Relative sweetness and sweetness quality of Xylobiose

Hye-Won Park¹ · Min-Ji Kim¹ · Sheungwoo Seo² · Sangho Yoo³ · Jae-Hee Hong¹

Received: 10 January 2017 / Revised: 9 March 2017 / Accepted: 10 March 2017 / Published online: 29 May 2017
© The Korean Society of Food Science and Technology and Springer Science+Business Media Dordrecht 2017

Abstract Xylobiose (XB), a xylose dimer, is a low-calorie sweetener with prebiotic activity. Unlike its well-defined biosynthesis and production methods, its sensory characteristics have not been well investigated. This study aims to identify the relative sweetness and sensory profile of XB. XB was prepared as an aqueous solution, and its relative sweetness (RS) compared to 5% sucrose was determined using the 2-alternative forced choice method. The sensory profile was identified by 10 trained panelists using descriptive analysis. The RS of XB was determined to be 0.34. XB was characterized by its yellowness, corn aroma and flavor, and its *nurungji* (scorched rice) candy flavor. The persistence of sweetness of XB was similar to that of sucrose, but its onset of sweetness was slower. When XB was mixed with sucrose at a ratio of 7:93, the mixture exhibited a similar sensory quality to that of sucrose, thereby making it a useful sucrose complement.

Keywords Relative sweetness · Descriptive analysis · Xylobiose · Bulk sweetener · Sweetness profile

Introduction

Sucrose is one of the main causes of obesity, which in turn can cause metabolic syndrome and diabetes [1]. This has led to a rise in consumers' interest in alternative sweeteners. In particular, the food industry is watching bulk sweeteners with a keen interest, not only for their sensory qualities similar to those of sucrose but also for their health benefits such as facilitating the growth of bifidobacteria and inhibiting a rapid increase in blood sugar levels [2].

Two of the most well-known varieties of bulk sweeteners are sugar alcohols and oligosaccharides. Xylitol, one of the most widely used sugar alcohols, is produced by hydrolyzing the xylan present in hardwoods or corn cobs [3]. Xylitol has a sweetness potency similar to that of sucrose, and its sweetness appears quickly and has a shorter persistence. Besides its low-calorie value, which is less than that of sucrose by 40% [4], it provides protection against dental cavities by inhibiting the production of acid by *Streptococcus mutans*, making it a promising ingredient for gums and candies [5]. Another sugar alcohol, erythritol, is a natural sweetening compound that has been found in fermented foods such as soy sauce, fermented fruit drinks, and rice wine [6]. Erythritol is known to be 0.6–0.8 times [6, 7] sweeter than sucrose, but also has bitterness and astringency [8]. Erythritol is non-caloric and prevents the growth of *S. mutans* [9].

Oligosaccharides are sugar oligomers that typically have 3–10 monosaccharides linked together. Xylo-oligosaccharides (XOSs) have recently received considerable attention due to their known role in improving gastrointestinal health by promoting the growth of bifidobacteria [10]. XOS consists of 2–10 xylose molecules linked by β -1,4 glycosidic bonds. Commercial XOS is a mixture of dimers, trimers, tetramers, and bigger molecules. It is found in

✉ Jae-Hee Hong
jhhong@kookmin.ac.kr

¹ Department of Foods and Nutrition, Kookmin University, Seoul 02707, Korea

² R&D Center, TS Corporation, Incheon 22300, Korea

³ Department of Food Science and Technology, and Carbohydrate Bioproduct Research Center, Sejong University, Seoul 05006, Korea

hemicellulose from cereal grains such as corn cob, corn bran, and rice bran [2], and has a limited daily intake allowance of 0.7–7.5 g due to a risk of diarrhea and bloating. Kim et al. [11] showed that XOS is 0.25 times sweeter than 5% sucrose solution and is characterized by yellowness, honey odor, sour odor, corn silk tea odor, sourish flavor, honey flavor, and sikhye (sweet rice beverage) flavor. The sweetness of XOS appears slowly and persists longer, as compared to sucrose. Moreover, XOS does not decompose in the stomach and small intestine, and therefore, does not have any effects on the blood glucose level. In addition, XOS is more effective in promoting the growth of probiotics than fructo-oligosaccharides [12–14].

