Original article

Effect of sugar replacement with stevianna and inulin on the texture and predictive glycaemic response of muffins

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Summary   The application of sugar replacers used in bakery products is of growing interest to the food industry, as it provides the possibility of delivering products with reduced energy and sugar. The aim of this study was to investigate the textural properties and glycaemic responses of muffins made using stevianna and inulin. Two levels of sugar replacer were used (50% and 100%). Total replacement of sucrose gave muffins with a firmer texture than the control ($P < 0.05$); 50% replacement, however, gave a similar texture to control. The predicted glycaemic response was reduced in sugar-replaced muffins compared to control samples. In particular, the replacement of sucrose with 100% stevianna caused a significant decrease in the standardised area under the curve values. Therefore, there exists the potential to regulate the glycaemic response of muffins by the incorporation of 50% stevianna or 50% inulin without affecting their textural properties.

Introduction

Muffins are a popular snack product with high consumer acceptance. Sugar is one of the main ingredients of muffins and contributes to the product structure as well as the characteristic taste and soft texture. However, sugar has a high glycaemic index, which can cause an acute increase in postprandial plasma glucose and insulin levels after eating these foods (Grigor *et al.*, 2016). Excessive consumption of sugar leads to high energy intakes and may cause dental problems, obesity, type 2 diabetes, high blood cholesterol and coronary heart disease (Rößle *et al.*, 2011).

Sucrose performs multiple functions in muffins. It is included to provide sweetness, control moisture retention, influence air incorporation, stabilise air bubbles and limit the swelling of starch during baking, all of which help to create a finer texture (Nip, 2014).

The structural and sensory properties of muffin system have been reported to be influenced by the reduction in sucrose levels (Martínez-Cervera *et al.*, 2014). Researchers have investigated the sugar substitutes needed to replace all major functions of sucrose, such as sweetness, colour, texture and flavour (Kocer *et al.*, 2007; Nip, 2014; Struck *et al.*, 2014). High-intensity sweeteners usually provide only sweetness to a product, that is why it is common practice to use bulking agents combined with them to provide the functional

properties of sugar and act as structure-building substances in foods. This represents a considerable challenge for the cereal food industry where consumers are interested in consuming sugar-reduced or sugar-free products based on health reasons and yet wish to have the sweet flavour and good texture from a hedonic point of view.

Stevia is a typical sucrose replacer in food products that satisfies the requirements for low-calorie and high-intensity sweeteners in these products (Azevedo *et al.*, 2015). Several researchers have studied the possibility of using stevia in the formulation of various baked goods, such as muffins (Zahn *et al.*, 2013), cakes (Manisha *et al.*, 2012) and cookies (Kulthe *et al.*, 2011). In our study, we used stevianna (product code ST001_SE supplied by Stevianna NZ) in muffin products. This sweetener is extracted from stevia (*Stevia rebaudiana*), a small, herbaceous, perennial shrub of the *Asteraceae* family. Stevia has zero calories, so does not affect blood glucose and insulin levels, as shown in human studies (Gregersen *et al.*, 2004); it is a natural sweetener with a relative sweetness 250–300 times sweeter than table sugar (Manisha *et al.*, 2012). In safety studies, stevia has been approved as a safe supplement by JECFA, WHO and FDA. Moreover, FSANZ (Food Safety Australia and New Zealand) have set the value for the acceptable daily intake (ADI) at 0–4 mg steviol equivalents (Geuns, 2010).

Inulin is a natural dietary fibre derived from chicory roots, garlic, wheat, bananas and artichokes and, as

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such, has always been part of the human diet (Rodríguez-García *et al.*, 2013). Chemically, native inulin is a mixture of oligomer and polymer chains with a variable number of fructose molecules joined by β (2–1) bonds, and usually includes a glucose molecule at the end of the chain (Bayarri *et al.*, 2011). The degree of polymerisation (DP) of chicory fructans varies from 2 to 60 (average DP = 12). Inulin offers a unique combination of nutritional and technological advantages (Rodríguez-García *et al.*, 2013). It is not only a dietary fibre but also a prebiotic that is linked to a variety of beneficial physiological effects, such as improved bowel habits, increased calcium absorption, lowered serum lipids, a positive effect on the feeling of satiety and stimulation of the immune system (Meyer *et al.*, 2011). Regarding its technological properties, inulin can be used for partial sucrose replacement or to give structure to low-fat foods (Tárrega *et al.*, 2011).

