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ORIGINAL PAPER

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EFFECTS OF INULIN AND XANTHAN GUM ON THE PHYSICAL, DIGESTIBILITY, SENSORY AND NUTRITIONAL PROPERTIES OF SUGAR-FREE GREEN BANANA FLOUR BISCUIT

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ABSTRACT

Background. Sweet biscuits are one of the most popular snacks in the world, but the long-term consumption of sucrose-containing high-glycaemic index (GI) biscuits can contribute to obesity, type 2 diabetes and cardiovascular disease. The present work explored the possibility of producing a sugar-free biscuit using green Saba banana flour, which has been reported to have a lower GI than wheat flour.
Material and methods. A 2 × 3 factorial design was used to investigate the effects of xanthan gum (0% and 1%) and inulin (0%, 25% and 50%) on a sugar-free biscuit made of Saba green banana flour. The quality of the biscuits was analysed in terms of water activity, geometric indices, texture, *in vitro* digestibility and estimated GI. A sensory evaluation was carried out to determine the changes caused by hydrocolloid modulation and to assess the acceptance of the sugar-free biscuits.
Results. The hydrocolloids notably affected the quality of the sugar-free biscuits, with greater positive effects observed as the levels of both ingredients increased. Comparatively, inulin had a more pronounced influence than xanthan gum in modifying the properties of the biscuits. The sugar-free biscuit with the highest sensory evaluation score (1% xanthan gum and 50% inulin) contained more dietary fibre and had a lower GI and glycaemic load (GL) than the sugar-containing control.
Conclusions. This study demonstrates the feasibility of producing a healthier, sugar-free biscuit with an improved starch digestion profile using inulin and xanthan gum. However, further improvements to the texture of the sugar-free biscuit are required. Future studies could investigate the relationship between dough rheology, biscuit structure and sensory perceptions to uncover more insights for product improvement.

Keywords: Sugar-free biscuit, inulin, xanthan gum, green banana flour, glycaemic index, glycaemic load

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INTRODUCTION

Biscuits are one of the most popular baked foods in the world and the global sweet biscuits market is valued at US$ 109 billion in 2023, with a projected CAGR (Compound Annual Growth Rate) of 5.8% until 2033, reaching an estimated US$ 192 billion by that time (Fact.MR, 2024). Conventional biscuits are primarily made of refined flour with high amounts of sugar and fat, resulting in high calories and a high glycaemic index (GI), alongside low dietary fibre content. GI indicates the tendency of foods to increase blood glucose after ingestion. Insulin and postprandial blood glucose levels rise quickly and sharply after the ingestion of high-GI foods (Brand-Miller et al., 2023). Long term consumption of high-GI foods thus promotes an increase in insulin demand and can lead to insulin resistance, which results in obesity, type 2 diabetes and cardiovascular disease (Olagunju, 2019). Excessive consumption of added sugars has been linked to obesity, heart disease and dental caries. The World Health Organization (WHO, 2015) recommends that daily sugar intake should not exceed 10% of total calories from food, or 50 g (12 teaspoons) for an average adult.

Replacing or eliminating sugar and refined flour in biscuit formulations could help reduce their GI. The sucrose in biscuits can be replaced by nutritive or non-nutritive and natural or artificial high-intensity sweeteners. Several studies have used high-intensity sweeteners like sucralose (Naseer et al., 2021), stevia (Stoin et al., 2021), xylitol and acesulfame-K (Kutyła-Kupidura et al., 2016) in sugar-free biscuits to reduce calories and modify sweetness levels. Refined flour in biscuits can also be replaced with alternative flours to reduce digestibility. Banana flour extracted from unripe/green fruit, so-called green banana flour (GBF), has attracted a lot of research interest in recent years due to its high resistant starch (RS) content. The high RS in GBF is attributed to the presence of densely packed starch granules with higher crystalline structure (Lee et al., 2021) in the flour, making it less susceptible to enzymatic hydrolysis. As a result, the impact of GBF on the postprandial glycaemic index is lower than that of most refined flours. RS is one of the components of dietary fibre, and the fermentation of indigestible RS in the colon by resident microflora results in the formation of short-chain fatty acids, which are beneficial for health. Other physiological benefits of consuming RS include improvement in glucose tolerance, greater cellular sensitivity to insulin and increased post-meal satiety (Bojarczuk et al., 2022). Higgins and Brown (2013) discovered that using GBF as a substitute for wheat flour improved the amount of dietary fibre and RS in cookies. Cahyana and Restiani (2017) attributed the decrease in the GI of cookies to the substitution of wheat flour with modified banana flour at a certain level, which is particularly beneficial to diabetic patients. The use of GBF to bake biscuits can also help control chronic diseases such as obesity and diabetes by reducing their GI (Fida et al., 2020).

