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Research Article

Optimization of Konjac Gel Texture Prepared with-κ-carrageenan and Sweeteners and their Applications in Orange Jelly

Adisak Akesowan and Anchan Choonhahirun
Department of Food Science and Technology, School of Science and Technology,
University of the Thai Chamber of Commerce, Bangkok 10400, Thailand

Abstract: This study investigated the effects of konjac proportion in 1% konjac/κ-carrageenan blend (25:75-50:50) and sweetener concentration (sucrose and xylitol at 2-20% and erythritol-sucralose at 0.25-2.5%) on gel strength of konjac gels using Response Surface Methodology (RSM). The statistical analysis revealed that all models of konjac gels with sweeteners were effective and adequate fitted. The most variable affecting gel strength was konjac/κ-carrageenan n blend. Quadratic effect of konjac/κ-carrageenan blend was more profound ($p<0.001$) on konjac gels with each sweetener. The variation of xylitol and sucrose had a linear effect ($p<0.001$) and a quadratic effect ($p<0.05$) on gel strength, respectively, while an increase in erythritol-sucralose had no significant effect. Also, the interaction between the two variables had no significant effect on gel strength. The optimal conditions for the highest gel strength were 1% konjac/κ-carrageenan (39.56:60.44) with 9.58% sucrose, 1% konjac/κ-carrageenan (39.87:60.13) with 2% xylitol and 1% konjac/κ-carrageenan (38.18:61.82) with 0.94% erythritol-sucralose. Orange konjac jellies made with three optimal conditions showed no significant differences in appearance and color. Most panelists preferred sweet and texture of the jelly with erythritol-sucralose than that with xylitol. Nevertheless, the jelly with sucrose significantly received the most scores of sweet and overall acceptance. The appropriate level of texture and sweet was evident on the jelly with sucrose, followed by that with erythritol-sucralose and xylitol, respectively.

Keywords: Biopolymers, gel formation, konjac, response surface methodology, sugar substitutes

INTRODUCTION

Konjac flour, water soluble dietary fiber obtained from *Amorphophallus konjac* tuber, has been extensively used for thickening and gelling in various food products. It mainly consists of glucomannan, a hydrocolloid polysaccharide composed of β- (1, 4) - mannose and glucose at a ratio of 1.6:1 with branches consisting of sugar units (Takigami, 2000). This flour produces a high viscosity and forms a gel by alkaline such as calcium hydroxide or by combining with secondary gum or co-gelated gum such as κ-carrageenan and xanthan gum (Huang and Lin, 2004). The konjac gel can be applied as fat analogue in low or reduced fat food products such as sausages, bolognas, burgers, cakes and chiffons (Chin *et al*., 1998; Akesowan, 2009; Jiménez-Colmenero *et al*., 2010). Regarding its linkage structure and health benefits including triglycerides and cholesterol reduction, weight controller and constipation alleviation, it is popular to use in health food products (Akesowan, 2010; Delgado-Pando *et al*., 2011).

In some products like jam and jelly, the gel system is an important criterion that concerns in quality of finished products. With a mixture of ingredients added, the gel texture is mainly dependent on a type of gelling agent and sugar used. Generally, one of jellies sold in the market is made with κ-carrageenan and sugar and all-aged consumers are familiar with such a gel texture. To meet a desirable konjac jelly, it is necessary for seeking a proper ratio between konjac and secondary gum in a condition that contains the sugar. The secondary gum such as κ-carrageenan and xanthan gum has been used in a combination with konjac to give an individual konjac gel texture. The konjac gel formed with κ-carrageenan is more brittle and firm than that with xanthan (Thomas, 1997). In addition, sugar was found to influence on gel properties; for example, it increased the firmness of a mixed gum gel between κ-carrageenan and locust bean gum as a result of its good water holding capacity (Bayarri *et al*., 2006).