Xylobiose (XB), a dimer accounting for 35% of the total XOS, is known to have the strongest prebiotic activity [15, 16] among xylose polymers. In addition, XB, which is 0.3–0.4 times sweeter than sucrose [10], contributes to the sweetness potency of XOS. For these reasons, the food industry begins to consider XB as a useful candidate as a health-promoting bulk sweetener ingredient. However, compared to the well-defined mechanisms of biosynthesis and effective production strategy [10, 15–17], its sensory characteristics, which are important for guiding food applications, are not well elucidated.

Like XOS, minor side-effects such as flatulence, bloating, abdominal discomfort, and diarrhea limit the daily intake allowance of XB to 0.7–7.5 g [18]. Thus, considering their low relative sweetness value, the application of XB or XOS to a food system as a single-compound sweetener is not feasible as the required quantity will easily exceed the daily allowance limit. Therefore, the food industry may find XB and XOS more useful as ingredients in a sweetener blend rather than as single-compound sweeteners. Sweetener blends such as Xylosugar, a recently launched xylose–sucrose blend that uses xylose as a complementary ingredient to inhibit sucrase activity [19], are not uncommon and highlight the use of several sweeteners in combination to improve the sensory quality and bioactivity [20].

This study aims to determine the relative sweetness and sensory characteristics of XB in comparison with sucrose and four other bulk sweeteners. In addition, to understand the sensory impact of XB in a sweetener blend, XB mixed with sucrose is tested.

Materials and methods

Stimuli

XB (98.0%) was purified from XOS in powdered form (XOSP) (XOS-95P; 95.0% purity, Shandong Longlive Biotechnology Co. Ltd., China) by using the ion-exchange

resin (Ion-Exchange Resin; Dowex-50Wx4, Sigma) in TS Corporation R&D center (Incheon, Korea). Sucrose (food-grade refined white sugar; TS Corporation) was tested as a control. Other bulk sweeteners were also tested to evaluate the sensory characteristics of XB within the context of natural bulk sweeteners. Xylose (99.6%, D-xylose; Qingdao Samin Chemical Co. Ltd., Qingdao, China) and XOSP were selected for their structural relevance with XB. Xylitol (99.7%, Xylisorb 700; Roquette Frères, Lestrem, France) and erythritol (99.9%, Cargill Incorporated, USA) were chosen because they are widely used commercial sugar alcohol sweeteners.

Determination of relative sweetness using the 2-alternative forced choice (AFC) method

Sample preparation

Based on a previous study [11], the five concentration levels were selected for each sweetener (Table 1). The samples were prepared by dissolving each sweetener in filtered water (H-300, Everpure, USA) using a magnetic stirrer (GLHPS-G; Global lab, Siheung, Korea) for 30 min. The samples were stored at 2 ± 1 °C and equilibrated at room temperature (22 ± 2 °C) for 30 min before the test. 10 mL of each sample was presented in a disposable cup (75 mL; Easepack Co., Namyangju, Korea) labeled with a random three-digit code. Filtered water (22 ± 2 °C) was served as a palate cleanser.

Panel

Forty-three panelists (29 females and 14 males, aged 19–49 years) were recruited from Kookmin University (Seoul, Korea) and the surrounding local community. Recruiting criteria excluded those who had health problems associated with the consumption of sucrose and bulk sweeteners and those who were or might be pregnant. The

Table 1 Concentration ranges of sweetener samples used in the 2-AFC test

Sample	Concentration (w/v ^a , %)
Xylitol	3, 4, 5, 6, 7
Xylose	6, 7, 8, 9, 10
Erythritol	6, 7, 8, 9, 10
XOSP ^b	12, 15, 18, 21, 24
XB ^c	8.5, 10.5, 12.5, 14.5, 16.5

^a Weight per volume

^b XOSP xylooligosaccharide powder

^c XB xylobiose

research protocol was approved by the Institution Review Board at Kookmin University (KMU-201410-HR-037-P1-C1).

Evaluation procedure

The relative sweetness to 5% sucrose was determined using the 2-AFC test protocol [11]. The panelists attended five sessions. In each session, they evaluated five pairs of solutions, with each pair consisting of a sweetener solution at one of the five concentration levels and 5% sucrose solution. The panelists were asked to select the sweeter solution from each pair. The order of the pair was randomized and counterbalanced within and between the sample pairs.

