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IMPACT OF SUCROSE REPLACEMENT ON GEL TEXTURE AND SENSORY PERCEPTION OF KONJAC JELLIES

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In this research, the effects of sucrose replacement with xylitol and erythritol-sucralose on the textural characteristics and sensory acceptance of konjac jellies were investigated. Two levels (50 and 100% sucrose replacement) were studied. Textural characteristics on hardness, cohesiveness, and springiness, and the 9-point hedonic scale were investigated. At 50% xylitol, konjac jellies prepared with either κ-carrageenan or xanthan displayed higher cohesiveness and springiness than that of the control ($p < 0.05$); however, total replacement showed superior effects but only in konjac/κ-carrageenan jellies. A softer texture was observed in both jellies with 100% xylitol. Konjac jellies with 50% erythritol-sucralose were harder and more cohesive but were not significantly different to the 100% erythritol-sucralose samples. Springiness decreased when erythritol-sucralose replaced the sucrose in konjac/κ-carrageenan jellies, in contrary tokonjac/xanthan jellies. Most of the panelists preferred the konjac/κ-carrageenan jellies. The higher sucrose replacement significantly decreased the taste and texture in both konjac jellies, while texture perception was increased in those with erythritol-sucralose. Jellies with 50% xylitol and erythritol-sucralose were sensorially acceptable compared to 100% sucrose replacement. The optimal low-sugar konjac jelly was achieved by using κ-carrageenan as a co-gelled gum and erythritol-sucralose for 50% and 100% sucrose replacement.
Keywords: Konjac flour, functional jellies, texture, sensory perception, sucrose replacer.

INTRODUCTION

Jellies are popular snacks with a desirable sweet taste. Sugar, the main ingredient in these products, contributes to the pleasantly sweet taste and flavor and other functional properties, including gel formation, textural/structural characteristics, shelf-life stability, moisture retention, and microbial growth (Saha and Bhattacharya, 2010). Excessive sugar consumption has been reported to increase the risks of health issues, such as cardiovascular disease, diabetes, obesity, high blood cholesterol, and dental decay (Sinchaipanit*et al*., 2013). The development of low-sugar jellies, with a similar sweet taste and textural characteristics to regular jellies, could help alleviate these concerns. In general, gelled food products such as jellies and jams are mostly sweetened by sugar. Simultaneously, their textural characteristics are influenced by gel-forming substances (hydrocolloids), like pectin, gelatin, carrageenan, and konjac gum. Vilela *et al*. (2015) denoted that the reduction in sucrose content primarily influenced the soluble solid content; however, it affects several quality characteristics in the strawberry, raspberry, and cherry jams. This reflects that a sucrose reduction alone leads to alter all ingredients contents in the formulation, consequently producing different physical and sensorial functionalities, such as texture/structure building properties, moisture transfer, and consumer perception in lower-sugar foods (Goa *et al*., 2016).

In the food industry, the sugar substitutes typically used in the manufacture of low-sugar gelled foods are sugar alcohols (which are less sweet than sugar and have a bulking effect), intense sweeteners (which are much more sweet than sugar and do not have a bulking effect), and the mixed sweeteners between sugar alcohols and intense sweeteners. Xylitol, a natural sugar alcohol with similar sweetness intensity to sucrose but fewer calories (2.4 kcal g^{-1}), has a cooling effect and oral cariogenic bacteria *(Streptococcus mutan*s) inhibition (Winkelhausen *et al*., 2007). In jams, jellies, and marmalades, xylitol acts as a preserving agent due to its high water affinity, osmotic pressure and bulking properties (Mushtaq *et al*., 2010). Regarding its insulin-independent action in the human body and toxicological harmlessness, xylitol can be used in diabetic foods. However, with a similar sweetness to sucrose, the same amount as sugar used can limit its utilization partially impaired by the high cost and laxative effects (Newsome, 1997).Hence, an erythritol-sucralose (98.6:1.4) blend, a mixed sweetener is an interesting alternative that has eight times sweeter than sugar, with only 0.18 kcal g^{-1} and a bulking effect (U-sing Co., 2016). It has heat and pH stability, no tooth decay, no effect on blood glucose, no aftertaste, and importantly, it is inexpensive than other sweeteners like stevia, sucralose, xylitol, and monk fruit extract.
Konjac flour is a nonionic, water-soluble, and highly viscous dietary fiber, derived from *Amorphophallus konjac* C. Koch