Different researchers have studied inulin and stevia and other sugar replacers in bakery products (Shevkani & Singh, 2014; Colla & Gamlath, 2015; Rumiyati *et al.*, 2015). The addition of inulin to gluten-free layer cakes is believed to slow the release of reducing sugars and, hence, lower postprandial blood glucose levels (Gularte *et al.*, 2012). Due to the structure of inulin, it resists digestion in the human intestines (Aravind *et al.*, 2012) and delays gastric emptying (Gularte *et al.*, 2011). Apart from these health benefits, inulin has also been used as a food substitute, and a bulking and structure-forming agent in food processing (Meyer *et al.*, 2011). Zahn *et al.* (2010) found that the replacement of 50% fat with inulin in a formulation resulted in muffins that were comparable or slightly higher in crumb firmness than the control muffin. Moreover, Zahn *et al.* (2013) indicated that a combination of inulin with rebaudioside A resulted in products with characteristics close to a reference muffin formulation by multivariate analysis of the instrumental and sensory data. The effects from a mixture of stevioside and liquid sorbitol on the rheological, microstructural and quality characteristics of cakes were observed by Manisha *et al.* (2012). However, while several studies have illustrated the benefit of consuming inulin or stevia-rich products, the results are still not fully understood. There is a paucity of studies documenting stevia or inulin additions and their effect on the quality, texture and *in vitro* starch digestion of muffins.

Therefore, the aim of this study was to substitute sucrose in muffin production with different levels of stevianna and inulin, added individually, in order to investigate the possible mechanisms involved in the modulation of postprandial glycaemia responses by delayed starch digestibility. Furthermore, the textural properties of the muffins, as affected by the different types and levels of sugar replacement, were measured and compared with a control muffin.

Materials and methods

Raw materials

Ingredients used for sample preparation were wheat flour (Medal Premium baker flour, Champion, New Zealand), white sugar (Chelsea, New Zealand), baking powder (Edmonds, New Zealand), iodised table salt (Cerebos, New Zealand), skim milk powder (0.1 fat, Pams, New Zealand), canola oil (Pams, New Zealand), fresh eggs from a local supermarket and tap water. Two kinds of sweeteners were used in the study. Inulin Frutafit IQ, an inulin with DP_{av} 5–7 and sweetness of 10% compared to 100% sucrose (Sensus, Netherlands), and stevia in the form of stevianna (produce code ST001_SE) (Stevianna, New Zealand). Stevianna utilises organic Reb-A 98% stevia as the main sugar substitute along with erythritol.

Muffins preparation

A control recipe was prepared according to the literature (Hui & Corke, 2006) and slightly modified (Table 1), where sugar was replaced by either stevia or inulin. The replacement levels of sugar were as follows: 50% and 100% stevianna/inulin

Table 1 Formulation of control muffin (C) and muffin prepared with two levels of sugar replacement by inulin (I) and stevianna (S) in grams

Ingredients (g)	Control (C)	50% inulin (I50)	50% stevianna (S50)	100% inulin (I100)	100% stevianna (S100)
Wheat flour	115.3	115.3	115.3	115.3	115.3
Sugar	69.2	35.0	35.0	0	0
Baking powder	5.8	5.8	5.8	5.8	5.8
Salt	1.4	1.4	1.4	1.4	1.4
Skim milk powder	8.7	8.7	8.7	8.7	8.7
Oil	57.6	57.6	57.6	57.6	57.6
Liquid whole egg	34.6	34.6	34.6	34.6	34.6
Tap water	57.6	57.6	57.6	57.6	57.6
Inulin	0	35.0	0	69.2	0
Stevia	0	0	35.0	0	69.2

Liquid whole egg was beaten into a plastic bowl by a wire whisk. Dry ingredients and prebeaten egg, oil and water weighted using a Ohaus SP602 Scout Portable Scales (Bradford, MA, USA). After weighing, batter was mixed in a mixer (Delta Food Equipment, Savannah, GA, USA) with the following mixing steps. Firstly, prebeaten egg, oil and water were mixed with the mixer for 60 s (10 s at speed 4; 50 s at speed 8). Next step, dry ingredients were add to the premixed liquid in the mixing unit and whisked for another 120 s (10 s at speed 2; 110 s at speed 8). After placing the batter into paper baking cases in 43 ± 0.1 g aliquots in a muffin pan, the muffins were baked in a Simpson gemini atlas series oven. Heat was set to 180 °C at fan bake, and baking time was 18 min. Baked muffins were cooled at room temperature for 1 h, then packed in plastic resealable bags and stored in the refrigerator (4 °C) overnight for further analysis.