The tasting protocol developed by Kim et al. [11] was used. Briefly, the panelists swirled 10 mL of the sample around in their oral cavity for 5 s, expectorated, and monitored any residual sensation for another 5 s. Thereafter, the panelists were asked to consider the overall sweetness intensity perceived for a total of 10 s when they made a judgment as to which sample was sweeter. The panelists were instructed to rinse their mouths with water during a 1–3 min break between the samples. The 2-AFC test was conducted under dim red light to mask the color differences.

Data analysis

The relative sweetness value was identified from the concentration–response (C–R) curves following the method suggested by Heikel et al. [20] and Kim et al. [11]. The CR curves were obtained by plotting the percentage of responses choosing a sample as being sweeter than 5% sucrose against the concentration levels. The concentration that received 50% of the responses was calculated from the regression equation of the C–R curves by interpolation. The relative sweetness value was obtained by dividing the sucrose concentration (5%) by the concentration of the sweetener that received 50% of the responses.

Characterization of the sensory attributes of sweeteners using descriptive analysis

Sample preparation

Descriptive analysis was conducted with sweetener samples at concentrations that produce equi-intense sweetness to 5% sucrose. These were determined based on the result of the 2-AFC test. The concentration of erythritol was re-adjusted from 8.85 to 7.80% through the validation process suggested by Gwak et al. [8]. As a result, the difference in sweetness between 5% sucrose and adjusted erythritol was

insignificant [analysis of variance (ANOVA), followed by Tukey's honest significant difference test (HSD), $p < 0.05$]. Besides XB, a mixture of XB and sucrose (XBSU) at a ratio of 7:93 was prepared to examine the sensory quality of a sweetener product where XB is used as a functional ingredient. Because XB was added at the maximum level, so as not to exceed the recommended daily allowance level, the relative sweetness of XBSU was not assessed to adjust the mixing ratio or the concentration in the sample. Finally, the sample set for the descriptive analysis comprised 5% sucrose, 5.1% xylitol, 8.21% xylose, 19.32% XOSP, 14.6% XB, XBSU made of 0.35% XB and 4.65% sucrose, and 7.8% erythritol.

The samples were prepared in the same way as for the 2-AFC test. The samples for evaluating odor, taste, flavor, and trigeminal sensation attributes were presented in a 75 mL white disposable cup labeled with a three-digit random number. In contrast, the samples for appearance were presented in a 50 mL screw-capped glass vial, labeled with different random numbers from those used for the other attributes to prevent stimulus bias caused by color [21].

Panel

Descriptive analysis was conducted by 10 panelists (10 women, aged 30–49). Seven of them had previously participated in descriptive analysis of intense sweeteners, while the other three were selected from the panel pool who participated in the previous sensory evaluations based on their ability of detection, discrimination, and verbal expression of perceived sensory attributes.

Evaluation procedure

Descriptive analysis was conducted following the generic procedure [21]. The panelists were trained over 17 sessions for 2 months. Training sessions were held four times a week, with each session taking approximately 1 h. Before the training, an orientation session was provided to introduce the panel to the purpose of the study and educate them about the principles of the descriptive analysis. During the training sessions, the panelists developed terminology, their definitions, reference standards (Table 2), and standardized tasting protocols by consensus. Practice tests were conducted in quadruplicates and the result was analyzed using ANOVA to check the panel performances [21]. A panelist who showed poor performance received additional training. The main session was repeated three times.