However, formulating biscuits with a substantial reduction or replacement of wheat flour and sugars has proven difficult because these ingredients perform various functional roles in biscuits. Gluten in wheat flour is responsible for binding all the ingredients during mixing to form an elastic dough that contributes to the desired shape, structure and texture of biscuits (Di Cairano et al., 2018). Sugar is also a key ingredient in biscuit recipes, not only for its sweetness but also for its bulking properties and its influence on dough rheology and processability (Clemens et al., 2016). As a result, the use of ingredients that mimic these functions of gluten and sugar is essential to ensure the successful development of a sugar-free and gluten-free biscuit. This project aimed to explore the effects of manipulating the quantity of inulin and xantham gum (XG) in a sugar-free biscuit made with GBF.

MATERIALS AND METHODS

Preparation of green banana flour

Matured Saba bananas (*Musa acuminata* × *Musa balbisiana*, AAB triploid hybrid) with total green peel were purchased from a local orchard in Tuaran, Sabah, Malaysia. The method described by Lee et al. (2021) was followed to prepare the green Saba banana flour (GSBF). The freshly received green bananas were peeled, sliced into pieces 1 cm thick, and immediately soaked in 0.3% (w/v) citric acid for 10 min. The slices were then further soaked in 0.2% sodium metabisulfite for 5 min. The banana slices were subsequently dried at 50°C for 24 h to a moisture content below 14%. The dried chips were ground into flour and sieved through a 120-mesh screen. The flour was stored in an air-tight container until further use.

Experimental design

A 2 × 3 factorial design was used. The two independent variables were the concentrations of inulin (0%, 25% and 50%, based on the % of flour in the biscuit formulation) and xanthan gum (XG) (0% and 1%, based on the % of flour in the biscuit formulation). A total of six experimental units were generated. GSBF biscuit prepared with sucrose was used as a control.

Preparation of biscuit

The basic biscuit formulations were based on the work of Stoin et al. (2021) with slight modifications. Table 1 shows the formulations of the control and sugar-free biscuits investigated in this work. The control was made of GSBF, sucrose, margarine, baking soda, cocoa powder, vanilla essence and water. The sucrose in the experimental samples was replaced by sucralose (0.085%) based on its sweetness compared to sucrose (600 times), as recommended by the manufacturer and preliminary experiment results. As the addition of hydrocolloids significantly increased dough consistency, the amount of water in the experimental samples was adjusted based on the results of the preliminary experiment to ensure proper dough formation. The margarine and sucrose/sucralose were creamed and added to the dry pre-mixed ingredients (GSBF, inulin, XG, baking soda and cocoa powder), followed by vanilla essence and water to mix, and later kneaded into a dough (6 mm thick). The sheeted dough was shaped into 3 cm diameter rounds and baked for 14 min at 170°C. After baking, the biscuits were cooled to room temperature and kept in air-tight containers for further analysis.

Water activity

The biscuit samples were ground into powder before water activity measurement. Water activity was measured using a Rotronic Hygrolab 3 water activity meter (Rotronic Instruments (UK) Ltd., West Sussex, UK).

Geometric indexes

The diameter, thickness and spread ratio of biscuit samples were determined using a previously described method (Di Cairano et al., 2021) with slight modifications. The diameter (mm) and thickness (mm) of five biscuits were measured before and after baking. The diameter of each sample was measured in three different positions. Biscuit thickness was measured by stacking five biscuits on top of each other and dividing the height by five. The spread ratio was calculated by dividing the mean diameter by the mean thickness.