Textural characteristics of the muffin

The instrumental texture measurements of the muffin samples were determined using a TA.XT.plus Texture Analyzer (Stable Microsystems, Godalming, UK) provided with Texture Expert software. Measurements were conducted using a 50-kg load cell and cylindrical probe with diameter of 75 mm. The texture parameters were determined with a test speed of 1.0 mm s^{-1}, and the application of strain of 25% of the original height, the compression test was a single compression on each of four muffins from each recipe. The Texture Expert software (Stable Microsystems, Surrey, UK) was used to determine the hardness of the whole muffin (resistance to force being applied to the muffin) and springiness (resilience of the muffing to reform when the probe was being retracted).

Muffin total starch

Total starch analysis was carried out in triplicate according to the official AACC method 76.13 (AACC, 1995).

In vitro predictive glycaemic response digestion analysis

Each muffin recipe was analysed for potential glycaemic response in triplicate following the method reported previously by Woolnough *et al.* (2010). Whole muffins were chopped with a domestic kitchen food chopper (Zyliss®) to stimulate particle size reduction which occurs during natural mastication for at least one minute of steady chopping until a fine crumb was achieved. A sample containing 0.25 g starch was weighed into a digestion pot; 30 mL of water was added and the temperature brought to 37 °C with constant stirring. Stomach digestion was mimicked by adding 0.8 mL HCl and 1 mL 10% pepsin solution in 0.05M HCl with continued stirring and heat maintained at 37 °C for 30 min. Stomach digestion was halted by the addition of 2 mL NaHCO$_3$. Small intestine digestion was mimicked by the addition of 5 mL 0.1 M Na maleate buffer pH 6 and 5 mL 2.5% pancreatin in 0.1 M Na maleate buffer pH 6 followed by the volume being made to 53 mL with continued stirring and heat maintained at 37 °C for 120 min. Amyloglucosidase (0.1 mL) was added to prevent end product inhibition. Aliquots (1 mL) were taken at 0, 20, 60 and 120 min and placed into ethanol to halt digestion. These samples were then analysed for their reducing sugar content using 3,5-dinitrosalicylic acid by Woolnough *et al.* (2010).

Statistical analyses

Analysis of variance (one-way ANOVA) was performed on the data, and the significance was determined using Tukey's comparison test ($P < 0.05$). These analyses were performed using Minitab.

Results and discussion

Textural properties of muffins

The textural characteristics of the muffins were investigated by conducting a texture profile analysis in terms of the firmness and springiness of the muffins. The mean values of the texture profile parameters are shown in Table 2.

Muffins with total sucrose replacement showed significantly higher firmness values compared to the control (Fig. 1). In particular, the sample with 100% inulin showed significantly different firmness ($P < 0.05$) values compared to the 100% stevianna sample. Inulin (100%) had significantly higher firmness values ($P < 0.05$) of all the samples analysed. However, the replacement of sucrose by 50% stevianna or inulin gave the muffins similar firmness values in comparison with the control. As shown in Fig. 1, no significant differences were found between the 50% stevianna and 50% inulin muffins. Similar observations have been made in the case of sugar replacers, where using inulin or fibre revealed significantly higher firmness values in the fat or sucrose-free muffins, and the higher concentrations of inulin led to higher hardness values (O'Brien *et al.*, 2003; Psimouli & Oreopoulou, 2013).

Those results agreed with the findings of Coleman & Harbers (1983), who added high levels of high fructose corn syrup to sugar-free cakes. The increased firmness might be due to either the decreased stiffness of the foams or premature starch gelatinisation. Rodríguez-

Table 2 Effect of inulin and stevianna on texture profile analysis and *in vitro* starch digestion profile in low-sugar muffins