The samples were presented following the Williams Latin square design to minimize the first-sample effect. The test was performed in a monadic sequence [22]. The panelists tasted the samples in the same way as for the

Table 2 Definitions of and reference materials for the descriptive attributes of sweetener samples

Attributes		Definition	Reference materials	Scale value (0–15)
Appearance	Yellow	Yellow color	NCSS1040-Y (NCS color index, Scandinavian Colour Institute AB, Stockholm, Sweden)	9.5
Odor	Corn	The smell associated with corn	Mixture of corn silk tea (Kwangdong corn silk tea, Kwangdong pharmaceutical Co., Pyeongtaek, Gyeonggi-do, Korea) and water at the ratio of 1:5	7.5
Taste	Sweet	Fundamental taste sensation of which sucrose is typical	4% (w/v), 5%, and 6% sucrose (Foodream refined white sugar, TS Co., Incheon, Korea) in water	4, 5, and 6
	Bitter	Fundamental taste sensation of which caffeine and quinine is typical	0.05% (w/v) caffeine (Sigma-Aldrich, St. Louis, MO, USA) in water	7.5
Flavor	Corn	Aromatics associated with corn	Mixture of corn silk tea (Kwangdong corn silk tea, Kwangdong pharmaceutical Co., Pyeongtaek, Gyeonggi-do, Korea) and water at the ratio of 1:5	7.5
	<i>Nurungji</i> candy	Aromatics associated with <i>nurungji</i> candy	<i>Nurungji</i> candy (<i>nurungji</i> on iron pot, Haitai Co., Gwangju, Korea)	11.25
Trigeminal senses	Acridness	Sharp, irritating, or biting sensation on the tongue	21 g radish sprout (radish sprout, Neulpureun farm, Goyang-si, Gyeonggi-do, Korea) steeped in 200 mL water	7.5
Texture	Body	General weight or fullness, which can be assessed by rate of sample flows on the tongue	1.5 g potato starch (potato starch, Ttureban, Goyang-si, Gyeonggi-do, Korea) in 500 mL water boiled on a low heat with stirring for 5 min	9.4
Aftertaste	Bitter	Bitter taste after expectoration	Abstraction and generalization using experience with bitter taste such as caffeine and quinine	N/A ^a
Persistence	Sweet	The persistence of sweet taste after expectoration	See reference material for sweet taste	N/A
Onset	Sweet	The time when maximum sweetness was first perceived	0.0575% (w/v) luo han guo extract (Guilin Layn Natural Ingredients Co., Guangxi, China) in water	13.75

^a N/A means that the reference standard of a sensory attribute does not have a specific scale value because the reference sample was only used for assessors' concept alignment

2-AFC test and rated the intensity of different attributes on a 15-cm line scale labeled with “very weak” or “very fast” located at 1.25 cm and “very strong” or “very slow” located at 13.75 cm. The panelists cleaned their mouths with the provided water while taking a 3 min mandatory break between the samples. Appearance was evaluated under a daylight setting (North sky day light, CIE-F7, 6500K, Multi Light Booth, Super Light VI; Bowoo engineering Co. Ltd., Gunpo, Korea), whereas other attributes were evaluated under dim red light to mask the color differences.

Data analysis

Two-way mixed model ANOVA was performed to test the significance of the main effects such as sample (fixed), panel (random), and replication, and two-way interactions of these factors on perceived intensities of sensory attributes. Tukey's honest significant difference test was conducted as a post hoc test ($p < 0.05$). Principal component analysis (PCA) was performed to obtain sensory

representation of the samples and attributes. The confidence ellipses around the samples were obtained by a bootstrapping technique (500 iterations) and examined using Hotelling's T test. SPSS for Windows version 18.0 (SPSS Inc., Chicago, IL, USA) and SensoMineR package in R (version 3.1.1) were used for ANOVA and PCA, respectively.

Results and discussion

Relative sweetness

The regression equations, regression coefficient (R^2), and relative sweetness from the C–R curves are summarized in Table 3. The R^2 value for each sample is in the range of 0.95–0.99, indicating that the regression equations are well-fitted to the C–R curves. In the present study, the relative sweetness values of xylitol, xylose, and erythritol are identified as 0.98, 0.61, and 0.57, respectively, showing similar values to those reported previously

Table 3 Relative sweetness of five bulk sweeteners calculated from the C–R curves

Sample	Regression equation	R ²	Relative sweetness obtained by 2-AFC	Relative sweetness from literature (References)
Xylitol	$y = 0.2633x - 0.8433$	0.9502	0.98	1 [3, 23]
Xylose	$y = 0.2067x - 1.1967$	0.9861	0.61	0.63 [8]
Erythritol	$y = 0.1884x - 1.1674$	0.9520	0.57	0.6–0.8 [6, 7]
XOSP ^a	$y = 0.0721x - 0.893$	0.9905	0.26	0.25–0.5 [11, 17]
XB ^a	$y = 0.0942x - 0.875$	0.9536	0.34	0.3–0.4 [10]

