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Effect of sucrose replacer on physicochemical properties and sensory analysis of rose tea gummy jelly

[1]*Bouphun, T., [2]Sassa-deepaeng, T. and [1]Krueaboon, R.

[1]*Department of Agro-Industry, Faculty of Science and Agricultural Technology, Rajamangala University of Technology Lanna Lampang, Pichai, Lampang 52000, Thailand*
[2]*Department of Science, Faculty of Science and Agricultural Technology, Rajamangala University of Technology Lanna Lampang, Pichai, Lampang 52000, Thailand*

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Abstract

Developing confectionery products by reducing sugar and using natural ingredients is an important response to health-conscious consumers. In the present work, we determined how different concentrations of sucralose (SC)—0, 25, 50, 75, and 100%—as a replacement for sucrose while maintaining the same level of sweetness of rose tea gummy jelly (RTGJ) could affect the physical properties, reducing sugar content, total phenolic content (TPC), total flavonoid content (TFC), antioxidant activity by DPPH method, sensory properties, and consumer attitude toward RTGJ. Results showed that the red colour (a* value) of 100% SC was the highest ($p < 0.05$). The hardness, gumminess, and chewiness values of 50% SC were the highest at a significant level ($p < 0.05$). The springiness and water activity of all samples were not significantly different ($p > 0.05$). Total reducing sugar content in the control sample was significantly higher ($p < 0.05$) than in other samples. The TPC and TFC of RTGJ were not significantly different ($p > 0.05$) among all samples, while antioxidant activity slightly decreased with increasing amount of SC in RTGJ. Remarkably, sensory analysis revealed no differences between the control sample and 100% SC, which had the highest liking scores in terms of sweetness, sourness, springiness, rose tea flavour, and overall liking. Consumers expressed that RTGJ with 100% SC could help them to relax and decrease tooth decay. The present work introduced a new functional jelly confectionery product using 100% SC and adding rose tea which showed potential for promoting phytochemical properties and enhancing emotional and health advantages.

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Introduction

Confectionery products are consumed widely around the world (Konar *et al*., 2022). Gummy jelly is one kind of confectionery product that consists of sugar as the main ingredient, typically in the form of sucrose syrup and/or glucose, combined with gelling agents, acids, aromas, and food colorants (Delgado and Bañón, 2015; Cano-Lamadrid *et al*., 2020). Due to the high levels of sugars and food additives, including undesirable compounds such as acrylamide formation which is correlated to the degree of browning produced by the heat treatment (Mutlu *et al*., 2018), it has been reported that consuming many of these confections can be harmful to one's health (Cano-Lamadrid *et al*., 2020), as is the case in Asia with obesity and diabetes. Thailand is now one of the countries with the highest prevalence of obesity (second only to Malaysia). Based on a recent report, obesity and diabetes are two major risk factors for COVID-19 hospitalisation, and people who have both are at a higher risk of severe illness (Al-Sabah *et al*., 2020). Konar *et al*. (2022) showed that there is a global confectionery trend to include confectionery products that are low-calorie, sugar-free, and/or enriched with phytochemicals, but these trends are not well reported. To help address these gaps, creating a jelly gummy formula to satisfy consumer needs is advantageous for the manufacturing sector, and contributes to the improvement of confectionery goods for consumers.

Sucralose (SC) has received approval from worldwide markets including in the USA, Canada, and the EU as a food additive (Bannach *et al*., 2009).

*Corresponding author.
Email: Than259@yahoo.com ; Tunyaluk@rmutl.ac.th

SC is manufactured chemically from sucrose. It is a sucrose molecule with three OH groups replaced by chlorine. It is relatively stable in an aqueous solution at high temperatures. It is partially absorbed and then excreted through the kidneys. It has no nutritional value, and is completely lacking in calories. SC is 600 times sweeter than sucrose, and permitted by the law in various food products. SC has been shown in several studies to be non-cariogenic. In drinking water, SC, sorbitol, and aspartame induced little or no caries development in desalivated rats infected with *Streptococcus sobrinus* and *Actinomyces viscosus* (Matsukubo and Takazoe, 2006). Previous research emphasised SC and stevia as valuable alternatives to sucrose in healthy citrus-maqui soft drinks, providing a non-significantly different plasma concentration and cumulative effect in the plasma, thus contributing to the prevention of a variety of metabolic disorders and health constraints (Agulló *et al*., 2021). An attempt was made to produce low-calorie mango jam by replacing sucrose with alternative sweeteners (stevioside and SC). However, only 25% stevioside or SC substitution is allowed for the production of mango jam with the desired jam-like soft solid characteristics. A recent study revealed that 50% SC replacement in strawberry gummy jelly had the highest consumer acceptance, and was lower in calories than the control (sucrose) (Takeungwongtrakul *et al*., 2020).