Product	Texture parameters		*In vitro* starch digestibility		
	Firmness (g)	Springiness (%)	RDS (mg g^{-1} sample)	Area RDS (mg g^{-1} sample)	Total AUC (mg g^{-1} sample)
C	243.43 ± 49.10[c]	56.343 ± 2.63b[c]	503.22 ± 23.75[a]	58.58 ± 2.26[a]	453.00 ± 28.55[a]
I50	237.97 ± 39.02[c]	48.95 ± 1.71[cd]	370.48 ± 15.92[b]	40.90 ± 1.97[b]	358.09 ± 6.52[b]
S50	152.24 ± 24.94[c]	58.53 ± 0.51[b]	340.06 ± 2.78b[c]	36.13 ± 0.33[b]	327.71 ± 15.40[b]
I100	2149.20 ± 213.78[a]	42.27 ± 0.18[d]	266.59 ± 69.73[cd]	25.87 ± 6.23[c]	256.92 ± 34.42[c]
S100	1418.87 ± 307.98[b]	68.79 ± 4.60[a]	185.26 ± 12.56[d]	19.40 ± 2.04[c]	189.90 ± 7.61[d]

All measurements are mean values ± SD of triplicate determinations.
Means in the same column with different letters are significantly different ($P < 0.05$).
Control (C); 50% inulin (I50); 100% inulin (I100); 50% stevianna (S50); 100% stevianna (S100).
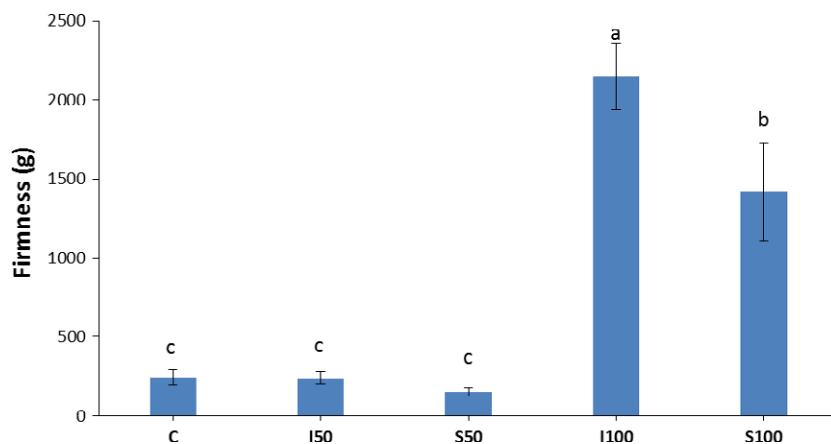

Figure 1 Firmness values for muffins containing different levels of inulin and stevianna as sugar replacer. Control (C); 50% inulin (I50); 100% inulin (I100); 50% stevianna (S50); 100% stevianna (S100).

García *et al.* (2014) have observed that in general, crumb hardness is significantly related to the volume and total air cell area, so that as the gas cell size increases, the product has a reduced density and a softer crumb structure. Manisha *et al.* (2012) showed that the sugar provided a considerable part of the bulking agent during cake baking, and this can delay starch gelatinisation and, consequently, improve the size of air bubbles due to carbon dioxide and water vapour before the cake sets. Furthermore, a previous study found that the cause of hardness and the rising and falling of volume could be attributed to a reduction in the aeration of the cake batter and the heat-assisted coagulation of proteins, leading to a very dense crumb structure (Kalinga & Mishra, 2009). Struck *et al.* (2016) suggested that fibre-enriched muffin firmness was highly sensitive to the density of the crumb, implying that the fibre affected the incorporation of air cells and contributed to mechanical resistance during compression. Martínez-Cervera *et al.* (2014) also found total sucrose replacement with erythritol caused a significant increase in muffin firmness. These effects are mainly related to the differences in water-binding capacities when the sucrose replacer competes for water with the starch, as noted by Juszczak *et al.* (2012), who considered that the water-binding ability of inulin played a key factor in modifying the dough properties of the system. This may be due to the influence of solvent availability on the other dough constituents, which would affect the retrogradation of the starch (Juszczak *et al.*, 2012).