An increasing trend for sugar reduction in food products has been investigated for lowering risk factors for sugar-related diseases such as diabetes, hypertension, obesity and dental caries (Alizadeh *et al*.,

Corresponding Author: Adisak Akesowan, Department of Food Science and Technology, School of Science and Technology, University of the Thai Chamber of Commerce, 126/1 Vibhavadee-Rangsit Road, Dindaeng, Bangkok 10400, Thailand, Tel.: 662-6976521; Fax: 662-277-7007

2014). Xylitol, a naturally substance occurring in various fruits and vegetables such as berries and oats, can be used in sugar-free chewing gums and other also has a mild laxative effect (Newsome, 1993). It is safe for tooth decay and can be used in foods for people with diabetes; however, it is more expensive than other sugar alcohols like sorbitol. Another chosen alternative in this study, erythritol-sucralose (98.6:1.4), a blend of sugar alcohol and intense sweetener, has been introduced to low-calorie food products. It has many advantages including relative sweetness 8 times compared to sucrose, very low caloric value (0.18 kcal/g), no cariogenic effect, no stomach problems, giving bulking and less laxative effect (U-sing Co. Ltd., 2014). However, an amount of erythritol-sucralose required for the same equivalent sweetness of sucrose is smaller. This may cause some changes on texture of gelled foods in which their sugar contents are partially or totally replaced.

Response Surface Methodology (RSM) is a tool used to describe how independent variables affect the responses. It can display an interaction effect among the variables (Anderson and Whitcomb, 2005). In present work, the different levels of konjac proportion in a blend of konjac and κ-carrageenan and sweeteners (sucrose, xylitol and erythritol-sucralose) were studied for their effects on gel strength of konjac gels using RSM. In addition, optimized conditions of konjac gels with each sweetener were investigated for their uses in orange jelly processing.

MATERIALS AND METHODS

Materials: Hydrocolloids and sweeteners used were konjac flour (Chengdu Newstar Chengming Bio-Tech Co., Ltd, China), κ-carrageenan (MSC5744, MSC Ltd., USA), sucrose (Carlo Erba Reagenti, Rodano, Italy), xylitol (XyloSweet®, Xlear Inc., USA) and erythritol-sucralose (U-sing Co. Ltd., 2014).

Experimental design: A Central Composite Rotatable Design (CCRD) for a two-variable, five level combinations coded -1.41, -1, 0, 1 and 1.41 was used. The total concentration of konjac/κ-carrageenan blend was fixed at 1% (w/v) level. The experimental design of the investigation subjected to different levels of konjac/κ-carrageenan blend and sweeteners (sucrose, xylitol and erythritol-sucralose) is presented in Table 1. The model for the response can be described in the mathematical equation:

candies. This sugar substitute provides the same sweetness as the sugar, but gives only 2.4 Kcal/g and

$$Y = b_0 + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{22}X_2^2 + b_{12}X_1X_2 \quad (1)$$

where,

Y = The response calculated by the model

X_1, X_2 = The coded konjac/κ-carrageenan blend and sweetener, respectively

b_1, b_2 = Linear; b_{11}, b_{22} = quadratic; and b_{12} is interaction coefficient, respectively

Konjac gel preparation: A mixture of konjac flour and κ-carrageenan was gradually added into distilled water and constantly stirred for 10 min using a magnetic stirrer. The mixture was heated in a water bath at 90±2°C for 10 min. The sweetener was added and further heated with stirring for 20 min. The hot mixture was filled into gel cups (3 cm diameter 2.5 cm height), cooled and kept in a refrigerator (10±2°C) for 24 h prior to analysis.

Gel strength measurement: All konjac gels were left in an instrumental room (23±2°C) for 2 h before measurement. Gel strength was measured by a Lloyd texture analyzer (Model LRX Plus, Lloyd Instruments, Hampshire, UK) equipped with a puncture-test cell (10 mm diameter flat ended cylinder). The crosshead speed and compression distance were set at 1 mms^{-1} and 50% of the gel height, respectively. The measurement was made in five replications and each gel strength value was calculated as follows: Gel strength = maximum load (kgf) ×deflection at maximum load (mm).