that has been granted as GRAS (generally recognized as safe) for food applications as a thickener, gelling agent, texture-modifier and stabilizer (Takigami, 2000). Structurally, konjac is composed of β-(1,4)-mannose and glucose at a 1.6:1 ratio. The flour does not gel alone but can form a gel, in the presence of alkali (e.g., calcium hydroxide or sodium carbonate) or by interaction with secondary or co-gelled gums (κ-carrageenan, xanthan or gellan) (Huang and Lin, 2004). The gel prepared with κ-carrageenan is clear and brittle compared to that with xanthan, which is relatively opaque, soft and elastic (Takigami, 2000). Besides, konjac flour has no calorie value, because of its β-linkage structure, and is rich in dietary fibers, thus a high viscous konjac solution that moves slowly through the digestive tract contributing to several health benefits. It can be beneficial for controlling blood sugar level, slowing down the absorption of carbohydrate, fat, and protein, binding with excess bile acids in the intestine that are converted into blood cholesterol, lowering the glycemic index of foods, and relieving constipation (Delgado-Pando *et al*., 2011).

A low-sugar jelly made with konjac flour, sugar substitutes, and added fruit juice, is considered to be a useful alternative for consumers' choices and healthy living. However, the textural changes in low-sugar konjac jellies, whose gel characteristics are dependent on the type of co-gelled gums (κ-carrageenan and xanthan) used, in conjunction with the sugar replacement (by xylitol and erythritol-sucralose), are still not fully understood. The gel texture characteristics are usually affected by the soluble solids content and the ingredient composition, which is associated with consumer acceptance. For instance, Tiwari and Bhattacharya (2014) showed that the addition of mango pulp could increase the firmness and cohesiveness of agar gels. Furthermore, gels with extensively varying textual characteristics could be prepared by altering the proportions of the agar, mango pulp and sugar ingredients. Therefore, this study aimed to compare the textural and sensory characteristics of low-sugar konjac jellies, made with κ-carrageenan and xanthan, respectively, in which xylitol and erythritol-sucralose were used as sugar replacers. Preference mapping was also analyzed to determine the trend of consumers' product preference.

MATERIALS AND METHODS

***Materials*:** Konjac flour (Chengdu Newstar Chengming Bio-Tech Co., Ltd, Chengdu, China), κ-carrageenan (MSC Ltd., Gyeongsangnam-do, South Korea), xanthan gum (Keltrol®, CP Kelco, San Diego, CA, USA), sucrose (Carlo Erba Reagenti, Rodano, Italy), xylitol (XyloSweet®, Xlear Inc., USA), erythritol-sucralose (U-Sing Co., Ltd., Bangkok Noi, Thailand) and 100% apple juice (Malee®, Bangkok, Thailand) were used.

***Apple konjac jelly preparation*:** Apple konjac jellies were prepared according to the formulation as shown in Table 1. A konjac and co-gelled gum (κ-carrageenan or xanthan) (3:1) mixture (1 g) was stirred with 100 ml water for 5 min, and heated at 90 ± 2°C for 5 min. Next, the sweetener was added, followed by apple juice, and heated for another 5 min. The mixture was poured into cups (2.5 cm diameter × 2 cm height) and stored in a refrigerator for 24 h before testing. The sucrose replacement with xylitol and erythritol-sucralose was made based on equivalent sweetness conversion; 1 g of sugar is equivalent to 1 g xylitol or 0.125 g erythritol-sucralose**.**

***Texture profile analysis (TPA) measurement*:** The konjac jellies were left at 25 ± 1°C for 2 h prior to removal from the cups. The TPA (hardness, cohesiveness and springiness) was determined using a texture analyzer (LRX Plus, Lloyd Instruments, Hampshire, UK), equipped with Nexygen® software. A test cell (50 mm width × 50 mm length) operating at 2 mm/min crosshead speed and 50% strain was established. Measurements were performed on five samples from each treatment group (Mutlu, *et al*., 2018).