Roses are a well-known decorative-purpose edible flowers that are high in phytochemicals but have received little attention as a food source (Bortolini *et al*., 2022). Rose petals are coloured by cyanidin and pelargonidin, which together with carotenoids produce an attractive rosy red coloration (Mlcek and Rop, 2011). Additionally, rose is high in amino acids, essential oils, vitamins, and minerals, but it is also high in physiologically active substances such as anthocyanins, polyphenols, polysaccharides, and flavonoids, which can provide significant human health benefits by inhibiting some chronic degenerative diseases (Qiu *et al*., 2021). Based on past studies, roses not only have antioxidant and reactive oxygen species scavenging properties, but they also have anti-inflammatory, antibacterial, antifungal, and antiviral substances (Choi and Hwang, 2003). Aside from that, water extracts of rose flowers have been shown to have sedative, antistress, haemostatic, stomach-fortifying, liver-fortifying, intestine-fortifying, fever suppressant, skin disease protection, and analgesic properties (Choi and Hwang, 2003; Kart and Çağındı, 2017), as well as to offer relief from diarrhoea, stomach ache, menoxenia, and women's diseases in China (Qiu *et al*., 2021). Roses have been used for centuries in fresh or processed food products such as confectionery and beverages or in combination with other herbal materials (Vinokur *et al*., 2006). Rose flowers can be used in functional food products.

Although the high-calorie content of confectionery products raises some concerns, confectionery consumption is still increasing, as these foods have been shown to improve people's moods. The focus of the present work was to develop new confectionery items that adapt to consumer moods and health. This novel functional confection is created by maintaining the sweetness level while using sucrose replacer and enhancing the phytochemical compound from rose tea. Since little research has been done on the phytochemical properties of rose tea in foods (Vinokur *et al*., 2006) and product quality when using sugar replacements, the present work also aimed to evaluate the physicochemical and sensory properties of rose tea gummy jelly (RTGJ) by preparing it with different concentrations of SC as a substitute for sucrose to reduce the sugar content while maintaining the same level of sweetness. The present work also sought to determine consumer attitudes toward this new low-sugar functional confectionery product with phytochemical content from rose tea.

Materials and methods

Chemicals

The 2,2-diphenyl-1-picrylhydrazyl hydrate (DPPH), gallic acid, 3,5-dinitrosalicylic acid (DNS), and quercetin were purchased from Sigma-Aldrich, St. Louis, MO, USA. Folin-Ciocalteu reagent was purchased from Merck KGaA, Darmstadt, Germany. Aluminium trichloride, glucose, sodium carbonate, and sodium nitrite were purchased from Ajax Finechem Pty Ltd, Australia. Sodium hydroxide was purchased from RCI Labscan, Thailand.

Materials

Rose tea mild formula (Chatramue, Thailand; 95% dried tea leaf and 5% dried rose tea), sucrose (Mitr Phol, Thailand), glucose syrup (Fancy Craft, Thailand), edible gelatine (McGarrett, Thailand), and citric acid (Sunshine, Thailand) were ingredients in RTGJ formulation, and purchased from a local supermarket in Lampang, Thailand. Sucralose (Anhui, China) was used as an alternative sweetener, and obtained from Chemipan Corporation Co., Ltd. (Bangkok, Thailand).

Rose tea gummy jelly preparation

The RTGJ was prepared using a standard gummy jelly candy formulation as described by Garcia and Penteado (2005) with slight modification by using the following ingredients: 26% rose tea solution, 8% edible gelatine, 31% glucose syrup, 1% citric acid powder, and 34% sucrose. Based on the experimental designed shown in Table 1, SC was used at four levels of sucrose substitution (25, 50, 75, and 100%). Therefore, RTGJ was formulated with an alternative sweetener that partially or completely replaced the 34% sucrose content. For RTGJ formulated with alternative sweeteners, the proportion of sucrose that was partially or completely replaced by the alternative sweetener was referred to as the sucralose level. For example, 25% SC represented RTGJ formulated by replacing 25% of sucrose with SC. Since the relative sweetening index value of SC is 600 times that of sucrose, the calculation was as follows: 75% sucrose + 25% SC = 25.5 g sucrose + 14.2 mg SC.

Table 1. Experimental design of RTGJ preparation with increasing levels of SC as sucrose replacer.