Table 1. Formulation of control and sugar-free biscuits used in the experiment

Sample†	Ingredient (%)					
	GSBF	Sucrose*	Sucralose*	Inulin*	Xanthan gum*	Water*
Control	100	50	0	0	0	10
0I0XG		0	0.085			
25I0XG				25		30
50I0XG				50		50
0I1XG				0	1	10
25I1XG				25		30
50I0XG				50		50

†The figures in the sample name abbreviations indicate the % of I (inulin) and XG (xanthan gum).
*The % of the ingredients was based on the % of GSBF (green Saba banana flour).
Other ingredients used: margarine (75%), baking soda (1%), cocoa powder (7.5%), vanilla essence (2%). The % of these ingredients was also based on the % of GSBF and was kept constant for all the formulations.

Hardness and fracturability

The hardness and fracturability of the samples were determined using a TA.XT Plus Texture Analyzer (TA-XT Plus; Stable Micro Systems Ltd., Godalming, Surrey, UK) and Texture Expert 1.05 software (Stable Microsystems). The biscuits were randomly selected and placed horizontally on a platform, using a three-point bend rig to snap them in half. The parameters of the analysis were a pre-test speed of 2 mm/s, a post-test speed of 10 mm/s, a test speed of 3 mm/s, a distance of 20 mm/s, a time of 5 s and a contact force of 50 g. Owing to the high variance, the textural parameters of the biscuit were averaged from 10 sub-samples of three replicates.

In vitro digestibility

In vitro starch digestibility was determined according to the method of Englyst et al. (1992). A starch sample (0.6 g, dry basis) was incubated at 37°C for 30 min with freshly prepared pepsin–guar gum solution and then hydrolysed with enzyme solution. An aliquot (0.2 mL) was taken at 20 and 120 min and mixed with absolute ethanol (4 ml) and centrifuged at 3000×g for 10 min. The supernatants were collected for measurement of glucose content using D-glucose assay kit GOPOD reagent (K-GLUC, Megazyme). The rapidly digestible starch (RDS) and slowly digestible starch (SDS) content were calculated by multiplying the glucose content by 0.9. For total starch (TS) content, 10 mL of 7M KOH was added to the remainder of the sample solution. An aliquot (0.2 mL) was taken, mixed with 1 mL of 1M acetic acid before the addition of amyloglucosidase solution (0.1 mL) and incubated at 70°C for 30 min prior to total glucose content measurement. Based on the hydrolysis rate, starch was classified as RDS (digested within 20 min), SDS (digested between 20 and 120 min), and RS (undigested within 120 min). RS was calculated as the difference between TS and digestible starch.

Estimated Glycaemic Index

The estimated glycaemic index (eGI) of the biscuits was determined using the procedure of Goñi et al. (1997). Briefly, 50 mg of sample (dry basis) was hydrolysed with pepsin followed by pancreatic α-amylase and amyloglucosidase. The glucose released was measured using D-glucose assay kit GOPOD reagent (K-GLUC, Megazyme). The hydrolysis index (HI) was calculated based on the starch hydrolysis curve (0–3 h) as the ratio of the glucose content of the sample to the glucose content of white bread (reference food) released over 3 h.

Sensory evaluation

A rating difference test was conducted to determine the sensory differences between the sugar-free biscuits and the control. The test was conducted by 35 panellists. Oral informed consent was obtained from all panellists before participation. A 9-point attribute scale was used. The definitions of the attributes and interpretations of the scores for the scale are shown in Table 2. The panellists were given representative biscuit samples (approximately 4 g with a total of 2 pieces, equivalent

Table 2. The descriptors for each biscuit attribute and the scale anchors used in the sensory evaluation

Attributes	Descriptor	Scale Anchors		
		1	5	9
Colour	degree of brown colour darkness	lighter	acceptable	darker
Crispiness	the force with which the biscuit breaks or fractures when bitten	not crispy at all	moderate	very crispy
Crumbliness	how easily the biscuit breaks apart into small pieces when bitten	not crumbly at all	just right	too crumbly
Sweetness	typical sweetness of sucrose	not sweet at all	just right	too sweet
Adhesiveness	how much biscuit sticks on the teeth after chewing	not sticky at all	just right	too sticky
Overall acceptance	degree of liking considering all the attributes	strongly dislike	neither like nor dislike	strongly like

to two-bite portions) coded with three-digit numbers. Drinking water was used for palate cleansing.

Proximate analysis

The proximate content of the biscuits was determined according to AOAC (2000). The moisture content was determine using the gravimetric method at 105°C (AOAC 931.01). The Kjeldahl method (AOAC 2001.11) was used to determine the crude protein content using a nitrogen-to-protein conversion factor of 6.25, and the Soxhlet extraction method was used to analyse the fat content of the samples (AOAC 991.36). The biscuit samples were ashed in a muffle furnace at 550°C for 24 h to determine the ash content (AOAC 930.05).

