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RESEARCH ARTICLE

Study on the effects of sugar alcohols and *Angelica keiskei* flour on cookie quality, antioxidant, and nutrition

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Abstract

Background and objectives: Low-glycemic index (GI) functional foods have great industrial potential, as obesity has become an important global public health issue. In this study, the effects of replacing sucrose with maltitol, xylitol, and erythritol on the quality, antioxidant, and nutrition of *Angelica keiskei* cookies were investigated.

Findings: The color and textural parameters of cookies formulated with xylitol and erythritol were significantly ($p < .05$) different from those of the sucrose cookies, while the cookies made with maltitol showed the color, hardness, and brittleness values closest to the sucrose cookies. Additionally, the cookies formulated with the three sugar alcohols showed lower acid value and peroxide value than the sucrose control. The results of functional analyses showed that *A. keiskei* flour further enhanced the antioxidant activity and α-amylase inhibitory activity of the maltitol cookies beyond that of maltitol alone. The maltitol *A. keiskei* cookies showed the lowest pGI of 53.9.

Conclusions: The cookie formulated with maltitol showed good quality and storability characteristics. Additionally, the incorporation of maltitol and *A. keiskei* flour in the cookie recipe significantly increased the antioxidant activity and α-amylase inhibitory activity of the cookies and reduced their glycemic index.

Significance and novelty: Maltitol could be considered to be an acceptable sucrose substitute for developing *A. keiskei* cookies. Furthermore, maltitol and *A. keiskei* flour are considered to be appropriate ingredients for the development of low-GI functional cookies.

KEYWORDS

antioxidant capacity, functional cookies, glycemic index, quality, storability

1 | INTRODUCTION

Due to sedentary living habits and excessive consumption of high-GI foods, the prevalence of type II diabetes and obesity is on the rise and has become a global public health problem (Góngora Salazar, Vázquez Encalada, Corona Cruz, & Segura Campos, 2018). With the general improvement of living standards, people are paying increasing attention to dietary health. Therefore, more types of low-GI products with functions of preventing obesity and hyperglycemia have become eagerly demanded by consumers.

Angelica keiskei is a perennial plant of the family Umbelliferae, widely cultivated in Asia (Zhang, Liu, & Gao, 2018). It contains various beneficial elements such as chalcones, coumarins, phenolic acids, and flavanones (Zhang et al., 2018). Abundant animal experiments have indicated that the extracts of *A. keiskei* have several protective benefits, including anti-obesity, antihypertension, antibacteria,

anti-oxidation, antidiabetes, and hepatoprotection (Zhang et al., 2018). Therefore, using *A. keiskei* to develop functional foods has great market potential and research value.

Cookies are a type of baked goods popular with consumers. However, cookies are typically high in sugar and calories, which do not meet the requirements of a modern healthy diet. The traditional sweetener used in cookie recipes is sucrose, but it can rapidly increase blood sugar level and is harmful to teeth health. In order to make healthy cookies, a previous study has suggested that sugar alcohols or other healthy sweeteners could and should replace the use of sucrose (Kweon, Slade, & Levine, 2010). Many other studies have shown that sugar alcohols such as maltitol, mannitol, xylitol, sorbitol, and erythritol can provide consumers with a variety of benefits, including calorie reduction, noncariogenicity, low GI, and prebiotic effects (Kweon, Slade, & Levine, 2016; O'Donnell & Kearsley, 2012).

As the second main ingredient after flour in many cookie formulations, the sweetener can vary in type and particle size, which are closely correlated with the sweetness, starch gelatinization temperature, water retention, browning reactions, and the overall quality and shelf life of the product (O'Donnell & Kearsley, 2012; Zoulias, Piknis, & Oreopoulou, 2000). Zoulias et al. (2000) reported that the replacement of sucrose by fructose, maltitol, lactitol, sorbitol, xylitol, or mannitol changed the baking performance of cookies. Although previous studies have investigated the effects of various sugar alcohols on the physical and sensory features of cookies, the influences of sugar substitutes on the storability and functional properties of cookies have rarely been studied.

In the current study, *A. keiskei* flour, with antidiabetes and anti-obesity functions, was added to a cookie formulation. Three sugar alcohols, namely maltitol, xylitol, and erythritol, were used to replace sucrose, and we evaluated the effects of these sugar replacers on the quality and storage characteristics of the *A. keiskei* cookies. The anti-oxidative capacity and glycemic index were also studied, in order to examine the functional potential of the developed cookies. This study will provide useful information for the development of low-GI bakery products.