Sample (SC level)	%Sucrose	Sucrose level	Amount of sucrose (g)	Amount of SC (mg)*
Control	34	100	34.0	0.0
25% SC	34	75	25.5	14.2
50% SC	34	50	17.0	28.3
75% SC	34	25	8.5	42.5
100% SC	34	0	0.0	56.7

SC: sucralose; Control: 100% sucrose; 25% SC: 25% SC + 75% sucrose; 50% SC: 50% SC + 50% sucrose; 75% SC: 75% SC + 25% sucrose; and 100% SC: 100% sucralose. *As calculated by the relative sweetness index, SC is 600 times sweeter than sucrose. All samples had a sweetness value of 34% sucrose.

Rose tea was extracted using 10 g of rose tea and 600 mL of water as instructed on the product label. Then it was boiled for 5 min at 100°C using an electric kettle (Cimi, China) (Murray *et al*., 2016). The rose tea solution was separated from the residue, and divided into two parts. The first part was mixed with gelatine, and stirred until the solution was a clear gel. The second part was mixed with sugar or SC at different levels, glucose syrup, and citric acid, and stirred until completely dissolved. Next, all solutions were homogenised in a brass pan by stirring on a stove at 80°C to prevent burning. The mixture was mixed until the Brix value was adjusted to 68 - 70 °Brix (Cano-Lamadrid *et al*., 2020). The mixed solution was poured into a non-stick silicone mould, which was flexible for easy removal, with 50 teddy bear cavities (size: 19 × 14 cm) coated with dry starch (6 - 8% moisture). The products were cooled for 30 min at room temperature, then in the refrigerator for 30 - 90 min or until coagulated. The jelly samples were removed from the mould, and stored at 4°C in an airtight polypropylene plastic container. Physicochemical properties and sensory evaluations were performed on five different gummy jelly formulations (Charoen *et al*., 2015; Ibrahim *et al.*, 2020; Takeungwongtrakul *et al*., 2020; Cano-Lamadrid *et al*., 2020).

Colour

Five RTGJ formulations were examined for colour. The HunterLab colour analyser (HunterLab, Model Colour Quest XE, USA) was used to determine the colour by reflectance measurement (L*, a*, and b*). The L* value represents the sample lightness index scale, ranging from 0 (black) to 100 (white). The a* value represents redness (+a) or greenness (-a*), whereas the b* value represents yellowness (+b) or blueness (-b*). Measurements were performed in triplicate for each RTGJ formulation.

Texture

Texture Profile Analysis (TPA) was performed using a Texture Analyser (TA-XT plus model, Stable Micro Systems, UK) according Delgado and Bañón's (2015) with slight modifications. Instead of using a flat cylindrical probe with a diameter of 35 mm (P/35) and a 5 kg load cell, the sample was compressed twice for each RTGJ sample (size: 1 × 2 cm). The testing conditions were as follows: a cross-head moved at a constant speed of 1 mm/s, 75% strain compression, and a trigger point of 0.05 N. The texture variables investigated were hardness, springiness, cohesiveness, gumminess, and chewiness. The TPA was carried out within the same gelation container, with five measurements for each RTGJ formulation (n = 15).

Water activity

The a_w was determined using a water activity meter (AquaLab LITE, Decagon, USA) with an accuracy of 0.015. Briefly, 3 g of finely minced sample was placed in the sample dish to perform the measurement. All measurements were performed in triplicate at 25°C.

Total reducing sugar

The total reducing sugar content was determined by the DNS method (Miller, 1959). Briefly, 500 mg of RTGJ sample was melted in 5 mL of DI water at 55°C in a hot air oven (Memmert GmbH + Co. KG, Germany) for 30 min, and then vortexed vigorously for 5 min prior to centrifugation at 3,000 rpm for 5 min. The supernatant was collected for further analysis. The diluted samples and DNS solvents were thoroughly mixed and then incubated for 10 min in a boiling water bath. After cooling down to ambient temperature, the absorbance was measured at 540 nm using a V-1200 spectrophotometer with UV-professional analysis software (Dshing Instrument Co., Ltd., China). All experiments were conducted in triplicate, and total reducing sugar content was expressed as milligrams of glucose equivalents per gram of sample dry weight (mg GE/g sample DW).

Total phenolic content

The samples were prepared as described earlier. The TPC of all samples was determined using a modified Folin-Ciocalteu colorimetric method (Sassa-deepaeng *et al*., 2019). Briefly, the volume of the sample and all reagents were reduced proportionally to minimise the waste. The sample (20 µL) was reacted for 5 min with 100 µL of Folin-Ciocalteu reagent in 1980 µL of DI water before mixing with 300 µL of 7% Na_2CO_3. After incubation for 60 min in the dark at ambient temperature, the absorbance was measured at 765 nm using a V-1200 spectrophotometer with UV-professional analysis software. All experiments were conducted in triplicates, and TPC was expressed as microgram gallic acid equivalent per gram of sample dry weight (µg GAE/g sample DW).