***Sensory evaluation*:** A 9-point hedonic scale (1 = extremely dislike, 9 = extremely like), was used to evaluate the appearance, taste and texture of konjac jellies. Forty untrained panelists (aged between 18 and 45 years), who usually consumed jelly, were the students and staffs from the University of the Thai Chamber of Commerce, Thailand. The samples (10 ± 2°C) were coded with 3-digit random numbers and served in the sensory room (25±1°C). Panelists were instructed to rinse their palates with water before testing each sample (Lawless and Heymann, 1998).

Table 1. Apple konjac jelly formulations.

Composition (g)	Konjac/κ-carrageenan jelly					Konjac/xanthan jelly				
	Control	XY50	XY0	ES50	ES0	Control	XY50	XY0	ES50	ES0
Konjac flour	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
κ-carrageenan	0.25	0.25	0.25	0.25	0.25	-	-	-	-	-
Xanthan gum	-	-	-	-	-	0.25	0.25	0.25	0.25	0.25
Sugar	20	10	-	10	-	20	10	-	10	-
Xylitol	-	10	20	-	-	-	10	20	-	-
Erythritol-sucralose	-	-	-	1.25	2.5	-	-	-	1.25	2.5
Apple juice	20	20	20	20	20	20	20	20	20	20

Control sample (only sweetened with sugar). XY50, XY0 are formulations with 50% and 100% sugar substitution with xylitol. ES50, ES0 are formulations with 50% and 100% sugar substitution with erythritol-sucralose.

Statistical analysis**:** All analyses were carried out in triplicate unless otherwise indicated. The analysis of variance (ANOVA), and Duncan's new multiple range test ($p < 0.05$) were tested (Cochran and Cox, 1992). The SPSS for Windows version 17.0 was used to analyze the data. The preference mapping was analyzed by principal component analysis using the program R)R Core Team, 2013.(

RESULTS AND DISCUSSION

Textural characteristics of konjac/κ-carrageenan jellies**:** The texture profiles of konjac/*κ*-carrageenan jellies with 50 and 100% sucrose replacement by xylitol and erythritol-sucralose are presented in Figure 1. Replacement of 50% sucrose content by xylitol did not affect ($p > 0.05$) hardness but significantly increased ($p < 0.05$) cohesiveness and springiness. The jellies with 100% sucrose replacement by xylitol revealed a significantly lower hardness compared to the control (Figure 1a). Konjac flour provides a viscous solution but cannot form a gel alone, whereas *κ*-carrageenan forms a heat-induced, brittle (hard) gel upon cooling. The combination of both gums can form a mixed gel which has been attributed to a synergistic interaction between the konjac molecules and helical *κ*-carrageenan molecules through hydrogen bonding, forming an ordered *κ*-carrageenan-konjac structure (Williams, 2009). The mixed gum gel is composed of the main junction zones; a three-dimensional polymer network of *κ*-carrageenan (hard, brittle), followed by molecular associations between *κ*-carrageenan-konjac molecules, and konjac islands (remaining ungelled konjac), which contribute to the viscosity properties (Kohyama *et al*., 1996). Thus, the higher interactions of both gums resulted in a reduction in gel hardness. Xylitol was used in an equal amount for sucrose replacement. Consequently, a similar total soluble solids content was maintained in each of these gel systems. However, xylitol has a higher water-holding capacity than sucrose, thus it could bind more water molecules, thereby increasing the viscosity of the surrounding water. This might slow down the movement of molecular chains of konjac and *κ*-carrageenan, allowing greater proximity for interactions and formation of a mixed gel. The increased interactions resulted in softer konjac/*κ*-carrageenan jellies which reflected by the lower hardness values. The competition for available water could be a key factor affecting textural characteristics of the gel. Similarly, McGee (2004) showed that when one-third of the sucrose in pectin jellies was replaced (w/w basis) with selected sweeteners, the gel strength decreased in the order of sucrose (highest gel strength) > fructose > glucose > sorbitol > xylitol (lowest gel strength). Gel hardness depends on a combination of various factors. Of particular relevance to the current study are factors such as competition for available water between the konjac, *κ*-carrageenan, sucrose and xylitol in the mixture, water structure changes, and restricted hydration of the gums (Totosaus *et al*., 2005; Sharma *et al.,* 2009).