2 | MATERIALS AND METHODS

2.1 | Materials

Commercial wheat flour (WF), containing 12.9% moisture, 8.7% protein, and 0.42% ash, was acquired from Weifang Kite Flour Co., Ltd. and processed from Australian soft white wheat. Sucrose, maltitol, xylitol, and erythritol were purchased from Guangzhou Fuzheng Donghai Food Co., Ltd, Henan WenBang Industrial Co., Ltd, Nanjing Ganzhiyuan Sugar Co., Ltd, and Shandong Longlive Bio-Technology Co., Ltd, respectively. Butter, shortening (i.e., edible lard), and fresh eggs were obtained from a local market (Shanghai, China). All other chemicals and reagents were purchased from Shanghai Titan Scientific Co., Ltd. and were of at least analytical grade.

2.2 | Preparation of *Angelica keiskei* flour

Fresh *A. keiskei* leaves were provided by Nanjing Lehehe Manor Agricultural Technology Co., Ltd in June 2018. After cleaning and dehydrating, these leaves were frozen at −18°C for 20 hr. Subsequently, the frozen sample was freeze-dried for 48 hr in a lyophilizer (CTFD-18T; Qingdao Creatrust Co., Ltd) at −64°C. The freeze-dried leaves were pulverized with a pulverizer and then filtered through an 80-mesh filter to obtain flour of uniform particle size.

2.3 | Preparation of *Angelica keiskei* cookies

Baked cookies were made according to the method reported by Lin, Lee, Mau, Lin, and Chiou (2010), with slight modifications. The recipe for *A. keiskei* cookies contained 120 g butter, 100 g shortening, 50 g liquid egg whites, 120 g icing sugar (extra fine crystalline sucrose), 294 g wheat flour, and 6 g *A. keiskei* flour (2% substitution level). The shortening and butter were whipped with a blender (DDQ-B01K1; Guangdong Bear Electric Co., Ltd) until completely melted, and then, sucrose and liquid egg whites were added and whipped for 5 min to mix well. Next, the sifted wheat flour and *A. keiskei* flour were poured into this mixture and stirred evenly. The obtained dough, containing approximately 15.5% moisture, was quickly placed in a mold and cut into uniform rectangular sheets of 5.8 cm*4.2 cm*0.8 cm. The weight of individual cut cookie dough pieces was approximately 15 g. The cut cookie sheets were baked in an electric oven (SM2-901C; Sinmag Equipment Co., Ltd) for 20 min, with an upper temperature of 175°C and a lower temperature of 150°C. Afterward, the cookies were taken out and cooled to room temperature, and then packed in ziplock bags for later analysis.

The low-GI *A. keiskei* cookies were prepared with 100% each of sugar alcohols (maltitol, xylitol, and erythritol) instead of sucrose. Dough-making and dough-baking were performed in duplicate, and the average of the two tests was taken as the result.

2.4 | Differential scanning calorimetry measurement

The Differential scanning calorimetry (DSC) method previously reported by Kweon et al. (2016) was used to investigate

the effects of three sugar alcohols on the thermal gelatinization behavior of the wheat flour starch in the cookie recipe. Approximately 30 mg of prepared cookie dough was weighed into a DSC pan (Φ 5.4*2.0 mm; Shanghai Jingyi Chemical Materials Co., Ltd), and the pan was sealed. Then, the sealed pan containing the dough was quickly placed in a DSC 204 F1 calorimeter (NETZSCH) and heated at a heating rate of 10°C/min from 20 to 180°C. An empty pan was used as a reference. The onset temperature (T_O), peak temperature (T_P), and end temperature (T_E) were determined.

2.5 | Quality assessment

2.5.1 | Color

The color of cookies was determined with a colorimeter (LabScan XE; Hunter Associates Laboratory, Inc.). Chroma values were given as L^* (lightness), a^* (redness/greenness), and b^* (yellowness/blueness).

2.5.2 | Textural characteristics

Textural characteristics of the cookies were determined using a Universal TA Texture Analyzer (Shanghai Tengba Instrument Technology Co., Ltd.) equipped with a P/2 cylindrical probe, according to the method described by Ou, Teng, El-Nezami, and Wang (2018). The basic single compression mode was used, and the strain level was 50% of the original height. Pretest speed was 2 mm/s, test speed was 1 mm/s, and post-test speed was 2 mm/s. Six repetitions were conducted. The hardness and brittleness of tested samples were recorded.