Total flavonoid content

The samples were prepared as described earlier. The TFC was determined by the aluminium trichloride ($AlCl_3$) colorimetric method with slight modifications (Yodthong *et al*., 2020a). Briefly, the volume of the sample and all reagents were reduced proportionally to minimise the waste. Next, 100 µL of various extract concentrations was added to 300 µL of DI water followed by 100 µL of 5% $NaNO_2$. After incubating for 5 min at ambient temperature, 100 µL of 10% $AlCl_3$ was mixed and allowed to stand for 6 min at ambient temperature. Finally, 400 µL of 1 M NaOH was added and then incubated for 30 min in the dark. The absorbance of the mixture was measured at 415 nm using a V-1200 spectrophotometer with UV-professional analysis software. The flavonoid quantitation was carried out in triplicates, and the content was expressed as micrograms quercetin equivalent per gram of sample dry weight (µg QE/g sample DW).

Antioxidant activity by DPPH method

The samples were prepared as described earlier. The 2,2-diphenyl-1-picrylhydrazyl hydrate (DPPH) radical-scavenging activity was employed to measure in triplicate according to Yodthong *et al*. (2020b). The DPPH solution (oxidised form) was prepared in absolute ethanol to get final absorbance of 0.8 - 1.0. Next, 100 µL of various concentrations of samples were added to 900 µL of DPPH radical solution. After shaking vigorously, the mixture was incubated for 30 min in the dark at ambient temperature. The radical scavenging capacity was determined by measuring absorbance at 517 nm. The percentage of inhibition of samples was calculated using Eq. 1:

$$\% \text{ inhibition} = [(\text{Abs control} - \text{Abs sample}) / \text{Abs control}] \times 100 \quad \text{(Eq. 1)}$$

Sensory

Sensory evaluation was carried out for five RTGJ samples from different formulations by 30 semi-trained panellists (20 - 25 years old) who were students and staff of the Food Science and Technology Division at Rajamangala University of Technology, Lanna Lampang. The attributes of RTGJ evaluated were colour, rose tea aroma, sweetness, sourness, springiness, rose tea flavour, and overall liking on a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely). Testing was conducted in a sensory evaluation laboratory maintained at 25°C. Briefly, 8 g (four pieces) of jelly samples per each formulation in plastic plates coded with random three-digit numbers were served to each panellist in an individual session. Panellists assessed five sample jellies in random order. Before the analysis, panellists were instructed to rinse their mouths with water to minimise residual flavour effects after each sample tasting. The highest mean score value of RTGJ with SC from four formulations was selected for consumer panel testing.

Consumer study

The consumer study comprised 75 untrained panellists (20 - 50 years old) who had previously purchased and were interested in consuming gummy jelly. The untrained panellists assessed the jelly sample which included two questionnaires: a preference test with a 9-point hedonic scale (1 = dislike extremely, 9 = like extremely) and another for investigating consumer attitudes as well as overall acceptance toward RTGJ with SC as a phytochemical ingredient and alternative sweetener. Home-use tests were used to conduct the surveys in Lampang province (Thailand). Consumers were given a sample in an airtight polypropylene plastic bag with 3-digit random numbers and questionnaire sheets. The responses of the samples to various attributes were statistically analysed, and the mean values were reported. Data on consumer attitudes and acceptance test was presented as a percentage.

Statistical analysis

The present work used a completely randomised design. All experiments on physicochemical properties were performed in triplicate. For the sensory analysis, a randomised complete block design was used; the block was panellists, and the treatments were SC levels of 0, 25, 50, 75, and 100%. The data were analysed using analysis of variance (ANOVA), followed by Duncan's multiple range test to compare mean differences at $p < 0.05$. All analyses were carried out using statistical software.

The present work was granted the ethical approval by Rajamangala University of Technology Lanna Ethics Committee (approval no.: RMUTL-IRB 004/2022).