Dietary fibre content

A Megazyme TDF test kit (K-TDFR, Megazyme, Wicklow, Ireland) was used to determine the insoluble dietary fibre (IDF), soluble dietary fibre (SDF), and total dietary fibre (TDF). The samples were digested and filtered to obtain the IDF, while the SDF was obtained by precipitating the filtrate with 95% alcohol. The SDF and IDF content were determined gravimetrically (105°C) and corrected for protein and ash.

Estimation of Glycaemic Load

The glycaemic load (GL) of the biscuit was calculated according to Louie et al. (2017). The available carbohydrate was calculated by subtracting the percentage of protein, fat, moisture, ash and dietary fibre in the food. For estimation, the biscuit portion size was fixed at 50 g. The following formula was used for the calculation of GL.

Glycaemic Load (GL) = % Glycaemic Index (GI) ×
available carbohydrate per serving

Statistical analysis

Measurements were performed in triplicate for each analysis unless otherwise mentioned. Statistical Package for Social Science (SPSS) version 29 was used to perform the statistical analysis. A two-way analysis of variance (ANOVA) was applied to determine the interaction between inulin and XG in affecting the dependent variables, followed by one-way (ANOVA) and Tukey's HSD test to compare the means. An independent sample t-test was used to separate the means of the two samples. 95% confidence intervals were used throughout.

RESULTS AND DISCUSSION

Water activity

Table 3 shows that the water activity (*Aw*) of the control and sugar-free samples without additives (0I0XG) and with added XG (0I1XG) were similar ($p > 0.05$).

Table 3. The water activity, geometrical and textural parameters of green banana flour biscuit containing sucrose and without sucrose

Sample†	Water activity	Diameter, cm	Thickness, cm	Spread ratio	Hardness, kg	Fracturability, cm
Control	0.29 ±0.01^{a}	3.07 ±0.06^{c}	4.30 ±0.10^{b}	0.71 ±0.01^{b}	2.43 ±0.06^{d}	2.43 ±0.02^{bc}
0I0XG	0.22 ±0.01^{a}	2.90 ±0.00^{a}	3.50 ±0.00^{a}	0.82 ±0.01^{c}	0.23 ±0.01^{a}	2.29 ±0.01^{a}
0I1XG	0.27 ±0.02^{a}	2.90 ±0.00^{a}	3.60 ±0.10^{a}	0.80 ±0.02^{c}	0.18 ±0.05^{a}	2.29 ±0.02^{a}
25I0XG	0.49 ±0.02^{b}	3.00 ±0.00^{b}	4.20 ±0.10^{b}	0.71 ±0.02^{b}	0.71 ±0.11^{b}	2.41 ±0.02^{b}
25I1XG	0.51 ±0.03^{b}	2.90 ±0.00^{a}	4.33 ±0.12^{b}	0.67 ±0.03^{b}	0.99 ±0.02^{c}	2.43 ±0.03^{bc}
50I0XG	0.62 ±0.05^{c}	3.10 ±0.00^{c}	4.43 ±0.06^{b}	0.70 ±0.01^{b}	0.75 ±0.17^{b}	2.48 ±0.01^{c}
50I1XG	0.70 ±0.01^{d}	2.90 ±0.00^{a}	5.27 ±0.31^{c}	0.56 ±0.03^{a}	1.08 ±0.04^{c}	2.55 ±0.02^{d}
Inulin*XG**	$p > 0.05$	$p > 0.05$	$p < 0.05$	$p < 0.001$	$p < 0.05$	$p < 0.05$

†The figures in the sample name abbreviations indicate the % of I (inulin) and XG (xanthan gum).
**Interaction effects between inulin and xanthan gum from two-way ANOVA.
Mean values within the same column with different superscripts are significantly different ($p < 0.05$).