2.6 | Storage evaluation

The cookie samples were packaged in ziplock bags (eight cookies per bag) and stored in a cabinet at ambient temperature (25 ± 2°C) for 28 days. In order to monitor the effects of the sugar alcohols on the storage stability of the functional cookies, the acid value (AV) and peroxide value (PV) of the samples were measured every seven days after baking.

2.6.1 | Water activity (a_w)

The so-called water activity (a_w) of the cookies (actually, their % relative humidity [RH]; Slade & Levine, 1991) was measured using an a_w meter (GBX Instrumentation Scientifique) at 25 ± 1°C on days 0, 2, 4, 6, and 8 after baking.

2.6.2 | Acid value

In accord with GB5009.229-2016 (2016), the lipid was extracted from the cookies with petroleum ether for 12 hr, filtered through anhydrous sodium sulfate, and evaporated at 60°C to remove water. The AV of the extracted lipids was estimated by the cold solvent indicator titration method.

2.6.3 | Peroxide value

In accord with GB5009.227-2016 (2016), the lipid was extracted from the cookies, and impurities and moisture were removed. The thus-prepared lipid was dissolved in a mixture of chloroform and glacial acetic acid (4:6, v/v), and potassium iodide was added. The PV of the lipid from the cookies was determined by titration.

2.7 | Functional analyses

2.7.1 | Extraction of sample

After a cookie sample was pulverized, 1 g of cookie powder was weighed into a 50-ml centrifuge tube. The cookie powder was extracted with 10 ml of 70% methanol in three portions (4, 3, and 3 ml) and sonicated for 30 min at room temperature. Next, the mixture was centrifuged at 8,000 *g* for 10 min at 4°C. The supernatant was filtered using a 0.45-μm filter and carefully collected in a brown vial. The obtained extract was used for the determinations of antioxidant activity and α-amylase activity inhibition.

2.7.2 | Free radical scavenging activity (DPPH) assay

The 1,1-diphenyl-2-picrylhydrazyl (DPPH) scavenging activity was estimated according to the protocol described by Góngora Salazar et al. (2018), with slight modification. 0.1 ml of the cookie powder extract was mixed with 3.9 ml of 50 μM DPPH solution. The mixture was reacted in the dark at 37°C for 30 min, before its absorbance at 517 nm was determined. The DPPH scavenging activity was expressed as the Trolox equivalent antioxidant capacity.

2.7.3 | ABTS radical cation scavenging activity assay

The 2,2-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) radical cation scavenging activity was determined according to a previously reported method (Abreu

et al., 2019). Briefly, 50 ml of 7 mM ABTS solution was mixed with 50 ml of 2.45 mM potassium persulfate solution, and the mixture was shaken and then kept at ambient temperature for 16 hr in the dark. Next, the mixture was diluted 50 times with methanol, to prepare the ABTS reaction solution. The cookie powder extract (80 μl) was mixed with 4 ml of the ABTS reaction solution and allowed to react in the dark for 30 min, before the absorbance of the reaction mixture was determined at 734 nm. The calibration curve was obtained by Trolox, and the results were expressed as the Trolox equivalent antioxidant capacity.

2.7.4 | Ferric reducing antioxidant power assay

The measurement of ferric reducing antioxidant power (FRAP) was conducted using the method of Abreu et al. (2019). The FRAP reaction solution was prepared by mixing 0.3 M sodium acetate buffer (pH 3.6), 10 mM 2,4,6-tripyridyl-triazine (TPTZ) solution prepared with 40 mM HCl, and 20 mM $FeCl_3$ solution in a ratio of 10:1:1 (v/v/v). The cookie powder extract (100 μl) was reacted with 3.9 ml of the FRAP reaction solution in the dark for 30 min at 37°C. Subsequently, the absorbance of the reaction mixture was measured at 593 nm. The calibration curve was obtained by Trolox, and the results were expressed as the Trolox equivalent antioxidant capacity.