Results and discussion

Colour

Table 2 shows the physical properties of RTGJ formulations with increasing levels of SC as sucrose replacer. In terms of colour (Table 2), the RTGJ with 50% SC had the highest value of lightness (L*) (83.16 CIE units), but there was no significant difference between RTGJ with 100% sucrose (control) and 25, 75, and 100% SC (76.04, 72.83, 73.58, and 76.1 CIE units, respectively). While the RTGJ with 100% SC had higher values of redness (a*) (55.09 CIE units) than RTGJ with 100% sucrose (control) and 25 - 75% SC (46.53, 48.51, 49.54, and 50.92 CIE units, respectively). Furthermore, the results revealed a trend in which decreasing the sugar content and increasing the amount of SC caused a high red value of RTGJ, which received its red colour from rose tea infusion. This might be explained by the browning reactions in food processing that are caused by the Maillard reaction and caramelisation, which occur when amino acids and sugar are heated together at high temperatures, thus creating a brown colour (Rufián-Henares and Pastoriza, 2016). The high sucrose content level of RTGJ samples had higher reducing sugar content (Table 3), thus indicating that Maillard reaction occurred and resulted in a decrease in a* value (Table 2), which might have caused a changing of colour; a decrease in the red colour in the formulation of RTGJ with sucrose. In contrast, SC is a white, crystalline powder that is non-hygroscopic and free flowing. It is highly soluble in water, and does not affect solution pH. SC is also heat resistant; so, it can be used in cooking and desserts that require high heat without losing sweetness (Grotz *et al*., 2001). It has no effect on the product's colour, and also helps to stabilise the product's colour. As a result, RTGJ with 100% SC had the highest red value, like the rose tea colour. This result was similar to a study done by Kongkaoroptham and Nopharatana (2015) which recorded the kinetics of browning pigment formation and reactant consumption of the Maillard reaction in a sucrose-SC-lysine model system at

Table 2. Physical properties of RTGJ preparation with increasing levels of SC as sucrose replacer.

Sample	Physical property							
	Colour			Textural property				
	L	a*	b*	Hardness (N)	Springiness (mm)	Cohesiveness (ratio)	Gumminess (N)	Chewiness (N)
Control	76.18 ± 1.74^{b}	46.53 ± 1.60^{c}	10.50 ± 1.337^{b}	47.15 ± 2.68^{d}	1.05 ± 0.07	0.97 ± 0.00^{a}	45.86 ± 2.70^{c}	48.43 ± 6.23^{c}
25% SC	72.83 ± 1.03^{b}	48.51 ± 1.35^{bc}	12.93 ± 1.98^{b}	70.01 ± 4.09^{b}	1.02 ± 0.03	0.94 ± 0.00^{ab}	66.53 ± 4.44^{b}	68.17 ± 4.33^{b}
50% SC	83.16 ± 2.06^{a}	49.54 ± 1.58^{b}	10.56 ± 1.44^{b}	92.12 ± 2.54^{a}	1.00 ± 0.04	0.92 ± 0.02^{c}	96.00 ± 5.98^{a}	86.80 ± 8.66^{a}
75% SC	73.58 ± 2.63^{b}	50.92 ± 0.89^{b}	19.76 ± 5.59^{a}	41.80 ± 2.19^{e}	1.01 ± 0.02	0.92 ± 0.02^{c}	38.49 ± 2.68^{d}	39.19 ± 3.07^{d}
100% SC	76.04 ± 2.65^{b}	55.09 ± 1.04^{a}	24.65 ± 0.44^{a}	52.71 ± 2.73^{c}	1.01 ± 0.01	0.93 ± 0.02^{bc}	49.02 ± 3.39^{c}	49.67 ± 3.74^{c}

Values are mean ± standard deviation of triplicates (n = 3). Means followed by different lowercase superscripts in the same column are significantly different ($p < 0.05$). SC: sucralose; Control: 100% sucrose; 25% SC: 25% SC + 75% sucrose; 50% SC: 50% SC + 50% sucrose; 75% SC: 75% SC + 25% sucrose; and 100% SC: 100% sucralose.

Table 3. Chemical composition of RTGJ preparation with increasing levels of SC as sucrose replacer.

Sample	a_w	Total reducing sugar content (mg glucose/g sample)	Total phenolic content (µg GAE/g sample)	Total flavonoid content (µg QE/g sample)	Antioxidant activity (%/mg sample)
Control	0.55 ± 0.42	90.24 ± 2.94^a	166.17 ± 1.22	54.47 ± 1.57	65.38 ± 1.41^a
25% SC	0.52 ± 0.19	54.27 ± 1.98^b	183.53 ± 1.97	54.47 ± 1.26	61.83 ± 1.40^a
50% SC	0.51 ± 0.01	53.23 ± 1.58^b	184.67 ± 1.24	54.81 ± 0.39	43.80 ± 0.83^b
75% SC	0.53 ± 0.02	48.22 ± 1.86^b	190.92 ± 1.41	55.77 ± 1.39	42.03 ± 0.31^b
100% SC	0.54 ± 0.02	42.67 ± 1.60^b	193.17 ± 1.66	54.53 ± 1.19	40.02 ± 1.24^b

Values are mean ± standard deviation of triplicates (n = 3). Means followed by different lowercase superscripts in the same column are significantly different ($p < 0.05$). SC: sucralose; Control: 100% sucrose; 25% SC: 25% SC + 75% sucrose; 50% SC: 50% SC + 50% sucrose; 75% SC: 75% SC + 25% sucrose; and 100% SC: 100% sucralose.