Fig. 1. Cross-sectional view of biscuits made with different formulations of green banana flour

A significant increase of *Aw* was observed as the quantity of inulin in the formulations was increased ($p < 0.05$). Both inulin and XG are hydrocolloids with high water affinity, but the quantity of XG was negligible comparing to that of inulin, hence the increase of *Aw* was mainly attributed to inulin. Mieszkowska and Marzec (2016) observed higher *Aw* in wheat-chickpea composite flour biscuits with added inulin. The adjustment of water quantity to ease dough formation (higher water for formulations with more inulin) could also contribute to the high *Aw* after baking. Higher *Aw* indicates higher water retention and molecular mobility in the biscuit, which can negatively influence texture and product stability.

Geometric indexes

The results in Table 3 suggest that the total removal of sucrose from the GSBF biscuit significantly reduced the diameter, thickness and spread ratio of 0I0XG ($p < 0.05$), highlighting the crucial role of sucrose in biscuit structuring. The addition of 1% of XG alone (0I1XG) did not affect the biscuit's geometrical properties, but incorporating 25% and 50% of inulin improved them. The aeration ability was enhanced by the addition of inulin and XG, causing the compact structure of biscuits (0I0XG and 0I1XG) to expand to a greater volume (50I1XG), as shown in Figure 1. The use of 1% XG appeared to create a hollow structure in the centre of biscuits 25I1XG and 50I1XG. An interaction effect between inulin and XG was found to influence the thickness and spread ratio of the biscuit ($p < 0.05$).

Hardness and fracturability

A bending or snap test was used to characterise the hardness and fracturability of the biscuits. The hardness was obtained from the maximum snap force required to break the biscuits into pieces, whereas the distance at break was used to determine the fracturability of the biscuits (Patil and Kalse, 2011). These two parameters are closely related to the firmness and structure of a product. Hardness indicates the breaking strength of the biscuits, which can be related to their crispness, whereas fracturability can reflect the crumbliness of the biscuit. Short distance at break means a biscuit is easy to fracture and crumblier. Sucrose plays an important role as a hardening agent in crystallization as the biscuit cools, contributing to the product's crispiness (Tsatsaragkou et al., 2021). Therefore, total sucrose removal significantly reduced the hardness of the biscuits (Table 3). The low hardness of 0I0XG and 0I1XG was consistent with the highly compact structure of these biscuits (Fig. 1). The presence of sucrose is vital in the product structuring process (van der Sman and Renzetti, 2019), because it sustains dough rising and traps air bubbles during baking. The hardness was increased by inulin and XG in the sugar-free samples. In a previous study, inulin was reportedly able to replace the bulking and physical properties of sugar in cake (Tsatsaragkou et al., 2021). Banerjee et al. (2014) also reported that an increase in the amount of inulin led to an increase in biscuit hardness. However, the hardness of biscuit with up to 50% inulin remained significantly lower than that of the control ($p < 0.05$). This was in line with expectations, as inulin was unable to crystallise after baking (Tsatsaragkou et al., 2021). The hygroscopic nature of sucrose contributes to good binding of the dough, producing a desirable balance between cohesiveness and crumbliness. Without sucrose as a binding agent, the fracturability of 0I0XG and 0I1XG was lower than that of the control ($p < 0.05$), indicating a weaker structure and increased biscuit fragility. Low fracturability means that biscuits can be broken with a shorter distance and in less time, which was associated with a less crispy and more crumbly texture, consistent with the results of the sensory evaluation. The inulin in 25I0XG and 25I1XG led to fracturability comparable to that of the control ($p > 0.05$), but a higher level of inulin in 50I1XG resulted in higher fracturability than the control ($p < 0.05$), highlighting the importance of selecting the right quantity of hydrocolloids to mimic the role of sucrose. Notably, the addition of 1% XG did not affect the hardness or fracturability of biscuits in the absence of inulin, as observed in 25I0XG, 25I1XG, 50I0XG and 50I1XG. A two-way ANOVA revealed a significant interaction effect between inulin and XG on these two properties of the sugar-free biscuits.

In vitro digestibility and estimated Glycaemic Index

The highest RDS and lowest RS content were recorded for the control biscuit ($p < 0.05$) (Table 4), signifying a faster enzymatic hydrolysis rate, which is consistent with this biscuit's high hydrolysis rate (HI) and estimated glycaemic index (eGI) ($p < 0.05$). Foods are classified as low GI (< 55), medium GI (55 to 70), or high GI (>70). All the tested biscuits were categorised as medium GI food, and thus had lower GI than wheat biscuits (whose GI is 87–107, using white bread as a reference food) (Atkinson et al., 2008). The high RS (68.9%) and dietary fibre (10.22%) content in GSBF (Lee et al., 2023) were responsible for the low GI of the resulting biscuits. Compared to the control, all the biscuits made with sucralose exhibited significantly lower RDS and higher RS ($p < 0.05$), highlighting the crucial impact of sucrose on *in vitro* digestibility. Sucrose, being a disaccharide, was hydrolysed into its component monosaccharides, including glucose, which contributed to higher digestibility.