Moreover, Rosell *et al.* (2010) reported an improvement in the stability and gas-holding capacity of inulin when it was solubilised and integrated into the cellular structure of bread. In our case, the results were consistent with those of Akesowan (2009) who observed that no significant differences in chiffon cake firmness were found when 50% sucrose was replaced by a sucralose–erythritol mixture. When inulin has been used to partially replace sucrose, no significant differences in firmness were observed by Rößle *et al.* (2011). Although Zahn *et al.* (2010) found the 50% replacement of fat by inulin significantly affected muffin crumb firmness, this was in contrast to our results. Therefore, this study indicated that partial sucrose replacement with inulin was accountable for keeping the muffins soft and close to the firmness of the control muffins.
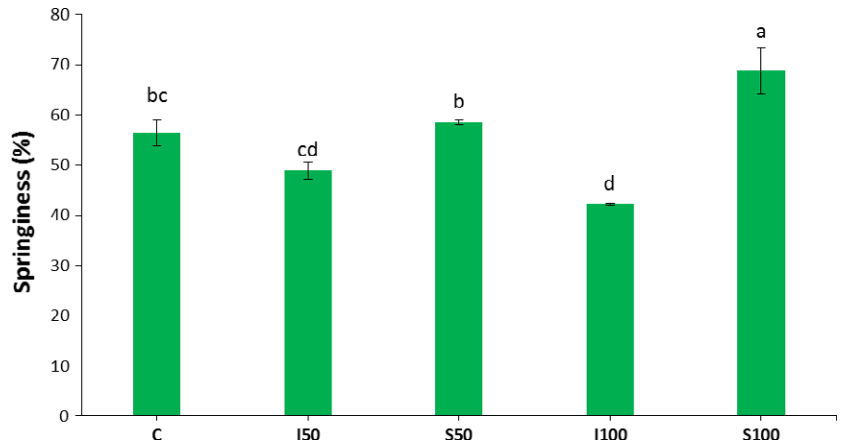
Figure 2 Springiness values for muffins made from different levels of inulin and stevianna as sugar replacers. Control (C); 50% inulin (I50); 100% inulin (I100); 50% stevianna (S50); 100% stevianna (S100).
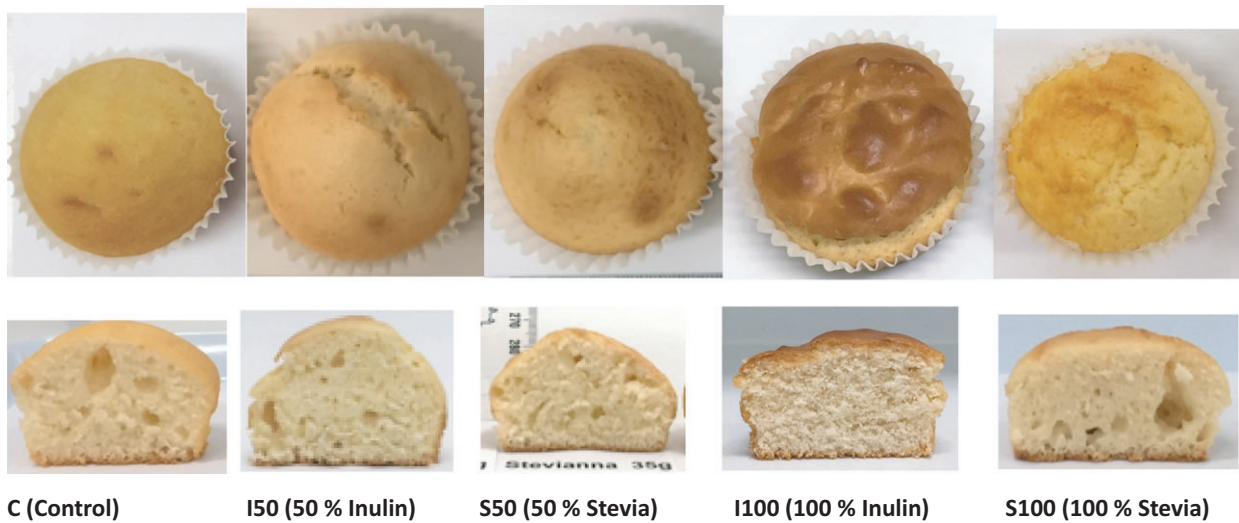

C (Control)   I50 (50 % Inulin)   S50 (50 % Stevia)   I100 (100 % Inulin)   S100 (100 % Stevia)

Figure 3 Effect of different levels of inulin and stevianna in low-sugar muffins: Control (C); I50, 50% inulin; I100, 100% inulin; S50, 50% stevianna; S100, 100% stevianna.