various sucrose-to-SC ratios, and reported that SC was used in place of sucrose in the model system to reduce changes in browning pigment formation as well as L*, a*, and b* values. In addition, Martínez-Cervera *et al*. (2012) also concluded that reduced-sugar muffins had a more orangey colour than the control muffins due to higher levels of polydextrose and SC substitution for sucrose in the formulations. However, the present work contrasted with previous research which found that replacing 50% of the sucrose in strawberry gummy jelly with SC decreased a* and b* values (Takeungwongtrakul *et al*., 2020), which could probably be due to the formulation and heating temperature that affected the level of browning reaction and colour, but this was not indicated. In general, red colour is determined by the total anthocyanin content and the chemical structure of the individual anthocyanin (Cano-Lamadrid *et al*., 2020). Red colour is very appealing to customers; so, it must be preserved during the jelly-making process. The colour behaviour observed in the present work is consistent with other previous study (Takeungwongtrakul *et al*., 2020).

Texture

The TPA is a technique commonly used in the industry to evaluate food textural behaviour because it can indicate sensory eating properties (Burey *et al*., 2009). The TPA test result (Table 2) shows that the hardness, gumminess, and chewiness values in RTGJ with 50% SC had the highest significance ($p < 0.05$) as compared to other samples and control. Hardness, gumminess, and chewiness are texture descriptors for gelled confections (Gunes *et al*., 2022). Hardness is proportional to the maximum force required to deform the jellies in the first bite. Gumminess is generated by multiplying hardness and cohesiveness, whereas chewiness is generated by multiplying hardness, cohesiveness, and springiness (Delgado and Bañón, 2015). Candy hardness values are generally affected by the amount of solids present (Vieira *et al*., 2008). Marfil *et al*. (2012) suggested that adding starch increases the gel strength and hardness of gelatine-based gummy confections. Kuan *et al*. (2016) reported a similar observation in which the kinetic gel increased with the addition of more sugars (40% sucrose). The mean number of e-OH groups increases with increasing sugar concentration, while the amount of water available for gelatine gelation decreases (Uedaira *et al*., 1990). As a result, the annealing and crystallisation of sugar molecules become more pronounced as compared to gelatine gelation upon cooling. Adding sugars at 5 - 20% concentrations, on the other hand, prevented gelatine chains from kinetically approaching each other during gelation (Kuan *et al*., 2016). However, as more sugars were added, the gelation rate remained constant while the gel strength increased, most likely due to the formation of smaller junction zones, thus resulting in a more rigid gel (Oakenfull and Scott, 1986). Furthermore, as the concentration of added sugars increased, the gelling and melting temperatures increased (Kuan *et al*., 2016). In the present work, remarkably, there were no significant differences in gumminess and chewiness ($p > 0.05$) between RTGJ with 100% SC and control. Furthermore, the hardness value in RTGJ with 100% SC (52.71 N) differed slightly from the control (47.15 N) ($p < 0.05$). This might be explained by the fact SC is freely soluble in water even at low temperatures, and has a negligible surface tension lowering effect in dilute solutions. This means that when pumped or mixed in gummy confection, it is unlikely to cause excessive foaming (Grotz *et al*., 2001). Furthermore, the comparatively low viscosities observed for SC solutions combined with Newtonian behaviour mean no viscosity issues when mixing or dispersing solutions (Jenner and Smithson, 1989). As previously reported, several prototype baking studies showed that SC would not hydrolyse into its constituent monosaccharide-like moieties or other materials, and no chlorine loss from SC would occur in food systems. SC hydrolysis can occur in trace amounts in particular food and beverage products depending on pH, time, and temperature (Grotz *et al*., 2001).

The springiness of all samples was not significantly different (p > 0.05). The samples had high springiness (values greater than 1.00) comparable to the control sample. As a result, the presence of SC in the gum structure had a positive effect on the elastic properties of the samples. Besides that, this springiness value was similar to those reported for other fruit gummy jellies (Castello *et al*., 2014; Garrido *et al*., 2015; Cano-Lamadrid *et al*., 2020).

Cohesiveness is influenced by the interactions of structural forces at the molecular level (Castello *et al*., 2014). Results of the present work indicated that the control sample had the highest significant difference (p < 0.05) when compared to the other samples (except 25% SC). The cohesiveness values in all samples with SC replacing sucrose in RTGJ were 0.92 - 0.94, similar to incorporating isomaltulose in the formulation of gummy confections (Castello *et al*., 2014). As a result, the addition of SC to the formulation of gummy confections improved the structural stability of the samples. This could be related to the effect of sucrose and SC on gelation properties, thus affecting the rheological properties of the gelation-sugar substituent composite (Castello *et al*., 2014).