Orange konjac jelly processing: Three optimized konjac gels were applied in the processing of orange konjac jellies. The jelly was prepared by mixing 1 g konjac/κ-carrageenan blend in 100 mL water and continuously stirred for 10 min. After heating in a water bath at 90±2°C for 10 min, the sweetener was added and heated for 15 min. A 25 mL pasteurized orange juice (14° brix, 0.63% acidity) was added and further heated for 5 min. The mixture was poured into jelly cups (2 cm diameter ×1.5 cm height) and stored in a refrigerator for 24 h prior to sensory evaluation.

Sensory evaluation: A 9-point hedonic scale test (1 = extremely dislike, 9 = extremely like) was used for evaluating appearance, color, sweet, texture and overall acceptance of three orange konjac jellies. The

Table 1: Two independent variables and their coded and actual values used for analysis

			Coded levels				
Independent variables	Unit	Symbol	-1.41	-1.00	0	1.00	1.41
Konjac/κ-carrageenan blend	%	X_1	25.00	28.66	37.50	46.34	50.0
Sweeteners							
-Sucrose	%	X_2	2.00	4.64	11.00	17.36	20.0
-Xylitol	%	X_2	2.00	4.64	11.00	17.36	20.0
-Erythritol-sucralose	%	X_2	0.25	0.59	1.38	2.17	2.5

X_1: % (w/w) konjac proportion in konjac/κ-carrageenan blend; X_2: % (w/v) sweetener appropriate level of texture and sweet of the samples was determined by a just-about-right scale test (-3 = strongly less than, 0 = ideal and +3 = strongly more than). All sensory tests were conducted by 50 untrained panelists from the University of the Thai Chamber of Commerce, Thailand. Panelists were invited to rinse their palates before testing each sample.

Statistical analysis: The gels of each treatment were prepared in triplicate. Data were subjected to analyze for Analysis of Variance (ANOVA) and multiple regressions using the Design-Expert Trial Educational version 8.0.2 software (State-Ease Inc., Minneapolis, Minnesota, USA). For sensory evaluation, data were statistically analyzed by ANOVA using SPSS for Window version 17.0. Means with a significant difference ($p<0.05$) were compared by Duncan's new multiple range test (Cochran and Cox, 1992).

RESULTS AND DISCUSSION

Statistical analysis and model fitting: Results of gel strength determined in konjac gels formed with different levels of konjac/κ-carrageenan blend and sweeteners are presented in Table 2. The analysis of variance and multiple regression shown in Table 3 reveal that all models were effective ($p<0.001$) and adequately accurate with determination coefficients (R^2) greater than 0.95 and insignificant lack of fit values (p 0.05). Also, adj-R^2 values observed in the models were more than 0.91, advocating the precision of the models (Koocheki *et al*., 2010). The most affecting variable was evident on konjac/κ-carrageenan blend. When considering an adequate precision value, which measures the signal to noise ratio, a ratio greater than 4 is desirable. In this study, the ratio obtained from all models was found to be more than 14, demonstrating that they can be used to navigate design space. At the same time, the model of konjac/κ-carrageenan/xylitol gel revealed the least Coefficient of Variation (CV), reflecting its lower standard deviation as a percentage of the mean. This shows a sign of this model is more reliable than other konjac gel models.

Table 3 exhibits linear and quadratic effects, in exception of their interaction effects on konjac gel strength values. For the konjac/κ-carrageenan /sucrose gel, gel strength was greatly affected by quadratic ($p<0.001$) and linear effects ($p<0.01$) of konjac/κ-carrageenan blend, while the quadratic effect of sucrose concentration was significant at $p<0.05$. At the same time, konjac/κ-carrageenan blend with quadratic ($p<0.001$) and linear ($p<0.05$) effects and xylitol with linear effect ($p<0.001$) were found to affect gel strength of the konjac/κ-carrageenan/xylitol gel. In case of erythritol-sucralose, no effect was found on gel strength, while the variation of konjac/κ-carrageenan