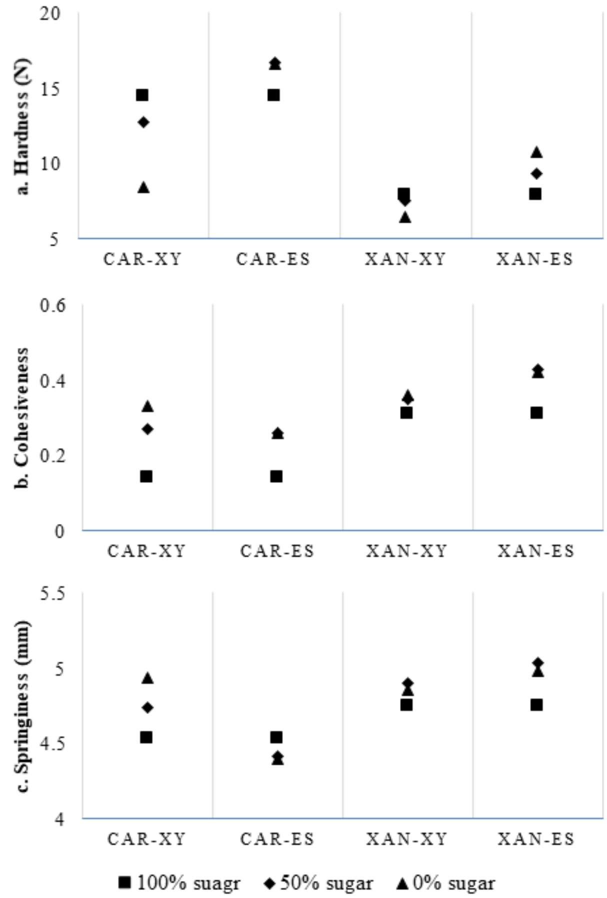

Figure 1. **Textural characteristics of low-sugar konjac jellies with xylitol (XY) and erythritol-sucralose (ES): (a) hardness, (b) cohesiveness, and (c) springiness**

Cohesiveness, which represents the structural integrity of the mixed gel, was increased in 50% xylitol jellies and further increased ($p < 0.05$) at 100% xylitol (Figure 1b). The increase in cohesiveness demonstrated the interactions of konjac and *κ*-carrageenan were stronger for maintaining the structure of the jellies, and the jellies were less brittle (Totosaus*et al.*, 2005). A similar behavior was observed in the springiness, where increasing replacement of sucrose by xylitol resulted in jellies with significantly higher springiness than the control (Figure 1c). This was in line with Imeson (2000) who reported that the konjac/*κ*-carrageenan gel had approximately 4 times higher rapture strength than the *κ*-carrageenan gel alone, indicating that the gel was more elastic or springy.

The 100% sucrose replacement by erythritol-sucralose generated konjac/*κ*-carrageenan jellies displaying significantly higher hardness and cohesiveness but lower springiness compared to the control (Figure 1). It was noticed that these changes in hardness and springiness values were different to those in 100% xylitol jellies, which showed decreased hardness but higher springiness. Lau *et al*. (2000) suggested that the strength of the gel structure, which is reflected in increased hardness, is influenced by the type and concentration of hydrocolloids and sweeteners, which was associated with the levels of total solids content in the gel system, water competition, and interactions of konjac, κ-carrageenan and water. Erythritol-sucralose was estimated to be eight times sweeter than sucrose. Thus, in the current study, it was used in a slight amount, leading to a higher decreasing the sucrose content compared to that with xylitol. This showed that the low quantity of erythritol-sucralose, in addition to its lower water-binding capacity than sucrose, has relatively less potential to retain or bind water for the interaction of the konjac and κ-carrageenan molecules. The lower synergistic interaction of both gums led to increased self-aggregation of κ-carrageenan junctions, resulting in the multi-molecules junctions that contributed to more rigid the gel (Saha and Bhattacharya, 2010). This concurred with Bayarri *et al*. (2006) who found that the texture of a κ-carrageenan/locust bean gum gel was stronger with sucrose addition, but no effect was found by aspartame addition. The observation suggests that unlike sucrose, erythritol-sucralose did not support konjac and κ-carrageenan interactions. The lower springiness correlated with the reduction of hydrogen bonds in the three-dimensional mixed gel network. From another perspective, however, the replacement of sucrose by erythritol-sucralose may be beneficial in reducing the economic costs because the preparation of the low-sugar jellies to have gel hardness similar to that made with sugar, could be done by using lower amounts of konjac and κ-carrageenan.