Chemical composition

Table 3 shows the chemical composition of RTGJ preparations with increasing levels of SC as sucrose replacer. The water activity (a_w) of RTGJ with SC and control was not significantly different (p > 0.05). In general, gummy jellies are 0.50 - 0.75 a_w (Bussiere and Serpelloni, 1985). The a_w of all samples in the present work ranged from 0.51 - 0.55, thus indicating that replacing sucrose with SC did not affect the a_w of gummy jelly, consistent with previous reports for other jellies (Charoen *et al*., 2015).

The total reducing sugar content in the control sample was significantly higher (p < 0.05) than in the other samples, particularly when compared with RTGJ with 25 - 100% SC. However, no significant difference (p > 0.05) was observed among the SC-replaced samples (all levels). This result indicated that sucrose, a non-reducing sugar, was affected by the chemical inversion of sucrose to glucose and fructose in the presence of heat, including the effect of constant reaction pH on sucrose degradation (Eggleston and Vercellotti, 2000), which may be responsible for the high reducing sugar content (Mutlu *et al*., 2018). On the other hand, SC (4-chloro-4-deoxy-a-D-galactopyranosyl-1, 6-dichloro-1, 6-dideoxy-b-D-fructofuranoside) is heat resistant while retaining its sweetness (Martínez-Cervera *et al*., 2012). As a result, it had less impact on reducing sugar content. However, the present work contradicted a previous study which found no difference in reducing sugar content between control and 50% SC samples of strawberry jelly gummy (Takeungwongtrakul *et al*., 2020).

The total phenolic content (TPC) and total flavonoid content (TFC) of RTGJ were not significantly different (p > 0.05) among all samples. The TPC were between 166.17 and 193.17 µg GAE/g sample, similar to the values reported by Ben Rejeb *et al*. (2020) for reduced sugar jellies produced from citrus fruits (123.16 - 192.76 mg GAE/100 g). The TFC of all RTGJ ranged between 54.47 and 55.77 g QE/g sample. The antioxidant activities of the control sample and 25% SC sample were significantly higher (p > 0.05) than those of the other samples. However, antioxidant activity did not increase with more SC but rather slightly decreased. The increased SC concentration was supposed to have no impact on antioxidant activity. Vinokur *et al*. (2006) postulated that gallic acid and other phenolic compounds, anthocyanins, polyphenols, and flavonoids play a substantial role in the antioxidant activity of rose petal teas, but the hot water did not extract all the antioxidant components present in rose petals. Previous reports showed sucrose as a good anthocyanin protector, especially at high concentrations, and hydrolysis of sucrose might increase the antioxidant capacity (Tsai *et al*., 2005). This might explain why RTGJ with 100% sucrose and 25% SC had higher antioxidant activity than RTGJ with lower concentrations of sucrose, or it may be stated that SC had no effect on antioxidant activity. The results of the present work revealed that SC did not affect TPC and TFC. Furthermore, the addition of rose tea composed of 95% dried tea leaf and 5% dried rose tea, was associated with the source of TPC and TFC and antioxidant activity. Previously, Kart and Çağındı (2017) reported that when dried roses tea were boiled at 98°C for 5 min, the TPC was 5.24 - 166.36 mg GAE/200 mL tea, the total amount of flavonoids was 2.02 - 14.83 mg CE/200 mL tea, and the antioxidant capacity values was 0.64 - 10.78 µM Trolox /200 mL tea were found. Moreover, these results were similar to previous report that the addition of 1% citric acid increased the TPC of pomegranate juice jelly as compared to control jellies (Cano-Lamadrid *et al*., 2020). As a result, adding rose tea could enhance the nutritional benefits of the jelly while potentially reducing the sugar content.