Table 2: Experimental conditions and results of gel strength of konjac gels subjected to different levels of konjac/κ-carrageenan blend and sweeteners

	Coded variables		Gel strength (kgf×mm) of konjac/κ-carrageenan gel with the following sweeteners		
Runs	X_1	X_2	Sucrose	Xylitol	Erythritol-sucralose
1	-1	-1	6.597	13.361	15.003
2	+1	-1	13.386	14.824	15.998
3	-1	+1	5.395	12.329	13.992
4	+1	+1	11.853	12.001	14.559
5	-1.41	0	4.009	9.893	11.166
6	+1.41	0	10.405	12.196	13.234
7	0	-1.41	16.947	18.177	19.669
8	0	+1.41	14.443	14.343	20.002
9	0	0	16.424	14.670	19.667
10	0	0	19.005	15.750	20.028
11	0	0	17.778	15.444	19.012
12	0	0	19.191	14.854	20.669
13	0	0	18.649	15.212	19.325

X_1: % (w/w) konjac proportion in konjac/κ-carrageenan blend; X_2: % (w/v) sweetener

Table 3: Regression coefficients of gel strength of konjac gels subjected to different levels of konjac/κ-carrageenan blend and sweeteners

	konjac/κ-carrageenan gel with the following sweeteners		
Source	Sucrose	Xylitol	Erythritol-sucralose
Model	-106.8860***	-26.8380***	-56.6440***
konjac/κ-carrageenan blend (X_1)	6.1270**	2.2630*	3.9750
Sweetener (X_2)	0.9060	-0.1040***	1.2810
X_1X_2	-1.465E-06	-7.96E-003	-0.0150
X_1^2	-0.0770***	-0.0280***	-0.0520***
X_2^2	-0.0440*	0.0100	-0.3720
R^2	0.9517	0.9591	0.9554
Adj-R^2	0.9172	0.9299	0.9235
Adeq-precision	15.2890	20.1310	14.7700
Coefficient variation (%)	11.5100	3.9600	5.1900
Lack of fit (p-value)	0.1606	0.2003	0.1511

X_1: % (w/w) konjac proportion in konjac/κ-carrageenan blend; X_2: % (w/v) sweetener; *: Significant at $p<0.05$; **: Significant at $p<0.01$; ***: Significant at $p<0.001$

blend showed a quadratic effect (p<0.001). The fitted models with significant terms can be explained by equations as follow:

$$Y_1 = -106.89 + 6.13X_1^{**} - 0.08X_1^{2***} - 0.04X_{2a}^{2*} \quad (2)$$

$$Y_2 = -26.84 + 2.26X_1^{*} - 0.10X_{2b}^{***} - 0.03X_1^{2***} \quad (3)$$

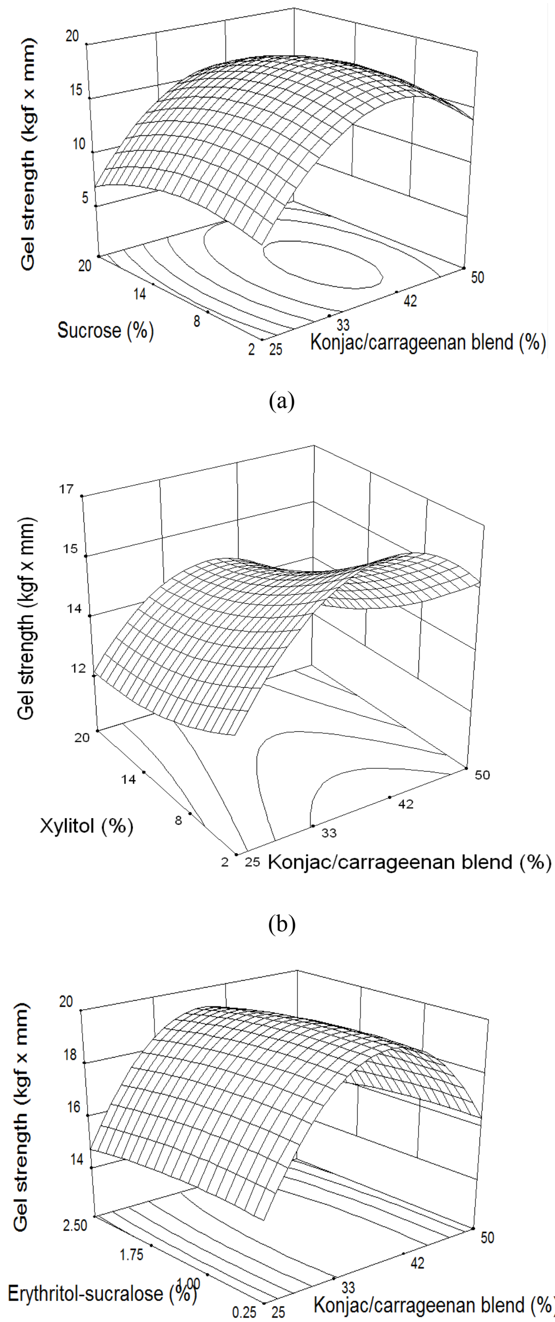
$$Y_3 = -56.64 - 0.05X_1^{2***} \quad (4)$$