^a See Table 1 for sample abbreviation

[3, 6–8, 10, 11, 17, 23]. Initially, the 2-AFC test yields a relative sweetness value of 0.64 for erythritol, but is reduced to 0.57 following panel discussion during the validation process. It is reported that erythritol has a weak but significantly stronger bitter taste than sucrose [8]. Because the bitterness of a sweetener can suppress the sweetness perception at high concentration levels, the decrease in the C–R curve slope caused by bitterness may have resulted in a higher estimated relative sweetness value for erythritol [24, 25].

Previously, Kim et al. [11] assessed the relative sweetness of XOS in a syrup form, which contained approximately 50% water, as 0.25. Thus, it was initially hypothesized that the relative sweetness of XOSP would be higher than 0.25 due to the decrease in water content. However, the relative sweetness of XOSP is identified as 0.26, almost identical to that of XOS syrup and lower than the previously reported values of 0.3–0.6 [10]. This may be due to the different approach used for determining the relative sweetness of XOS. In a previous study [11], XOS was delivered in 2% sucrose solution to prevent curve flattening caused by a strong sour flavor of the XOS syrup. Therefore, the equi-intense sweetness of XOS is actually assessed relative to 3% sucrose, not 5% sucrose. In contrast, since XOSP does not elicit a strong sour odor and taste, its equi-sweetness is measured relative to 5% sucrose. Because the sweetness potency of alternative sweeteners changes depending on concentrations [26–28], relative sweetness may have been influenced not only by XOS composition but also by the concentration ranges used.

The relative sweetness of XB is determined as 0.34, which is close to the relative sweetness values of 0.3–0.4 reported in previous studies [10]. Since XB accounts for 30–35% of XOS [17], the sweetness of XOS seems to be largely dependent on the presence of XB in XOS.

Sensory profiles

There are significant differences ($p < 0.05$) in perceived sensory intensities between the samples. Figure 1 shows

the sensory attributes and samples. Dim 1 and dim 2 explain 58.08 and 33.50% of the total variances, respectively. Dim 1 distinguishes XB and XOSP from the other samples. *Yellowness*, *corn aroma*, *corn flavor*, *nurungi candy flavor*, *body*, and *persistence/onset of sweetness* are highly loaded in the positive direction of dim 1. Particularly *yellowness*, *corn aroma and flavor*, and *nurungi candy flavor* are only present in XB and XOSP samples (Table 4). XOSP and XB share a similar sensory profile due to their structural similarities. However, compared to XOSP, XB exhibits significantly weaker *yellowness*, *corn aroma and flavor*, and *body*, and stronger *nurungi candy flavor* (Table 4). This may result from the purification process that separates XB from other xylose oligomers using an ion-exchange column. In particular, decrease in *body* seems to be associated with the removal of xylose oligomers with higher molecular mass. In contrast, increase in *nurungi candy flavor* implies that this roasted cereal-like flavor is an inherent characteristic of XB.

Bitterness, *bitter aftertaste*, and *acridness* are highly loaded in the positive direction of dim 2 (Fig. 1A). Dim 2 also contrasts erythritol and xylose to the other sweeteners (Fig. 1B). The ANOVA result shows that they have significantly but slightly stronger *bitter taste*, *aftertaste*, and *acridness* (Table 4). This result is consistent with the previous findings that reported slightly stronger bitterness and acridness of xylose compared to sucrose [11] and strong bitterness of erythritol [8].