0I0XG and 0I1XG exhibited similar RS and eGI ($p > 0.05$), but higher RS and lower GI when compared to other sugar-free biscuits ($p < 0.05$). This observation suggests that 1% of XG did not affect the digestibility of the biscuit, and the resistance to enzyme hydrolysis was mainly attributed to the total removal of sucrose in the formulations. On the other hand, the use of 25% and 50% of inulin slightly increased the *in vitro* digestibility of the sugar-free biscuits, though it remained lower than that of the control ($p < 0.05$). According to the manufacturer's specifications, the pre-mixed inulin product was at least 90% inulin, with the remaining 10% potentially consisting of glucose, fructose, or sucrose. These sugars were responsible for the rise in the eGI of the biscuits containing high quantities of inulin (25I0XG, 25I1XG, 50I0XG and 50I1XG, as opposed to 0I0XG and 0I1XG, which did not content inulin). Furthermore, inulin is classified as dietary fibre with a GI of 5 (Ahsan, 2023), and thus could potentially increase the GI of the biscuits when its quantity in the

Table 4. *In vitro* digestibility (RDS, SDS, RS), hydrolysis index (HI) and estimated glycaemic index (eGI) of green banana flour biscuit containing sucrose and without sucrose

Sample†	RDS (%)	SDS (%)	RS (%)	HI	eGI
Control	22.64 ±1.64^{c}	14.13 ±0.89^{b}	63.23 ±0.94^{a}	53.08 ±0.18^{c}	68.85 ±0.10^{c}
0I0X	3.93 ±0.70^{a}	6.71 ±0.53^{a}	89.36 ±1.02^{c}	31.15 ±1.91^{a}	56.81 ±1.05^{a}
0I1X	2.45 ±0.36^{a}	7.07 ±0.58^{a}	90.48 ±0.93^{c}	29.17 ±0.98^{a}	55.73 ±0.54^{a}
25I0X	7.67 ±0.60^{b}	21.72 ±0.86^{e}	70.61 ±0.67^{b}	35.74 ±0.74^{b}	59.33 ±0.40^{b}
25I1X	8.69 ±0.77^{b}	20.72 ±0.37^{de}	70.60 ±1.12^{b}	35.64 ±1.62^{b}	59.28 ±0.89^{b}
50I0X	8.83 ±0.83^{b}	19.24 ±0.57^{cd}	71.93 ±0.48^{b}	36.98 ±2.02^{b}	60.01 ±1.11^{b}
50I1X	8.40 ±1.20^{b}	18.49 ±0.70^{c}	73.11 ±1.28^{b}	38.57 ±1.23^{b}	60.88 ±0.67^{b}
Inulin*XG **	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$

†The figures in the sample name abbreviations indicate the % of I (inulin) and XG (xanthan gum).
RDS – rapidly digestible starch, SDS – slowly digestible starch, RS – resistant starch.
Mean values within the same column with different superscripts are significantly different ($p < 0.05$).
**Interaction effects between inulin and xanthan gum from two-way ANOVA.

formulation is increased. As a dietary fibre, inulin also imparts health benefits by increasing the SDS content, as was observed in 25I0XG, 25I1XG, 50I0XG and 50I1XG ($p < 0.05$). SDS can deliver a slow and sustained release of blood glucose which leads to low glycaemic and insulinemic response (Miao et al., 2015). No significant interaction was found between the two hydrocolloids in affecting the SDS and RS and eGI ($p > 0.05$).