where,

X_1 = Konjac proportion in konjac/κ-carrageenan blend
X_2 = Sweetener concentration (X_{2a} = sucrose, X_{2b} = Xylitol and X_{2c} = erythritol-sucralose)
Y_1- Y_3 = Gel strength of konjac/κ-carrageenan gel with sucrose, xylitol and erythritol-sucralose, respectively
* = Significant at p<0.05
** = Significant at p<0.01
*** = Significant at p<0.001

Analysis of response surface plots: The relationships between konjac/κ-carrageenan blend and sweeteners (sucrose, xylitol and erythritol-sucralose) on gel strength are simplified by illustrating into three dimensional graphs in Fig. 1. As seen in Fig. 1a, at low level of sucrose, gel strength was found to be increased with increasing a konjac ratio in konjac/κ-carrageenan blend from 25:75 to approximately 40-45:55-60; afterwards, it decreased. This indicated an optimal ratio of the two gums combination to yield the highest gel strength. Same patterns were found in RSM graphs of konjac/κ-carrageenan gels with xylitol (Fig. 1b) and with erythritol-sucralose (Fig. 1c). The gel formation of these two gums combination might be due to the interaction between ordered heliced structure of κ-carrageenan and konjac molecules through hydrogen bonding (Williams, 2009). As an amount of konjac portion was higher, a number of available konjac and κ-carrageenan interactions was highly occurred, resulting in a stronger gel texture. In general, an increase in gel strength implied more synergistic interactions between the gums in a gel system (Morris, 1984). Nevertheless, when konjac molecules exceed a proper condition, unoccupied konjac portions may hinder the interactions and get inside the gel network, resulting in a gel with lowered gel strength.

The effect of sucrose concentration from 2 to 15% exhibited a slight increasing gel strength of the konjac/κ-carrageenan gel; however, it tended to decrease as the sucrose concentration was over 15% (Fig. 1a). The low level of sucrose promoted the konjac gel formation, which was confirmed by the study of Bayarri *et al*. (2006) who showed that the addition of sucrose causedan increase in gel texture of κ-carrageenan/locust bean gum gels as a consequence of good water holding capacity of sucrose to retain or



(a) (b) (c)

Fig. 1: Response surface graphs of gel strength, (a) konjac/κ-carrageenan/sucrose gel, (b) konjac/κ-carrageenan/xylitol gel, (c) konjac/κ-carrageenan/erythritol-sucralose gel

entrap water molecules for the two gums interactions. Nevertheless, a high level of sucrose over 15% resulted in a slight decrease in gel strength. Totosaus *et al*. (2005) reported that the competition between sucrose and gums for the available water and the reduction of water molecules accessing to molecular chains of the