In contrast, sucrose, XBSU, and xylitol are characterized by the absence of the abovementioned attributes (Fig. 1)—being located in quadrant 3, where no attribute vectors are positioned. Hotelling's T^2 test and confidence ellipses (Fig. 1B) indicate that XBSU and sucrose do not have a significant difference. Thus, it can be concluded that XB does not affect the sensory profile of sugar when added at 7%. The sensory quality of xylitol is similar to that of sucrose, even though it is globally differentiated from sucrose (Fig. 1). When cross-checked with Fig. 1A which shows directions of attribute vectors, global difference seems to be largely due to the faster onset and shorter persistence of sweetness compared to sucrose. Table 3

Fig. 1 Principal component loading of the sensory attributes (A) and scores of the samples (B) from sucrose and six bulk sweeteners on dim 1 and dim 2

Table 4 Mean intensities of descriptive sensory attributes elicited by sucrose and six bulk sweeteners

	Sucrose	XBSU	Xylitol	Xylose	Erythritol	XOSP	XB
Yellowness	0.00 ^{a1} (0.00) ²	0.00 ^a (0.00)	0.00 ^a (0.00)	0.00 ^a (0.00)	0.00 ^a (0.00)	5.85 ^c (1.20)	3.42 ^b (0.65)
Corn aroma	0.00 ^a (0.00)	0.00 ^a (0.00)	0.00 ^a (0.00)	0.00 ^a (0.00)	0.00 ^a (0.00)	4.72 ^c (0.94)	1.80 ^b (1.22)
Sweetness	5.04 ^{abc} (0.46)	4.96 ^{ab} (0.59)	4.73 ^a (0.48)	5.13 ^{bc} (0.45)	5.02 ^{abc} (0.58)	5.33 ^c (0.27)	5.08 ^{bc} (0.41)
Bitterness	0.07 ^a (0.28)	0.18 ^a (0.55)	0.15 ^a (0.40)	2.48 ^b (1.16)	4.51 ^c (1.36)	0.00 ^a (0.00)	0.00 ^a (0.00)
Corn flavor	0.00 ^a (0.00)	0.00 ^a (0.00)	0.00 ^a (0.00)	0.00 ^a (0.00)	0.00 ^a (0.00)	5.06 ^c (0.60)	2.63 ^b (0.51)
Nurungji candy flavor	0.00 ^a (0.00)	0.00 ^a (0.00)	0.00 ^a (0.00)	0.00 ^a (0.00)	0.00 ^a (0.00)	3.13 ^b (0.69)	6.12 ^c (1.56)
Acridness	0.00 ^a (0.00)	0.11 ^a (0.42)	0.08 ^a (0.32)	2.59 ^b (1.54)	4.14 ^c (1.32)	0.04 ^a (0.17)	0.02 ^a (0.11)
Body	1.07 ^a (1.33)	1.43 ^a (1.51)	1.15 ^a (1.21)	1.47 ^a (1.70)	4.20 ^c (2.55)	5.85 ^d (1.66)	3.55 ^b (1.43)
Bitter aftertaste	0.02 ^a (0.09)	0.08 ^a (0.32)	0.04 ^a (0.18)	1.71 ^b (0.98)	3.37 ^c (1.13)	0.00 ^a (0.00)	0.00 ^a (0.00)
Persistence of sweetness	2.59 ^{ab1} (1.07) ²	2.74 ^b (1.20)	2.11 ^a (0.93)	3.02 ^{bc} (1.09)	3.40 ^{cd} (1.13)	3.95 ^d (0.87)	3.01 ^{bc} (1.18)
Onset of sweetness	1.77 ^a (1.14)	1.78 ^a (1.35)	1.45 ^a (0.64)	2.66 ^b (1.79)	4.56 ^{cd} (2.08)	5.29 ^d (1.88)	4.28 ^c (2.15)

¹ Different alphabet letters indicate a significant difference among the samples ($p < 0.05$, Tukey's HSD test)

² Standard deviation

showed that there were no significant differences in these attributes between xylitol and sucrose, but significant differentiation between two samples could be inferred from bootstrapping with 500 iterations to create confident ellipses.

Since the samples are formulated to elicit a perceived intensity of sweetness equivalent to that of 5% sucrose, there is no significant difference in sweetness intensity between sucrose and all other sweetener samples. However, xylitol is perceived as being slightly but significantly less sweet than xylose, XOSP, and XB. Meanwhile, XOSP is significantly sweeter than xylitol and XBSU (Table 4). Similar results have been reported in previous studies [8, 11, 29], which have suggested that temporal sweetness

and flavors other than sweetness cause significant differences in sweetness intensity among the samples that are formulated to have equi-sweetness. Increased complexity of stimuli can change the sensory context for perception, resulting in different perception [30]. Particularly for XOSP and XB, it is assumed that *corn aroma* and *nurungji candy flavor* might have contributed to increased perception of sweetness by flavor–aroma interaction [31].