***Textural characteristics of konjac/xanthan jellies*:** Figure 1 shows the TPA results of the konjac/xanthan jellies as affected by xylitol and erythritol-sucralose replacers. Regarding the full-sugar jellies, it was observed that the texture of the konjac/xanthan samples was softer and springier than konjac/κ-carrageenan jellies (Figure 1). This might be due to the different structures and properties of the co-gelled gums used (κ-carrageenan or xanthan), which seemed to directly affect the konjac gel characteristics. Xanthan is a non-gelling hydrocolloid which produces a relatively more viscous solution, while κ-carrageenan is a gelling hydrocolloid (brittle gel). Molecular associations, resulting from the attachment of konjac to the backbone of xanthan molecules, lead to the formation of the ordered three-dimensional network or gel structure (Chandrasekaran *et al*., 2003; Agoub *et al*., 2007). The synergistic interaction produces a mixed gum gel with increased textural characteristics such as higher gel strength (Saha and Bhattacharya, 2010). Increasing level of xylitol resulted in softer jellies which might be due to the superior ability of xylitol than sucrose to compete for available water. A lower level of hardness (Figure 1a) suggests that the interactions between konjac and xanthan were affected, which might be due to various factors such as the restricted hydration of konjac and xanthan, sucrose-konjac or -xanthan interactions and xylitol-konjac or -xanthan interactions, reduced the number of water molecules participating in hydrogen bonding with the molecular chains of the gum, or changed the water structure (Knecht, 1990; Sharma *et al*., 2009). The sucrose replacement by xylitol might influence rheological properties of the konjac-xanthan gel system to achieve increased viscosity (Huang and Lin, 2004). This could increase the opportunity for konjac molecules to form hydrogen bonds within the gel system, thereby reinforcing the gel cohesiveness and springiness (Figure 1b and 1c).

Compared to the control, the replacement of 50% sucrose by erythritol-sucralose, resulted in harder, and more cohesive and springy jellies (Figure 1) that were comparable to the 100% sucrose replacement. It might be due to the inferior quantity and water binding properties of erythritol-sucralose against the sucrose, allowing both konjac and xanthan completely solubilized. This seemed to increase randomly dispersed molecules of each gum which led to higher three-dimensional network or gel formation. However, in contrast to the decreased springiness of the konjac/κ-carrageenan jellies, the springiness values in the konjac/xanthan jellies increased with increasing level of erythritol-sucralose replacer. This implies that the selection of co-gelled gums to combine with konjac molecules is essential for desirable gel characteristics pertaining to food products.

***Sensory evaluation of konjac jellies*:** The likability scores for appearance, taste and texture of the konjac jellies prepared with κ-carrageenan and xanthan, respectively, at various sucrose levels, are shown in Table 2. Control (sucrose) konjac jellies prepared with κ-carrageenan were given higher scores for appearance, taste and texture than those with xanthan, which suggested the panelists preferred the clarity and breakdown behavior of the konjac/κ-carrageenan jellies. In comparison, the konjac/xanthan jellies were more opaque and sticky, thereby requiring higher force or energy to masticate before swallowing. As the sucrose replacement by xylitol increased, the konjac/κ-carrageenan jellies appeared softer, which correlated with decreased scores for appearance ($p < 0.05$). On the contrary, the jellies with erythritol-sucralose were firmer and rated higher for appearance, especially the 100% erythritol-sucralose sample showed the highest ($p < 0.05$) against the control. This indicates that the firm texture influences the perception of jellies appearance. The taste attribute was particularly affected with the low-sugar jellies achieving lower scores than the control ($p < 0.05$).It might be due to the panelists were not accustomed to the sweet taste of both xylitol and erythritol-sucralose. The jellies with 50% sucrose replacement scored higher for taste than jellies with 100% replacement. Although the jellies were sweet, xylitol

Table2. Sensory evaluation of low-sugar konjac jellies with xylitol and erythritol-sucralose