2.7.5 | α-amylase activity inhibition assay

The α-amylase activity inhibition was analyzed according to the procedure reported by Moussou et al. (2017). 100 μl of the cookie powder extract was mixed with 100 μl of 2 U/ml α-amylase solution in a test tube and reacted for 15 min at 37°C. Next, 200 μl of soluble starch, with concentration gradients of 0.5, 1.0, 1.5, and 2.5 mg/ml, respectively, was added to the test tube. The mixture was allowed to incubate for 10 min at 37°C. 1 ml of DNS reagent was added, and the reaction was terminated by boiling in water for 10 min. After the colored solution was cooled to room temperature, the absorbance was measured against a blank at 540 nm. The activity inhibition was calculated as follows:

$$\text{Activity inhibition } (\%) = \left(1 - \frac{A_2 - A_3}{A_1}\right) \times 100$$

where A_1 is the absorbance of the mixture containing enzymes without inhibitor, A_2 is the absorbance of the mixture containing enzymes and inhibitor, and A_3 is the absorbance of the mixture containing inhibitor without enzymes.

2.8 | Predicted glycemic response

Based on the use of white bread as a reference, the in vitro digestion of the prepared cookies was determined according to the method described by Naknaen, Itthisoponkul, Sondee, and Angsombat (2016), with some modifications. 500 mg of ground sample was added to 25 ml of phosphate buffer (pH 6.9). Fifteen glass beads (4.5 mm diameter) were added, and the mixture was shaken for 5 min. Next, 25 U of pancreatic enzymes and 41 U of amyloglucosidase were added, and the mixture was incubated in a shaking water bath at 37°C. Sample solutions (1 ml) were removed after 0, 30, 60, 90, 120, 150, and 180 min of incubation and placed into preheated centrifuge tubes in boiling water for 5 min to stop the reaction. Hydrolyzed glucose, according to the glucose oxidase/peroxidase colorimetric method, was determined.

The hydrolysis index (HI) was estimated from the ratio of the area under the sample hydrolysis curve (0–180 min) to the area for white bread over the same time period. The predicted glycemic index (pGI) was calculated using the following formula put forward by Granfeldt, Björck, Drews, and Tovar (1992):

$$\text{pGI} = 8.198 + 0.862\text{HI}$$

2.9 | Statistical analysis

Each sample was analyzed at least twice in parallel, and the results were presented as mean ± *SD*. Data were analyzed with one-way analysis of variance (ANOVA) by Duncan's test, to reflect the effects of sugar type on the overall quality, storage stability, and functionality of the *A. keiskei* cookies. All the analyses were conducted using the SPSS 22.0 Statistical Software Program (IBM Corporation), with a significance level of $p = .05$.

3 | RESULTS AND DISCUSSION

3.1 | Thermal gelatinization behavior of wheat flour starch in each cookie recipe

Based on the use of sucrose cookies as a control, the starch gelatinization temperatures (T_O, T_P, and T_E) for three sugar alcohol cookies are shown in Table 1. Several previous studies have shown that the presence of sugars or other sweeteners can significantly increase the gelatinization temperature of wheat starches (Allan, Rajwa, & Mauer, 2018; Slade & Levine, 1991), which is in accord with the results of this study, and several different explanations have been offered for this effect. As illustrated in Table 1, the T_O, T_P, and T_E for starch gelatinization show

TABLE 1 Effects of three sugar alcohols on the thermal gelatinization behavior of the wheat flour starch in each cookie recipe

Parameter	Sugar type			
	Sucrose	Maltitol	Xylitol	Erythritol
T_O (°C)	109.8 ± 0.9 b	116.5 ± 1.1 a	105.1 ± 0.5 c	102.0 ± 0.5 d
T_P (°C)	124.2 ± 0.4 ab	125.7 ± 1.2 a	123.0 ± 0.9 b	122.0 ± 0.3 b
T_E (°C)	135.4 ± 0.6 b	138.0 ± 0.7 a	132.1 ± 0.4 c	126.6 ± 0.7 d

Note: Results are represented as mean ± *SD*. Means with different letters in each row are significantly different ($p < .05$).

TABLE 2 Effects of three sugar alcohols on the color and texture of the *Angelica keiskei* cookies

Parameter	Sugar type			
	Sucrose	Maltitol	Xylitol	Erythritol
L^*	71.1 ± 0.3 c	71.8 ± 0.4 bc	73.5 ± 0.3 a	72.1 ± 0.3 b
a^*	7.12 ± 0.18 a	7.05 ± 0.10 ab	6.62 ± 0.23 b	7.23 ± 0.08 a
b^*	36.4 ± 0.3 ab	37.1 ± 0.3 a	35.7 ± 0.3 b	37.3 ± 0.4 a
Hardness (gf)	619 ± 25 b	630 ± 32 b	527 ± 24 c	829 ± 28 a
Brittleness (gf)	360 ± 14 b	371 ± 17 b	295 ± 21 c	447 ± 18 a

