *60*, 337–341.

HICSASAMAZ, Z., YAZGAN, Y., BOZOGLU, F. and KATNAS, Z. 2003. Effect of polydextrose-substitution on the cell structure of the high-ratio cake system. Lebensm.-Wiss. Technol. *36*, 441–450.

HIROAKI, H. 2005. Functional properties of sugar alcohols as low-calorie sugar substitutes. Cultor. Food. Sci. *2*, 3–4.

KIM, J.N. and SHIN, W.S. 2009. Physical and sensory properties of chiffon cake made with rice flour. Korean J. Food Sci. Technol. *41*, 69–76.

KIM, S.S., KIM, Y.J. and LEE, Y.J. 1994. Effects of waxy rice flours on rice muffins containing various combinations of nonwaxy/waxy rice flour. Food Biotechnol. *3*, 57–59.

KOCER, D., HICSASMAZ, Z., BAYINDIRLI, A. and KATNAS, S. 2007. Bubble and pore formation of the high-ratio cake formulation with polydextrose as a sugar-and fat-replacer. J. Food Eng. *78*, 953–964.

LEE, C.C. and HOSENEY, R.C. 1982. Optimization of the fat-emulsifier system and the gum-egg white-water system for a laboratory scale single stage cake mix. Cereal Chem. *59*, 392–396.

LIAN, Y.N., CHEN, A.T., SUURKUUSK, J. and WADSÖ, I. 1982. Polyol-water interactions as reflected by aqueous heat capacity values. Acta Chem. *36*, 735–739.

LIN, S.D., HWANG, C.F. and YEH, C.H. 2003. Physical and sensory characteristics of chiffon cake prepared with erythritol as replacement for sucrose. J. Food Sci. *68*, 2107–2110.

LOMBARDO, Y.B., DRAGO, S., CHICCO, A., FAINSTEIN, D.P., GUTMAN, R., GAGLIARDINO, J.J. and GOMEZ, D.C.L. 1996. Long-term administration of a sucrose-rich diet to normal rats: Relationship between metabolic and hormonal profiles and morphological changes in the endocrine pancreas. Metab. Clin. Exp. *45*, 1527–1532.

LUMDUBWONG, N. and SEIB, P.A. 2000. Rice starch isolation by alkaline protease digestion of wet-milled rice flour. J. Cereal Sci. *31*, 63–74.

NGO, W.H. and TARANTO, M.V. 1986. Effect of sucrose level on the rheological properties of cake batters. Cereal Food World *31*, 317–322.

NUTRITION.COM. 2012. Application note. http://www.nutrition.com.sg (accessed September 15, 2012).

PATON, D., LAROCQUE, G.M. and HOLME, J. 1981. Development of cake structure: Influence of ingredients on the measurement of cohesive force during baking. Cereal Chem. *58*, 527–529.

PETERAS, I.M.C., HOWELLS, K.F. and ROSENTHAL, A.J. 1994. Hot-stage microscopy of cake batter bubbles during simulated baking: Sucrose replacement by polydextrose. J. Food Sci. *59*, 168–178.

PSIMOULI, V. and OREOPOULOU, V. 2012. The effect of alternative sweeteners on batter rheology and cake properties. J. Sci. Food Agric. *92*, 99–105.

RONDA, F., MANUEL, G., CARLOS, A.B. and PEDRO, A.C. 2005. Effect of polyols and nondigestible oligosaccharides on the quality of sugar-free sponge cakes. Food Chem. *90*, 549–555.

SAMUEL, P.H., JEAN-PIERRE, D., NAZIMAH, H., WINNA, H. and CONOR, M.D. 2010. The influence of ingredients and time from baking on sensory quality and consumer freshness perceptions in a baked model cake system. Lebensm.-Wiss. Technol. *43*, 1032–1041.

SARI, E., KHALIA, S., ADRIENE, W., NICOLE, G., DIANA, B., SUN HYUNG, K., WAI LING, H., KATHY, G., JENNIFER, A. and GINA, G. 2008. Comparisons of six new artificial sweetener gradation ratios with sucrose in conventional-method cupcakes resulting in best percentage substitution ratios. J. Culinary Sci. Technol. *5*, 62–74.

SIVARAMAKRISHNAN, H.P., SENGE, B. and CHATTOPADHYAY, P.K. 2004. Rheological properties of rice dough for dough for making rice bread. J. Food Eng. *62*, 37–45.

WENNERHOLM, K., EMILSON, C.G. and BIRKHED, D. 1991. Sweeteners and dental health. In *Handbook of Sweeteners* (S. Marie and J.R. Piggott, eds.) pp. 205–224, The Blackie Publishing Group, New York, NY.