Sucrose replacement (%)	Appearance		Taste		Texture	
	Xylitol	Erythritol-sucralose	Xylitol	Erythritol-sucralose	Xylitol	Erythritol-sucralose
0	7.5 ± 0.8^{b}		7.5± 0.6^{a}		7.0± 0.4^{b}	
50	7.3± 0.8^{c}	7.6± 0.4^{ab}	6.7± 0.6^{b}	6.9± 0.4^{b}	6.7± 0.3^{b}	7.2± 0.9^{ab}
100	7.2± 0.7^{c}	7.8± 0.9^{a}	6.1± 0.8^{d}	6.5± 0.5^{c}	6.4± 0.7^{c}	7.4± 0.5^{a}
0	7.0± 0.6^{a}		7.1± 0.5^{a}		6.4± 0.5^{c}	
50	7.1± 0.2^{a}	7.0± 0.4^{a}	6.6± 0.2^{b}	6.6± 0.5^{b}	6.3± 0.8^{c}	6.9± 0.4^{b}
100	7.1± 0.5^{a}	7.1± 0.6^{a}	6.3± 0.6^{c}	6.1± 0.4^{c}	6.2± 0.7^{c}	7.2± 0.5^{a}

Means in the same column with different superscripts are different ($p < 0.05$).

and erythritol-sucralose have a sharp taste and cooling effect, thus they can affect the sweetness and taste characteristics of foods to which they are added, as seen in this study. The increased gel hardness of the konjac/κ-carrageenan jellies by erythritol-sucralose replacement (Figure 1a) seemed to affect the sweetness ratings. At 100% sucrose replacement, the erythritol-sucralose jellies (harder gel) scored higher than the xylitol jellies (softergel). In this work, the soft type of the konjac/κ-carrageenan gel was stickier than the hard gel, hence it was less broken down into small fragments during chewing. The higher number of fragments led to a large surface of contact between sweeteners and taste receptors, resulting in a high taste intensity (Mosca *et al*., 2012). Besides, the 100% erythritol-sucralose jellies were perceived as the highest texture acceptance. The finding implies that the change in gel texture of konjac jellies is related to the enhancement or suppression of sensory perception; however, a further understanding is required an investigation.

In view of the konjac/xanthan jellies, no significant difference was found for appearance among the control and low-sugar jellies. The taste remained a key attribute influencing consumers' preference, as evident by the lower taste liking scores ($p < 0.05$) observed in all low-sugar formulations. The texture results revealed that both 50 and 100% xylitol jellies had similar texture likability scores to the control sample ($p < 0.05$). It was noted that increasing the erythritol-sucralose level increased the instrumental gel hardness of the jellies (Figure 1), which correlated with the favorable increase in the texture sensory scores relative to the control ($p < 0.05$).

***Principal component analysis and preference mapping*:** The relevance of konjac jelly's textural and sensory properties and product acceptance are presented in Figure 2. The principal component analysis demonstrated a high cumulative value (89.8% in total; the first component 69.37% and the second component 20.43% of the observed variation) denotes that the consumers could satisfactorily discriminate between the samples. The Dim 1 axis (Figure 2a) was positively correlated with all sensory attributes of appearance, flavor, and texture, and hardness.