Note: Results are represented as mean ± *SD*. Means with different letters in each row are significantly different ($p < .05$).

the order: erythritol < xylitol < sucrose < maltitol. In a cookie dough system, sugars are easily hydrated by water molecules, thus inhibiting fluidity and resulting in a decrease in water activity (Allan et al., 2018). Furthermore, sugar molecules could interact with proteins and starches to form nonchemical bonds (Pareyt & Delcour, 2008). Both of these factors have been suggested to account for the increase in the starch gelatinization temperature. Additionally and alternatively, the gelatinization temperature of starch has been shown to increase with a decreasing extent of plasticization by a sugar–water solution, relative to water alone (Slade & Levine, 1991). Kweon et al. (2010) reported that maltitol showed a greater retardation of starch gelatinization than sucrose, while xylitol showed a lesser retardation, which is consistent with our results. The degree of starch gelatinization in baked cookies is closely related to the final quality of the cookies. In the study by Kweon, Slade, Levine, Martin, and Souza (2009), starch gelatinization was retarded in the order: xylose < fructose < glucose < sucrose, and the cookies formulated with xylose had the largest height (a quality negative; Kweon, Slade, Levine, & Gannon, 2014) and the most irregular off-round shape.

3.2 | Quality assessment

3.2.1 | Color

Color is one of the more important characteristics of cookies (Kweon et al., 2014), which directly influences the acceptance of products by consumers. The L^* (+ = lightness, − = darkness), a^* (+ = redness, − = greenness), and b^* (+ = yellowness, − = blueness) values for the sample cookies are shown in Table 2. Compared with sucrose, the xylitol cookies showed significantly ($p < .05$) decreased a^* value, while the maltitol and erythritol cookies showed no significant differences. Furthermore, the b^* values for the sample cookies did not show significant differences. As illustrated by the data in Table 2, replacing sucrose by maltitol, xylitol, or erythritol led to increased lightness of the final cookies (generally, another quality negative for typical low-moisture cookies; Kweon et al., 2014) by 0.9%, 3.4%, and 1.4%, respectively. This result might be explainable by the fact that sugar alcohols do not contain reducing groups and thus cannot participate in the Maillard or caramelization reactions (Lin et al., 2010; Zoulias et al., 2000). The lightness of cookies formulated with xylitol and erythritol was significantly ($p < .05$) greater than that of the control, while the cookies made with maltitol showed a color closest to that of the control, as well as a slightly lower moisture content. Therefore, based on these two positive quality attributes (Kweon et al., 2014), maltitol might be the best replacement for sucrose in such a cookie recipe.

3.2.2 | Textural characteristics

Hardness and brittleness were the key textural parameters for evaluating the quality of cookies. As shown in Table 2, the hardness and brittleness of the cookies formulated with sucrose were 619 and 360 gf, respectively, while the cookies made with maltitol had hardness and brittleness values closest to those for the sucrose cookies. In contrast, the replacement of

sucrose by xylitol resulted in decreased hardness and brittleness of the xylitol cookies by 14.9% and 18.1%, respectively. This finding was in agreement with that by Zoulias et al. (2000), who reported that xylitol produced softer cookies than sucrose, while maltitol showed no difference. Furthermore, the cookies formulated with erythritol had the highest hardness and brittleness values, which might have been because erythritol, being the sweetener with the lowest water solubility, might have promoted the formation of a gluten network in the cookie or because erythritol had a greater tendency to crystallize (Lin et al., 2010; O'Donnell & Kearsley, 2012). However, Lin et al. (2010) found that the replacement of sucrose by erythritol resulted in no significant differences in the textural characteristics of the cookies. This apparent discrepancy might be due to differences in recipes and processes.

3.3 | Storage evaluation

3.3.1 | Water activity (a_w)

Water activity (actually, % RH) is one of the most important factors affecting the shelf life of products such as cookies (Slade & Levine, 1991). The plot of the change in a_w during the 8-day storage period, for all the cookie samples, is shown in Figure 1a. The cookies prepared with sucrose and the three sugar alcohols all showed the same change trend. The a_w of the cookies reached a maximum after 2 days of storage and then gradually decreased with increasing storage time. As illustrated in Figure 1a, the effect of the sweeteners on the a_w of the cookies during the 8 days of storage showed the same order of xylitol < maltitol < sucrose < erythritol. Sahin, Axel, Zannini, and Arendt (2018) reported that the replacement of sucrose by maltitol or xylitol reduced the a_w in burger buns, which is in line with our results. The measured a_w values for the cookies made with sucrose or the sugar alcohols were below the values that would have allowed microbial growth and lipid peroxidation (Zoulias et al., 2000).