The temporal aspect of sweetness, such as onset and persistence, is also evaluated in the descriptive analysis (Table 4). Sweetness of XB appears significantly more slowly than that of sucrose, but lasts to a similar degree. Temporal sweetness of XBSU is not significantly different from that of sucrose. Sweetness of xylitol appears the

fastest and persists the shortest among the samples, whereas XOSP and erythritol demonstrate slower onset and longer persistence compared to the other samples.

In summary, the present study showed that XB exhibits a weak (smaller than 6 on a 15-point scale) *yellowness* and *corn aroma* and *flavor*, *nurungji candy flavor*, a slight *body*, and a slow onset at an equi-sweetness concentration of 5% sucrose. However, these attributes become imperceptible when mixed with sucrose at the ratio of 7:93. This XB–sucrose mixture is indistinguishable from sucrose with regard to its sensory characteristics. Therefore, XB can be used as a useful complement for a functional table sugar product that has an identical sensory profile to ordinary sugar.

The results of the present study provide the food industry with a useful guideline for the commercial application of XB to food systems. However, how the sensory characteristics of XB are influenced by processing conditions such as pH, heat, and interactions with other ingredients remains to be determined. Further studies are warranted to elucidate the changes in the sensory characteristics of XB in various food and beverage systems.

Acknowledgements This research was supported by the High Value-added Food Technology Development Program (Project No. 313024-03-2-HD030), Ministry of Agriculture, Food and Rural Affairs, Republic of Korea.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