Figure 2 shows that no differences were observed among the I50 (50% Inulin) and S50 (50% Stevianna) muffin formulations for springiness, but I100 (100% Inulin) had significantly lower values than the other samples, reflecting a more compact muffin texture (Fig. 3). The most surprising aspect of the data was in the springiness of S100 (100% Stevianna) ($P < 0.05$), which increased when 100% of the sucrose was replaced by stevianna. Martínez-Cervera *et al.* (2014) showed a decrease in the springiness of sugar-free muffins prepared with erythritol, isomalt or sorbitol. This differs from the findings presented in our results. A correlation obtained by Akesowan (2009) showed that the properties of sugar can retard the gelatinisation of starch and, consequently, lead to a tenderising effect on the muffin texture. This inconsistency may be due

to the different types of constituents in the muffin recipes and indicated that muffin springiness can be improved by replacing sucrose with stevianna. However, several similar results were found in cakes when fat was partially replaced by inulin (Kalinga & Mishra, 2009), or sugar was partially replaced with sorbitol (Martínez-Cervera *et al.*, 2014). A possible explanation for this result may be because the same total solid content was maintained in each of these samples. In addition, Zahn *et al.* (2013) also found that springiness values fell as the fat was increasingly replaced by dietary fibre (DF). This can be related to a decrease in the strength of the hydrogen bonds in the three-dimensional protein network in cakes (Kalinga & Mishra, 2009). Furthermore, in our study, the effects on the muffin texture might depend on

the type and concentration of the sucrose replacer used.

In vitro predictive glycaemic response

The nutritional quality of the stevianna or inulin-enriched muffins, in terms of their starch digestibility and predictive glycaemic response, was determined by an *in vitro* enzymatic digestion that mimics the human digestive track. This investigated the effect of the starch gelatinisation properties on starch digestion and reducing sugar release (Foschia *et al.*, 2015). Values for reducing sugar release during *in vitro* digestibility studies varied according to the type and quantity of sugar replacer used in the muffins. The effects of sugar replacer (stevianna or inulin) on the *in vitro* starch digestion were investigated by measuring the reducing sugars released during the 120-min starch digestion process. Figure 4 illustrates that reducing sugar release was significantly decreased ($P < 0.05$) in muffins containing stevianna or inulin, compared with the control sample. In particular, the amount of reducing sugars in samples containing inulin or stevianna was significantly lower after 20 and 60 min of digestion. The strongest decrease was registered after the addition of 100% stevianna followed by I100, S50 and I50 muffin samples, and this trend was maintained for 120 min.

The reducing sugar release measurements using enzymatic assays were divided into rapidly digestible starch (RDS) and slowly digestible starch (SDS) based on the amount of reducing sugar released by *in vitro* digestion. The amounts of RDS and area under the curve values of RDS in the control and stevianna or inulin-enriched muffins are presented in Table 2. RDS was the predominant fraction in muffin samples that were measured as glucose after 20 min of digestion, to reflect the rate of absorption in the small intestine. From this table, it can be seen that muffin products containing stevianna or inulin had significantly lower RDS ($P < 0.05$) than the control. In addition, the

amounts of RDS reduced as the replacement sugar levels increased. Table 2 shows another parameter, total AUC (area under the curve), which was always lower in the 100% sugar replacement than in the 50% sugar replacement for the corresponding stevianna or inulin formulations. The effect of the presence of stevianna in reducing total AUC contents was more pronounced than the samples containing inulin.

Standardised AUC values more clearly illustrated in Fig. 5 for all samples and treatments. The effects of the replacement of sucrose in muffin preparation with 50%, 100% inulin or stevianna on standardised AUC values are shown in comparison with the control sample. In all samples, a clear decrease in AUC reducing sugar levels after the addition of stevianna or inulin was observed. In particular, the replacement of sucrose with 100% stevianna in the muffin samples caused a major decrease in the standardised AUC values.

In summary, for this study, the addition of stevianna and inulin to muffins was found to depress reducing sugar release by digestive enzymes and, thus, reduce the potential glycaemic impacts with increasing amounts of sugar replacer.