3.3.2 | Acid value and peroxide value

Cookies are a type of baked product with high lipid content, and one of the main reasons for their possible deterioration is the rancidity of lipids. Lipid oxidative deterioration can create bad flavors and even produce harmful substances, affecting the quality of cookies when stored (Theagarajan, Malur Narayanaswamy, Dutta, Moses, & Chinnaswamy, 2019). In order to investigate the effects of the three sugar alcohols on the storability of the cookies, the AV and PV were determined at different storage times, as shown in Figure 1b,c, respectively. As the storage period increased, the AV and PV of all the samples gradually increased. Nevertheless, after 28 days of storage, the AV and PV were still well below the National Hygiene Standards of 5 mg/g and 0.25 g/100 g, respectively, which might be attributable to the high antioxidant activity of *A. keiskei* flour, thereby inhibiting oxidative deterioration (Zhang et al., 2018). Furthermore, the cookies formulated with the three sugar alcohols showed lower AV and PV than the sucrose control. This might be explained by the fact that the sugar alcohols could react with free radicals to form complexes that have a metal ion chelation ability to inhibit oxidation (Jang et al., 2015). The research of Wada, Kuragano, Fuse, and Takai (1978) found that maltitol was superior to sucrose in preventing lipid rancidity. O'Donnell and Kearsley (2012) reported that erythritol and xylitol could be successfully used in baked products, where they significantly improved the storability and shelf life of those products.

It is possible to directly replace sucrose in the recipes of baked products by several sugar alcohols, and those sugar alcohol products having the most similar properties to the sucrose products are most readily accepted by consumers and most likely to succeed in the market (O'Donnell & Kearsley, 2012). Among the three sugar alcohols, the color and textural properties of the cookies formulated with maltitol were closest to the sucrose control. All the sugar alcohol cookies showed good storage stability. Hence, in the following analyses, the maltitol cookies were selected,

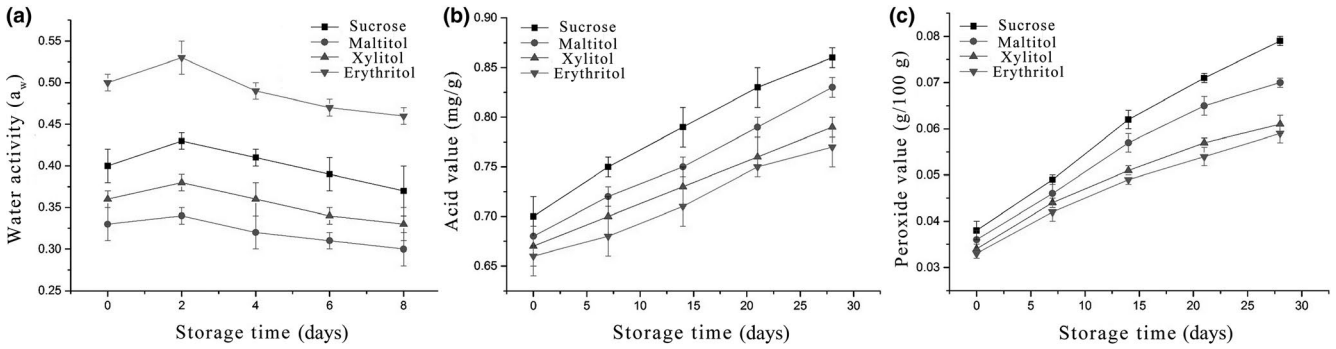

FIGURE 1 Changes in water activity (a), acid value (b), and peroxide value (c) with storage time, for cookies formulated with different sugar alcohols. The vertical bars show the standard deviations

and the effects of maltitol and *A. keiskei* flour on the antioxidant activity and glycemic index of those cookies were investigated.