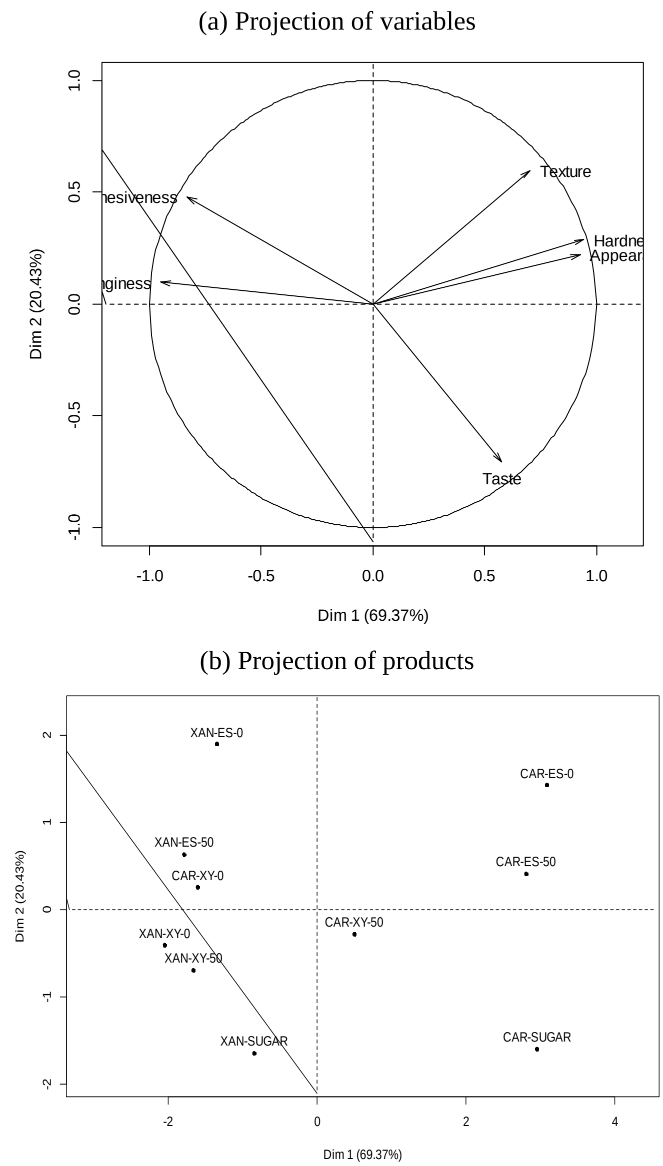

Figure 2. Preference mapping of low-sugar konjac jellies: (a) projection of variables and (b) projection of products

All of these contributed to distinguish all low-sugar jellies with xylitol and erythritol-sucralose from the full-sugar control. Simultaneously, cohesiveness and springiness showed a negative correlation. According to Figure 2b, three konjac/κ-carrageenan jellies, including full-sugar (CAR-SUGAR), 50% (CAR-ES50), and 100% (CAR-ES0) sucrose replacement with erythritol-sucralose, which were located in the positive of axis 1, were strongly received higher sensory acceptability than other jellies. The full-sugar control was a preferable sensory perception; mainly, it was superior in sugar sweet style and firm texture. The way the firm gel is broken down during oral mastication was satisfied by the panelists' eating sensation, in addition to the gel is easily chewed before swallowing. The sugar reduction correlated with the taste decrease in low-sugar ones, as confirmed by the hedonic results in Table 2. In this regard, the sensory texture was a subsequent criterion for preferable sensory evaluation. The consumers preferred the jellies' firm texture with erythritol-sucralose than those with xylitol and control sample (Table 2). The observation pronounces that co-gelled gums, sugar reduction, and sugar substitutes significantly affected the samples' positioning and consumer preference.

The konjac/xanthan jellies, which were placed on the negative quadrant, were less acceptable because the jelly texture was tough and difficult to chew into smaller pieces before swallowing against the konjac/κ-carrageenan jellies. The sugar replacement displayed prominent discrimination in the analyzed samples based on the relevance of sugar substitutes and amounts of sugar reduction. This observation indicates that the greater the sugar reduction, the lower the sensory acceptance. Moreover, these samples correlated with the higher springiness and cohesiveness, reflecting more springy and elastic gel texture that affected the consumer preference. Comparatively, ANOVA shows the mean values of attributes but no consumer trend for product preference. Regarding the preference mapping, the consumers preferred the low-sugar konjac/κ-carrageenan jellies, both 50% and 100% sugar replacement, with erythritol-sucralose than xylitol. They are likely to a firm texture that is easier to chew into smaller ones during oral mastication.

***Conclusion*:** The gel texture of konjac jellies changedwhen sucrose was replaced by xylitol and erythritol-sucralose, in addition to the type and quantity of co-gelled gums (κ-carrageenan and xanthan) used. The inclusion of xylitol produced significantly softer konjac jellies, while these were harder with erythritol-sucralose as the replacer. Changes in textural characteristics could enhance or suppress the sensory perception. Increasing the levels of xylitol and erythritol-sucralose similarly decreased the likability scores for taste and texture; however, the texture score was increased in the jellies with erythritol-sucralose.

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