Table 4: Sensory scores of orange konjac jellies

	Sensory scores**				
Formulation*	Appearance	Color	Sweet	Texture	Overall acceptance
T1	7.24±1.08[a]	7.18±0.95[a]	6.58±1.31[a]	6.47±1.15[ab]	6.87±1.09[a]
T2	7.05±1.30[a]	7.10±1.06[a]	6.00±1.66[c]	6.12±1.02[b]	6.29±1.34[c]
T3	7.12±0.98[a]	7.07±1.40[a]	6.18±1.43[b]	6.60±1.32[a]	6.68±0.99[b]

Means in the same column with different superscripts are different (p<0.05); *: Formulation included: T1: Orange jelly made with 1% konjac/κ-carrageenan (39.56:60.44) with 9.58% sucrose, T2: Orange jelly made with 1% konjac/κ-carrageenan (39.87:60.13) with 2% xylitol, T3: Orange jelly made with 1% konjac/κ-carrageenan (38.18:61.82) with 0.94% erythritol-sucralose; **: Based on a 9-point hedonic scale test (1 = extremely dislike, 9 = extremely like)

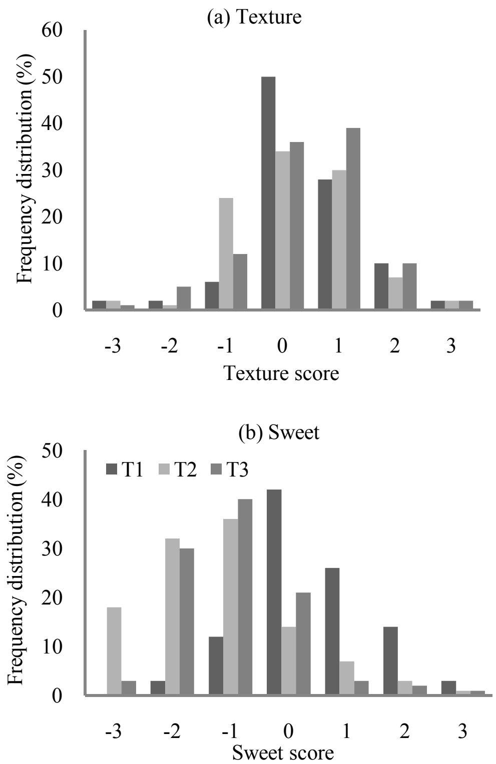


Fig. 2: Frequency distribution of sensory scores of orange konjac jellies, (a) texture, (b) sweet. Based on a just-about-right scale test (-3 = much less firm or sweet than the ideal, 0 = as same as the ideal, +3 = much more firm or sweet than the ideal). T1-T3 refer to formulation codes on Table 4

gums might be the reason for this case. Additionally, it may be due to the changes of water structure and restricted gums hydration by a specific sucrose-gum interaction (Knecht, 1990; Sharma *et al*., 2009). Figure 1b shows a decrease in gel strength of the konjac/*κ*-carrageenan gel with increasing xylitol concentration. Although, xylitol has a water holding capacity or bulking effect like sucrose, its effect was not consistent with that of sucrose, possibly due to the water holding capacity of xylitol was inferior to the sucrose. This finding implies that total sugar replacement by xylitol should be emphasized on product texture of konjac gel. Regarding the result in Fig. 1c, an amount of erythritol-sucralose (0.25-2.5%) to provide equivalent sweetness for 2-20% sucrose is so small. As a consequence, an increase in erythritol-sucralose concentration did not show any significant effects.

Optimization and validation: The maximum gel strength of the konjac/κ-carrageenan gels with different sweeteners was optimized using the Design-Expert® software. The optimal conditions were obtained as follow: 1% konjac/*κ*-carrageenan (39.56:60.44) with 9.58% sucrose, 1% konjac/*κ*-carrageenan (39.87:60.13) with 2% xylitol and 1% konjac/κ-carrageenan (38.18:61.82) with 0.94% erythritol-sucralose, which showed gel strength values approximately 18.62, 19.83 and 17.80 kgf×mm, respectively.