3.4 | Functional analyses

3.4.1 | Evaluation of antioxidant activities of cookies made from different recipes

More and more attention has been paid recently to antioxidant ingredients in the daily diet. In the current study, DPPH, ABTS, and FRAP assays were conducted to evaluate the antioxidant potentials of the developed functional cookies, and the results are shown in Table 3. In the DPPH assay, the antioxidant activity of the cookies made from different recipes ranged from 0.45 to 3.21 μmol Trolox/g. The maltitol *A. keiskei* cookies had the highest DPPH radical scavenging activity. The antioxidant activity of the cookie samples, from the ABTS assay, ranged from 1.16 to 4.19 μmol Trolox/g. The FRAP of the cookie samples ranged from 8.62 to 13.7 μmol Trolox/g. According to the results shown in Table 3, the antioxidant activities of the cookies in the ABTS and FRAP assays showed the same trend as that in the DPPH assay: sucrose cookies < maltitol cookies < sucrose *A. keiskei* cookies < maltitol *A. keiskei* cookies. The replacement of sucrose by maltitol significantly ($p < .05$) increased the antioxidant activities of the cookies in all three assays (DPPH, ABTS, and FRAP). Several earlier studies have documented that maltitol has a high free radical scavenging activity, and the addition of maltitol in food formulations could notably increase the antioxidant activities of the products (Kim et al., 2010). As illustrated by the results in Table 3, *A. keiskei* flour further enhanced the antioxidant activities of cookies beyond that of maltitol alone. Indeed, *A. keiskei* flour is rich in phenolic compounds and flavonoids, which is responsible for its higher antioxidant activity (Zhang et al., 2018). Accordingly, maltitol and *A. keiskei* could be used in combination in the development of functional cookies with high antioxidant activity.

3.4.2 | α-amylase activity inhibition assay

High inhibition of α-amylase activity in functional products has received increasing recent attention, because it can reduce the digestion and absorption of carbohydrates, control and reduce postprandial blood glucose, and have potential anti-obesity and antidiabetic effects (Moussou et al., 2017). The effects of extracts, from cookies made from different recipes, on α-amylase activity were investigated using acarbose as a positive control. As shown in Figure 2, the inhibition of α-amylase activity by the four cookies increased with the increase in soluble starch concentration, which showed the same trend as for acarbose. Furthermore, the inhibition of α-amylase activity by all the cookie samples was lower than that of acarbose, in the following order: sucrose cookies < maltitol cookies < sucrose *A. keiskei* cookies < maltitol *A. keiskei* cookies < acarbose. The half-maximal inhibitory concentration (IC_{50}) values for the sucrose cookies, maltitol cookies, sucrose *A. keiskei* cookies, maltitol *A. keiskei* cookies, and acarbose were 8.08, 2.59, 1.86, 1.47, and 1.32 mg/L, respectively. These results suggested that maltitol and *A. keiskei* flour, used in combination, could significantly improve the α-amylase inhibitory activity of the cookies. The α-amylase inhibitory activity of maltitol has been documented by the research of Kang et al. (2014). Furthermore, the abundant polyphenolic compounds and flavonoids have been suggested to be responsible for the high α-amylase inhibitory activity of *A. keiskei* flour (Zhang et al., 2018). Therefore, maltitol and *A. keiskei* flour can be used in combination to develop functional foods that help to modulate carbohydrate digestion and postprandial blood glucose response.

3.5 | Predicted glycemic response

The GI is a quantitative indicator used to evaluate the potential impact of diet on blood sugar levels. On the basis of the GI value, foods can be divided into three categories: substances with low GI (<55), medium GI (55–69), and high

TABLE 3 The antioxidant activities (DPPH, ABTS, and FRAP) and glycemic responses of the cookies formulated with different recipes

	Cookies prepared from different recipes			
Parameter	**Sucrose cookies**	**Sucrose *A. keiskei* cookies**	**Maltitol cookies**	**Maltitol *A. keiskei* cookies**
DPPH (μmol Trolox/g)	0.45 ± 0.04 d	2.65 ± 0.10 b	1.73 ± 0.08 c	3.21 ± 0.12 a
ABTS (μmol Trolox/g)	1.16 ± 0.09 d	3.54 ± 0.12 b	1.65 ± 0.09 c	4.19 ± 0.11 a
FRAP (μmol Trolox/g)	8.62 ± 0.20 d	11.4 ± 0.3 b	10.8 ± 0.2 c	13.7 ± 0.2 a
HI	76.4 ± 1.5 a	68.5 ± 2.0 b	61.8 ± 1.3 c	53.0 ± 1.3 d
pGI	74.1 ± 1.3 a	67.3 ± 1.7 b	61.4 ± 1.1 c	53.9 ± 1.1 d

Note: Results are represented as mean ± *SD*. Means with different letters in each row are significantly different ($p < .05$).