- Howard BV, Wylie-Rosett J. Sugar and cardiovascular disease. A statement for healthcare professionals from the committee on nutrition of the council on nutritional, physical activity, and metabolism of the American Heart Association. *Circulation* 106: 523–527 (2002)
- Aidoo RP, Depypere F, Afoakwa EO, Dewettinck K. Industrial manufacture of sugar free chocolates-applicability of alternative sweeteners and carbohydrate polymers as raw materials in product development. *Trends Food Sci Tech*. 32: 84–96 (2013)
- Zacharis C, Stowell J. Xylitol. In: *Alternative sweeteners*. 4th ed. Nabor LO (ed). CRC Press, Boca Raton, FL, USA, pp. 349–378 (2012)
- Winkelhausen E, Jovanovic-Malinovska R, Velickova E, Kuzmanova S. Sensory and microbiological quality of a baked product containing xylitol as an alternative sweetener. *Int. J. Food Prop*. 10: 639–649 (2007)
- Tranhan L. Xylitol: a review of its action on mutans streptococci and dental plaque-its clinical significance. *Int. Dent. J*. 45: 77–92 (1995)
- Goossens J, Roper H. Erythritol: A new bulk sweetener. *Int. Food Ingredient* 1/2, 27–33 (1994)
- Munro IC, Bernt WO, Borzelleca JF, Flamm G, Lynch BS, Kennepohl E, Bar EA, Modderman J. Erythritol: an interpretive summary of biochemical, metabolic, toxicological and clinical data. *Food Chem. Toxicol*. 36: 1139–1174 (1998)
- Gwak MJ, Chung SJ, Kim YJ, Lim CS. Relative sweetness and sensory characteristics of bulk and intense sweeteners. *Food Sci. Biotechnol*. 21: 889–894 (2012)
- Mäkinen KK, Isotupa KP, Kivilompolo T, Mäkinen PL, Toivanen J, Söderling E. Comparison of erythritol and xylitol saliva stimulants in the control of dental plaque and mutans streptococci. *Caries Res*. 35: 129–135 (2005)
- Vazquez MJ, Alonso JL, Dominguez H, Parajo JC. Xylooligosaccharides: manufacture and applications. *Trends Food Sci. Tech*. 11: 387–393 (2000)
- Kim MJ, Yoo SH, Jung S, Park MK, Hong JH. Relative sweetness, sweetness quality, and temporal profile of xylooligosaccharides and *luo han guo* (*Siraitia grosvenorii*) extract. *Food Sci. Biotechnol*. 24: 965–973 (2015)
- Okazaki M, Fujikawa S, Matsumoto N. Effect of xylooligosaccharide on the growth of bifidobacteria. *Bifidobact. Microflora* 9: 77–86 (1990)
- Moure A, Gullón P, Domínguez H, Parajó JC. Advances in the manufacture, purification and applications of xylo-oligosaccharides as food additives and nutraceuticals. *Process Biochem*. 41: 1913–1923 (2006)
- Chou YT, Lin KW. Effect of xylooligosaccharides and sugars on the functionality of porcine myofibrillar proteins during heating and frozen storage. *Food Chem*. 121: 127–131 (2010)
- Guerfali, M, Gargouri A, Belghith H. Talaromyces thermophilus β -D-xylosidase: purification, characterization and xylobiose synthesis. *Appl. Biochem. Biotech*. 150: 267–279 (2008)
- Rizzatti A CS, Jorge JA, Terenzi HF, Rechia CGV, Polizeli MLTM. Purification and properties of a thermostable extracellular β -D-xylosidase produced by a thermotolerant *Aspergillus phoenicis*. *J. Ind. Microbiol. Biot*. 26: 156–160 (2001)
- Choi JH, Park H, Park C, Wang NHL, Mun S. Highly efficient recovery of xylobiose from xylooligosaccharides using a simulated moving bed method. *J. Chromatography A* 1465: 143–154 (2016)
- Kyung M, Choe H, Jung S, Lee K, Jo S, Seo S, Choe K, Yang C, Yoo S, Kim Y. Effects of xylooligosaccharide-sugar mixture on glycemic index (GI) and blood glucose response in healthy adults. *J. Nutr. Health* 47: 229–235 (2014)
- Krog-Mikkelsen I, Petersen S, Hels O, Tetens I, Holst JJ, Bukhave K, Andersen JR. Effects of xylose on intestinal sucrose activity, in vitro and in vivo. *Clin. Nutr*. 3: suppl 1, 32 (2008)
- Heikel B, Krebs E, Köhn E, Busch-Stockfisch M. Optimizing synergism of binary mixtures of selected alternative sweeteners. *J. Sens. Stud*. 27: 295–303 (2012)
- Lawless HT, Heymann H. *Sensory evaluation of food: Principles and practices*. 2nd ed. Springer, New York, NY, USA (2010)
- MacFie HJ, Bratchell N, Greenhoff K, Vallis LV. Designs to balance the effect of order of presentation and first-order carry-over effects in hall test. *J. Sens. Stud*. 4: 129–148 (1989)
- Uhari M, Tapiainen T, Kontiokari T. Xylitol in preventing acute otitis media. *Vaccine*. 19: S144–S147 (2001).
- Schiffman SS, Both BJ, Losee ML, Pecore SD, Warwick ZS. Bitterness of sweeteners as a function of concentration. *Brain Res. Bull*. 36: 505–513 (1995)
- Moskowitz HR, Klarman L. The tastes of artificial sweeteners and their mixtures. *Chem. Senses* 1: 411–421 (1975)
- Choi JH, Chung SJ. Optimal sensory evaluation protocol to model concentration-response curve of sweeteners. *Food Res. Int*. 62: 886–893 (2014)
- Fujimaru T, Park JH, Lim JY. Sensory characteristics and relative sweetness of tagatose and other sweeteners. *J. Food Sci*. 77: S323–S328 (2012)

28. Cardello HM, da Silva MA, Damasio MH. Measurement of the relative sweetness of stevia extract, aspartame, and cyclamate/saccharin blend as compared to sucrose at different concentrations. *Plant Food Hum. Nutr.* 54: 119–130 (1999)
29. Portmann MO, Kilcast D. Descriptive profiles of synergistic mixtures of bulk and intense sweeteners. *Food Qual. Prefer.* 9: 221–229 (1998)
30. Stone H, Sidel L. Special problems. Chapter 8. pp 273–276. In: *Sensory evaluation practices*, 2nd ed. Stone H, Sidel L. Academic Press, San Diego, CA, USA (1993)
31. Prescott J, Johnsotone V, Francis J. Odor-taste interactions: Effects of attentional strategies during exposure. *Chem. Senses* 29: 331–340 (2004)