Sensory evaluation

According to Table 5, the colour of the control appeared to be the lightest ($p < 0.05$). The lower expansion capacity of 0I0XG and 0I1XG (Fig. 1) reduced their brightness. The sensory panellists found that the colour of sugar-free biscuits (25I0XG, 25I1XG, 50I0XG, 50I1XG) was darker than that of the control ($p < 0.05$), which most likely relates to the high level of inulin (contained reducing sugars) in these formulations accelerating Maillard browning during baking (Tsatsaragkou et al., 2021). However, no colour difference was reported between samples containing 25% and 50% inulin ($p > 0.05$). The results obtained suggests that the colour of the biscuits was significantly affected by the interaction effect between inulin and XG ($p < 0.05$). The sweetness of the control was perceived as appropriate by the panellists, but once the sucrose had been replaced with the artificial sweetener, the sweetness was reduced in 0I0XG and 0I1XG ($p < 0.05$), even though the amount of sucralose used was based on the recommended sweetness equivalent with sucrose. As explained earlier, the addition of inulin increased the glucose/fructose/sucrose content in the biscuit formulations, further enhancing the sweetness in the rest of the sugar-free biscuits ($p < 0.05$).

Corresponding to the results of the physical analysis, all sugar-free biscuits were rated as less crispy, more crumbly and stickier than the control ($p < 0.05$), with the sole exception of 50I1XG, for which no significant difference in crumbliness was reported ($p > 0.05$). The results indicate gradual improvement in these attributes with increasing levels of inulin. The effect of XG was negligible for all qualities except for crumbliness and adhesiveness, where a significant interaction effect with inulin was reported ($p < 0.05$). Although a high level of inulin resulted in a similar crumbliness to that found in the control, it also led to an unfavourable stickiness in 50I1XG. Biscuits without sugar or inulin (0I0XG and 0I1XG) were the least accepted ($p < 0.05$) due to their poor sweetness and structural and textural characteristics. Conversely, biscuits with added inulin and XG received higher mean scores for overall acceptance ($p < 0.05$). Thus, the poor quality of sugar-free GSBF biscuits can be

Table 5. The mean score of sensory attributes for sugar-containing and sugar-free biscuits made with green Saba banana flour

Sample†	Colour	Sweetness	Crispiness	Crumbliness	Adhesiveness	Overall Acceptance
Control	3.51 ±1.46^{a}	5.60 ±1.27^{c}	7.09 ±1.20^{d}	5.94 ±1.57^{ab}	5.03 ±1.95^{a}	7.31 ±1.23^{c}
0I0XG	4.60 ±1.56^{b}	3.29 ±1.27^{a}	2.11 ±1.51^{a}	7.20 ±1.59^{d}	7.89 ±1.18^{c}	4.00 ±1.46^{a}
0I1XG	5.46 ±1.20b^{c}	3.57 ±1.58^{a}	1.89 ±1.21^{a}	6.71 ±1.98^{bc}	7.97 ±1.07^{c}	4.00 ±1.63^{a}
25I0XG	5.60 ±1.46^{c}	4.26 ±1.20^{ab}	4.11 ±1.91^{b}	6.20 ±1.57^{abc}	6.43 ±1.56^{b}	5.43 ±1.77^{b}
25I1XG	5.77 ±1.35^{c}	4.54 ±1.60^{ab}	4.20 ±1.69^{b}	6.03 ±1.81^{abc}	6.57 ±1.34^{b}	5.49 ±1.69^{b}
50I0XG	5.26 ±1.15^{bc}	4.91 ±1.44^{bc}	5.54 ±1.70^{c}	6.71 ±1.38^{bc}	6.71 ±1.38^{b}	5.20 ±1.71^{b}
50I1XG	5.37 ±1.24^{bc}	4.77 ±1.48^{bc}	6.03 ±1.51^{c}	5.40 ±1.82^{a}	6.23 ±1.75^{b}	6.23 ±1.37^{bc}
Inulin*XG **	$p < 0.05$	$p > 0.05$	$p > 0.05$	$p < 0.05$	$p < 0.05$	$p > 0.05$

†The figures in the sample name abbreviations indicate the % of I (inulin) and XG (xanthan gum).
Mean values within the same column with different superscripts are significantly different ($p < 0.05$).
** Interaction effects between inulin and xanthan gum from two-way ANOVA.

effectively overcome by the addition of inulin and XG. Sample 50I1XG emerged as the best sugar-free formulation, with a similar overall acceptance to the control ($p > 0.05$). However, it is important to note that the sensory qualities of 50I1XG still require further improvement, particularly in terms of colour, crispiness and adhesiveness.