The *in vitro* digestion of inulin or stevianna inclusions into muffin products clearly illustrated that the type and quantity of sugar replacer reductions on the rate and extent of reducing sugar release may be due to the reduction in the starch content. Several researchers have studied the effect of dietary fibre (DF) and polysaccharides on starch digestibility in a range of food products (Brennan, 2005; Cleary & Brennan, 2006; Oh *et al.*, 2014). Their results were similar to our observations, which showed that inulin has a rate regulatory role in reducing sugar release. This consistent result may be due to the inulin preferentially hydrating, aggregating and forming a matrix to encase starch granules in a semisolid gel (Tolstoguzov, 2003). The encasing of starch granules could be attributed to the limitation of water movement during the hydrolysis process of DF, which leads to a reduced
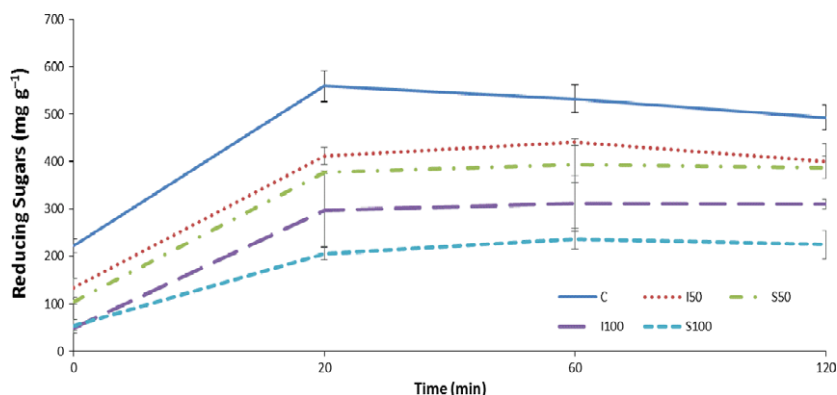
Figure 4 Amount of reducing sugars released (mg g^{-1} of starch) during *in vitro* digestion. Control (C); 50% sugar replaced by inulin (I50); 50% sugar replaced by stevianna (S50); 100% sugar replaced with inulin (I100); 100% sugar replaced with stevianna (S100).
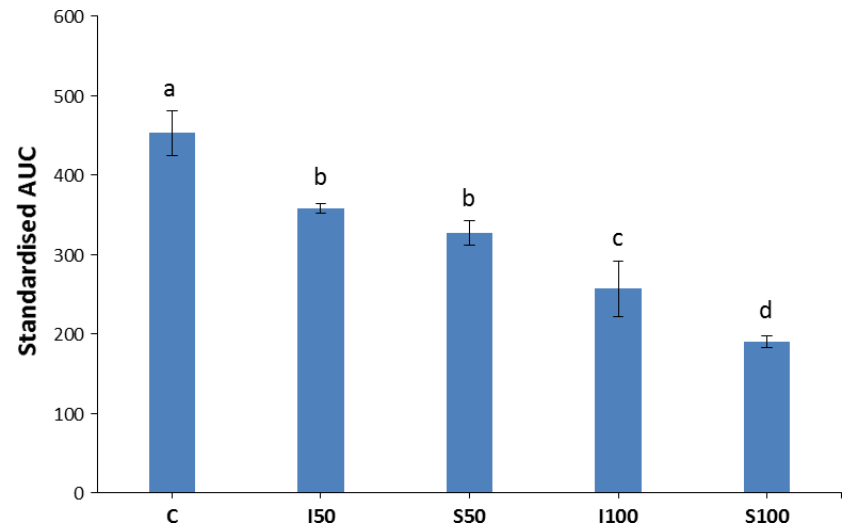
Figure 5 Values for area under the curve (AUC) comparing the control and other low-sugar muffins made with different levels of inulin and stevianna.

degree of starch gelatinisation (Oh *et al.*, 2014). Other studies indicated that the accessibility of starch-degrading enzymes in the partially gelatinised starch granules may also be interfered with by a reduction in water movement (Foschia *et al.*, 2015). In addition, studying the activity of inulin in reducing starch digestibility was a necessary and important step in developing an understanding of the mechanisms of action of inulin in reducing glycaemic responses in actual food systems. Brennan & Samyue (2004) suggested that the low glycaemic response of an individual was attributable to a decrease in the accessibility of α-amylase to starch within a food matrix, accounting for the inclusion of DFs. This could be possibly explained by the function of DF, which was recognised as encapsulating the starch granules in a protective coat, resulting in the suppression of enzymic degradation and, consequently, the reduced potential for starch degradation and sugar liberation (Tudorică *et al.*, 2002; Bae *et al.*, 2016). Brennan *et al.* (1996) observed a similar effect on starch degradation according to the incorporation of guar galactomannan in bread. They observed that the fibre formed a physical barrier around starch granules and protected them from enzymic degradation, thus decreasing starch hydrolysis. Regarding the specific effect on the DP of the inulin fraction, Aravind *et al.* (2012) clarified that higher DP will make it more likely to form a cohesive encapsulating layer. In our case, a higher DP inulin was used and that indicated that the attenuation of reducing sugars release was possibly attributed to its well-formed polysaccharide matrix with a strong entrapment of starch.