The suitability of the optimal conditions was validated by the experimental processing. The experimental gel strength values (n = 3) of 1% konjac/*κ*-carrageenan incorporated with sucrose, xylitol and erythritol-sucralose were found to be 19.08, 20.62 and 18.28 kgf mm, respectively. The relative error tested for each model was 2.41, 3.83 and 2.63, respectively, showing that the predicted models were accurate.

Sensory evaluation of orange konjac jellies: The results of panelists' acceptance on orange konjac jellies prepared with optimized condition of konjac/*κ*-carrageenan and sweeteners are given in Table 4. All sensory attributes among the jellies were significantly different (p<0.05), in exception of appearance and color. In comparison, the konjac jelly made with sucrose was the most sweet (p<0.05), while that with xylitol was the least (p<0.05). This may be due to the difference in an amount of each sweetener used and sweet taste. Based on scores of texture, panelists liked texture of konjac jellies made with erythritol-sucralose, which was similar to that with sucrose, followed by that with xylitol. In this konjac jelly processing, orange juice was used; therefore, it increased sugar (fructose and glucose), soluble solids and acids in gel system, causing a decrease of konjac gel strength. As previously described, the addition of erythritol-sucralose showed no effect on konjac gel texture; hence, the orange konjac jelly obtained was more firm and received (p<0.05) higher texture score as compared to the jelly with xylitol. Among all jellies, the orange konjac jelly with sucrose was achieved ($p<0.05$) the most overall acceptance with a score of 6.87, indicating a moderate preference level. In this study, erythritol-sucralose is a proper alternative for sucrose replacement in orange konjac jelly with an overall acceptance score of 6.68.

The just-about-right scale results of texture and sweet are illustrated in Fig. 2. The konjac jelly made with sucrose was considered as "ideal" texture and sweet attributes as influenced by most frequency distribution presented at 0 score. The jelly with xylitol was clearly rated for the most frequency of score -1 (Fig. 2a), indicating a softer gel texture. Based on the score of 0 and 1, most panelists exhibited the appropriate level of jelly texture made with each sweetener in the following: sucrose > erythritol-sucralose > xylitol. For sweet results in Fig. 2b, the konjac jelly with sucrose evidently showed the highest frequency distribution at 0 score, indicating the sweet was the most accepted. The sweet of the jelly with xylitol was less than the ideal, because most of its frequency was highly found in the score between -1 to -3. This result was in accordance with the acceptant test (Table 4) in which this jelly received the lowest sweet score. Although, the sweet of jelly with erythritol-sucralose was more appropriate than that with xylitol, both jellies needed to be improve for desirable sweet to meet consumer acceptance.

CONCLUSION

The changes of gel strength of konjac gels as affected by konjac/κ-carrageenan blend and sweeteners (sucrose, xylitol and erythritol-sucralose) can be successfully described by the RSM. The models of gel strength of konjac/κ-carrageenan gels with three sweeteners were effective ($p<0.001$) and reliable with high R^2 greater than 0.95. The konjac/κ-carrageenan ratio greatly influenced on gel strength of the gels with any sweeteners and the highest gel strength was obtained as a ratio of konjac and κ-carrageenan about 40-45:55-60 was used. The sucrose concentration (2-15%) slightly increased gel strength; however, higher level than 15% showed an opposite effect. The increase in xylitol concentration decreased gel strength, while the use of erythritol-sucralose exhibited no effect. Optimal conditions for the maximum gel strength were 1% konjac/κ-carrageenan (39.56:60.44) with 9.58% sucrose, 1% konjac/κ-carrageenan (39.87:60.13) with 2% xylitol and 1% konjac/κ-carrageenan (38.18:61.82) with 0.94% erythritol-sucralose. Orange konjac jellies, produced by the three optimal conditions, receiving the most overall acceptance was the jelly with sucrose, followed by that with erythritol-sucralose and xylitol, respectively. The sweet of jelly with erythritol-sucralose was more appropriate than that with xylitol; nevertheless, they required a sweet taste increment.

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