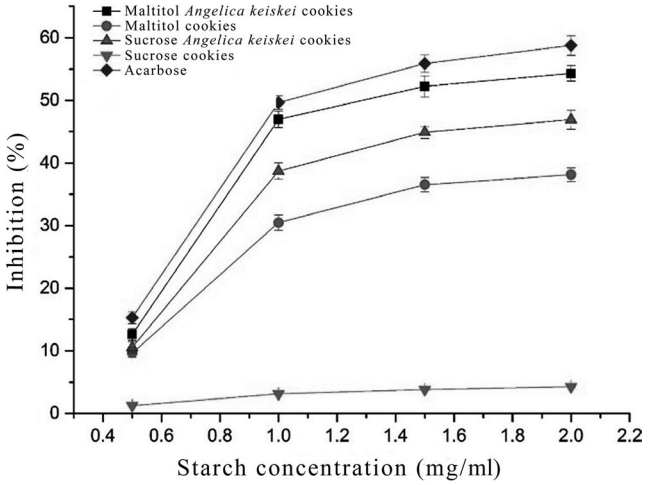

FIGURE 2 The effects on α-amylase activity, using acarbose as a positive control, for cookies formulated with different sugar alcohols. The vertical bars show the standard deviations

GI (>70), and a large number of experimental studies have indicated that this criterion is useful for guiding the diet planning of diabetic patients (Feng et al., 2018). In the present study, the HI and pGI for cookies made from different recipes were calculated, as shown in Table 3, with white bread as the reference food. The sucrose cookies showed the highest HI of 76.4, in accord with the mean HI of control cookies reported by Giuberti et al. (2018). Incorporating either maltitol or *A. keiskei* flour in the cookie recipe resulted in a significant ($p < .05$) decrease in the HI and pGI of the cookies. Since the GI (35.3) of maltitol is much lower than that (65.4) of sucrose, the product formulated with maltitol would be expected to have a lower glycemic response (Dobreva et al., 2013). Furthermore, our DSC results (Table 1) confirmed that maltitol would prevent the gelatinization of the native wheat flour starch in the cookies during baking, because the internal temperature of the dough during baking would be expected to not exceed much above about 110°C (Kweon et al., 2014), resulting in high resistance to enzymatic hydrolysis, which was also responsible for the low HI of the maltitol cookies. *Angelica keiskei* flour is rich in dietary fiber, phenolic compounds, and flavonoids, and these functional components have been reported to cause a decrease in the digestibility of starch in foods (Giuberti et al., 2018; Naknaen et al., 2016).

Knowledge of the GI is essential for choosing between different carbohydrate foods within a meal, especially for obese and diabetic patients (Dobreva et al., 2013). As shown by the results in Table 3, the maltitol *A. keiskei* cookies showed the lowest pGI of 53.9, which was also consistent with the results for α-amylase inhibitory activity. Compared to the sucrose cookies, the pGI for the maltitol *A. keiskei* cookies was decreased by 27.3%. Incorporating both maltitol and *A. keiskei* flour together in the recipe changed these traditional Danish cookies from a high-GI food to a low-GI food. Low-GI foods are thought to be beneficial in the prevention of diabetes, cardiovascular disease, and other obesity-related diseases.

4 | CONCLUSIONS

In the current study, replacing sucrose by maltitol, xylitol, or erythritol in the cookie recipe produced different effects on the quality and storability of *A. keiskei* cookies. Compared to sucrose, the three sugar alcohols were beneficial in the inhibition of lipid oxidative deterioration, in order to prolong the shelf life of the cookies. Furthermore, the color and texture of the cookies made with maltitol were closest to that of the sucrose cookies, among the tested polyols. Thus, maltitol was determined to be an acceptable sucrose substitute in this application. Moreover, incorporating either maltitol or *A. keiskei* flour notably enhanced the antioxidant activity of the cookies in the DPPH, ABTS, and FRAP assays. It was also found that maltitol and *A. keiskei* flour, in combination, showed large inhibitory effects on α-amylase activity and carbohydrate hydrolysis. According to the GI classification of foods, cookies formulated with maltitol and *A. keiskei* flour, rather than sucrose, could be classified as a low-GI food. Therefore, *A. keiskei* flour and maltitol have been shown in the present study to be suitable as potential functional ingredients for the production of low-GI functional foods.

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