As a result, the variations in RDS values could be good indicators of the glycaemic responses of *in vitro* starch digestibility in muffin products. More recently, Gularte *et al.* (2012) illustrated that inulin, as a fibre source in cakes had a significantly lower RDS fraction

when compared to the control cakes. Brennan *et al.* (2012) showed a similar occurrence in mushroom co-product material (MCM) extruded products, which indicated that it did, indeed, restrict the amount of readily digestible carbohydrates from the fibre-fortified extruded products. As shown in Fig. 5, this further illustrated a trend for decreased starch digestion with increasing inulin levels for the average AUC relating to the release of sugar over a hydrolysis period of 120 min. These results demonstrated that stevianna or inulin as a source of sugar replacer in the muffins was extremely effective in lowering the predicted glycaemic response and overall AUC. Starch digestibility in cakes (Oh *et al.*, 2014) and pasta (Brennan *et al.*, 2004) with added inulin also reduced the predicted glycaemic index values. The theory exists to explain the effect of soluble polysaccharides on the digestibility of cereal products *in vivo* and they support the previous observations of Brennan *et al.* (1996). The reduction in blood glucose levels in guar-enriched breakfast cereal products has been proposed to increase the viscosity in the small intestine, possibly resulting in dietary fibres adhering to starch granules (Brennan *et al.*, 1996). As mentioned above, the addition of inulin to the cake led to lower starch hydrolysis, and hence, one could postulate that lower sugar liberation would occur under *in vivo* conditions. Previous work has shown that the reduced glycaemic response was more likely to be due to a slowing down of gastric emptying and a reduced rate of intestinal absorption of glucose (Gularte *et al.*, 2012).

Previous reports using different *in vivo* digestion methods showed that the interaction between stevia and other food components has the potential to influence postprandial glucose and insulin levels in humans (Alizadeh *et al.*, 2014; Anton *et al.*, 2010; Di Silvestro *et al.*, 2014). However, none of the studies assessed the

mechanism by which stevia was related to the release of reducing sugar during *in vitro* digestion and, thus, the glycaemic response in muffin products. In our case, the addition of stevianna to muffins revealed two important factors – showing the slowest release of sugars during *in vitro* starch digestion and, therefore, having a reduction in the predicted glycaemic response by up to hundred per cent. Stevia does not contribute to the available carbohydrate and glycaemic responses in food products as it is a natural sweetener that contains no glucose. Similar trends have been observed in previous research. Alizadeh *et al.* (2014) produced ice cream by replacing sucrose with stevia and that resulted in significant reductions in postprandial insulin levels compared to those of sucrose-based formulations, and this indicated that stevia can decrease a large part of the caloric and carbohydrate intake effect on postprandial glucose levels (Anton *et al.*, 2010). Standardised AUC (Fig. 5), observations may also support the hypothesis that stevianna would have a beneficial effect in terms of weight management and the potential glycaemic impacts of such foods. Therefore, stevianna could be used to create a model of lower calorie content of traditionally readily digestible starchy foods.

Conclusions

On the basis of the results obtained, the evaluation of the usefulness of stevianna or inulin as improvers for replacing sugar in muffins has focused on the texture and glycaemic response effects on these muffins compared with the control muffins. *In vitro* digestion analysis conducted in this study has highlighted that the inclusion of stevianna or inulin in muffins can significantly reduce the predicted glycaemic response from the muffin material. The results suggested that increasing levels of the stevianna or inulin in muffins resulted in a decrease in RDS values. Moreover, when comparing the different sugar replacement level formulations, sugar release was lower in the 100% muffins than in the 50% muffins. In particular, the 100% stevianna formulation was significantly more efficient in reducing AUC values when compared with the control muffins. We believe that the stevianna can be used for the production of appropriate food samples with low calories and low glycaemic responses.

The textural properties of muffins significantly depended on the level of sugar replacement. Increased additions of stevianna or inulin led to muffins with increased firmness. However, replacement of 50% sugar resulted in muffins similar to the control muffins for texture, firmness and springiness. Therefore, good-quality muffins with a 50% sugar replacement can be obtained using stevianna or inulin at low levels. Further work to conduct a sensory evaluation to assess consumer acceptability of the low-sugar muffins produced by the addition of stevianna is underway.

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