Nutrient content of biscuits

The nutrient content of 50I1XG was compared to that of the control (Table 6). Corresponding to the higher *Aw* and adhesiveness, the moisture content of this sugar-free sample was far higher than that of the control ($p < 0.05$). This effect can be ascribed to the numerous hydrophilic groups in inulin that contribute to water retention. There was a marginal difference in the protein and fat content of 50I1XG and the control. Nakov et al. (2018) also found a higher protein content in biscuits made with fructose and inulin, as opposed to biscuits with fructose but no inulin. Since the same amount of margarine was used in the biscuit formulations, the high level of inulin in 50I1XG diluted the fat content, reducing the amount of fat in the biscuit. As expected, the incorporation of inulin and XG caused an approximately twofold increase (24.44% vs. 12.23%) of total dietary fibre in 50I1XG ($p < 0.05$). Though inulin is known as a soluble fibre, a noticeable increase of insoluble fibre was also observed in the sugar-free biscuit compared to the control ($p < 0.05$).

The glycaemic index (GI) of a food provides an estimate of how quickly the carbohydrates in the food will be hydrolysed during digestion and how rapidly they are absorbed into the bloodstream, which indicates the quality of the carbohydrate. The GL of a food is defined as the product of the GI value of the food and the amount of available carbohydrate in grams per serving of that food (Foster-Powell et al., 2002). GL is classified as low (≤ 10), medium (11–19) or high (≥ 20) (Vega-López et al., 2018). The total removal of sucrose from the GSBF biscuit successfully lowered the GL from a high level (34.87) to a medium level (18.58), indicating that 50I1XG has a better nutrient profile and more health benefits than the control.

Table 6. Macronutrient composition, available carbohydrate and estimated glycaemic load of control and 50I1XG

Composition (%)	Control	50I1XG†
Moisture	2.61 ±0.28^{a}	10.08 ±0.28^{b}
Protein	2.55 ±0.02^{a}	2.87 ±0.10^{b}
Fat	28.76 ±0.11^{b}	28.46 ±0.12^{a}
Ash	1.90 ±0.08^{a}	1.91 ±0.06^{a}
Crude fibre	1.31 ±0.08^{a}	1.72 ±0.12^{b}
Total carbohydrate*	62.87 ±0.54^{b}	54.96 ±0.24^{a}
Insoluble dietary fibre	7.08 ±0.97^{a}	15.28 ±1.10^{b}
Soluble dietary fibre	5.15 ±0.35^{a}	9.16 ±0.41^{b}
Total dietary fibre	12.23 ±0.86^{a}	24.44 ±0.83^{b}
Available carbohydrate**	50.64	30.52
Estimated glycaemic load (eGL)	34.87	18.58

†The figures in the sample name abbreviations indicate the % of I (inulin) and XG (xanthan gum).

*Total carbohydrate was obtained by subtraction.

**Available carbohydrate = Total carbohydrate – Total dietary fibre.

CONCLUSIONS

This study demonstrates the functions of inulin and XG in a sugar-free biscuit made from GSBF. By using appropriate amounts of these hydrocolloids, it was possible to overcome most techno-functional challenges caused by total sucrose removal. The hydrocolloids notably affected the characteristics of various biscuit formulations, with more intense positive effects observed as the levels of both ingredients were increased. Owing to the relatively higher amount of inulin in the formulations, it had a more pronounced influence on the properties of the biscuits than XG. It is worth noting that the interaction effect between inulin and XG mainly influenced the water retention and structural (geometry) and textural properties of the sugar-free biscuits. The study also reveals the potential of GSBF as a healthy alternative flour for biscuits due to its high dietary fibre and RS content. The health benefits of GSBF biscuit were further enhanced when sucrose was entirely removed and inulin was added to the formulation, leading to a remarkable increase in TDF along with a significant reduction in estimated GI and GL. The optimum combination of inulin and XG for the sugar-free biscuits was identified through sensory evaluation. As suggested by the sensory evaluation results, further improvement in the texture of the sugar-free biscuits is necessary, therefore future work should investigate the reformulation or adjustment of processing parameters to improve biscuit structure. An in-depth investigation into how hydrocolloids modulate dough rheology and its relationship to biscuit structure and sensory perception will provide deeper insights and potential solutions for this food system.

DECLARATIONS

Data statement

All data supporting this study has been included in this manuscript.

Ethical Approval

Not applicable.

Competing Interests

The authors declare that they have no conflicts of interest.

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