Sensory

Figure 1 shows the sensory liking score on a 9-point hedonic scale of RTGJ with increasing levels of SC as the sucrose replacer. Sensory analysis was carried out to evaluate the sensory profile of the RTGJ, and to actually look for significant differences among formulations. The effect of formulation (addition of rose tea) and sweetener (sucrose and SC) on six characteristics and overall liking of RTGJ was investigated. The colour and rose tea aroma scores of RTGJ with sucrose (control) and increasing levels of SC (25, 50, 75, and 100%, respectively) were not significantly different ($p > 0.05$). Despite this, the red (positive a* value) colour of RTGJ with 100% SC had the highest significant difference. Nonetheless, panellists assessed that the red colour of all RTGJ samples did not affect colour liking score; this result agreed with a previous study in which gummy strawberry jelly was replaced with SC, and the result had no impact on colour liking score (Takeungwongtrakul *et al.*, 2020). The control sample had the highest score for all attributes. Remarkably, no significant differences in sweetness, sourness, springiness, rose tea flavour, and overall liking were found between the control sample and the RTGJ with 100% SC. The sweetness of RTGJ with sweetener was adjusted by using SC. It was adjusted to be similar to the sweetness of sucrose because consumers are used to the sweet taste of commercial confections with sugar content. One of the purposes of the present work was to reduce the amount of sugar in gummy jelly. Aside from that, it is important to note that no differences in sweetness were observed between the control sample and RTGJ with 100% SC, but a significant difference was observed when 50% SC was used. Previous studies reported that adding 50% SC for sucrose replacement in strawberry gummy jelly had the highest consumer acceptance, but the present work showed the opposite (Takeungwongtrakul *et al*., 2020). This might have been due to the formulation parameters such as formula, pH, heating, and time, as well as the addition of rose tea, which could affect perceptions of other sensory attributes. Interestingly, mean scores for the liking of all attributes tested for all RTGJ samples exceeded 6.0 on a nine-point hedonic scale, and could therefore be considered acceptable because, in general, if the mean score on a nine-point hedonic scale is above 5.0, they can be regarded as acceptable, and their acceptance can be improved (Cano-Lamadrid *et al*., 2020). As a result, RTGJ with 100% SC was selected for consumer acceptance testing to reduce sugar as much as possible while still being accepted by consumers.

Consumer study

Figure 2a shows the liking scores of RTGJ with 100% SC by consumer testing. All 75 consumer panellists filled out the questionnaire. The result indicated that on a 9-point hedonic scale, mean scores for colour, rose tea aroma, sweetness, sourness, springiness, rose tea flavour, and overall liking of RTGJ with 100% SC were above 7.0, hence was clearly acceptable.

Figure 2b shows the consumer attitudes and acceptance test toward RTGJ with 100% SC as a phytochemical ingredient and alternative sweetener. The reasons and expectations indicated by the participants regarding consuming RTGJ with 100% SC (sugar-free) were reported as follows: 75% said to help to relax, 70% said to help to decrease tooth decay, 67% said to reduce calorie intake, 48% said to control blood sugar, 40% said to improve the nourishment of the skin, 39% said to enhance metabolic functions and help the excretory system, and 32% said to slow down the aging process. Participants also fully (100%) agreed on the acceptability of this sample. These results reflected the confectionery product attitudes and expectations of the new formula, which contained phytochemical ingredients from rose tea and the use of sweeteners

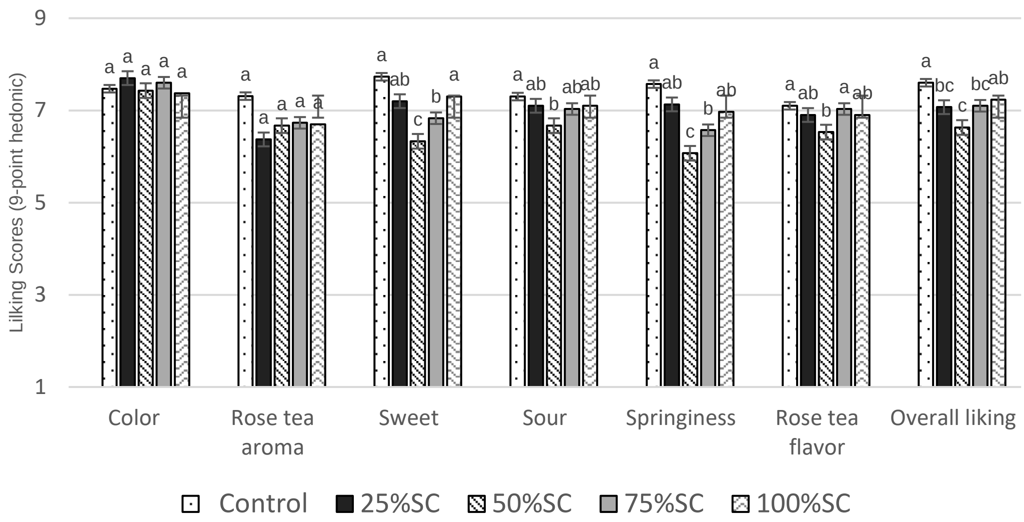

Figure 1. Sensory scores of RTGJ preparation with increasing levels of SC as sucrose replacer. Means with different lowercase letters are different at $p < 0.05$. Bars indicate standard error of the mean. SC: sucralose; Control: 100% sucrose; 25% SC: 25% SC + 75% sucrose; 50% SC: 50% SC + 50% sucrose; 75% SC: 75% SC + 25% sucrose; and 100% SC: 100% sucralose.

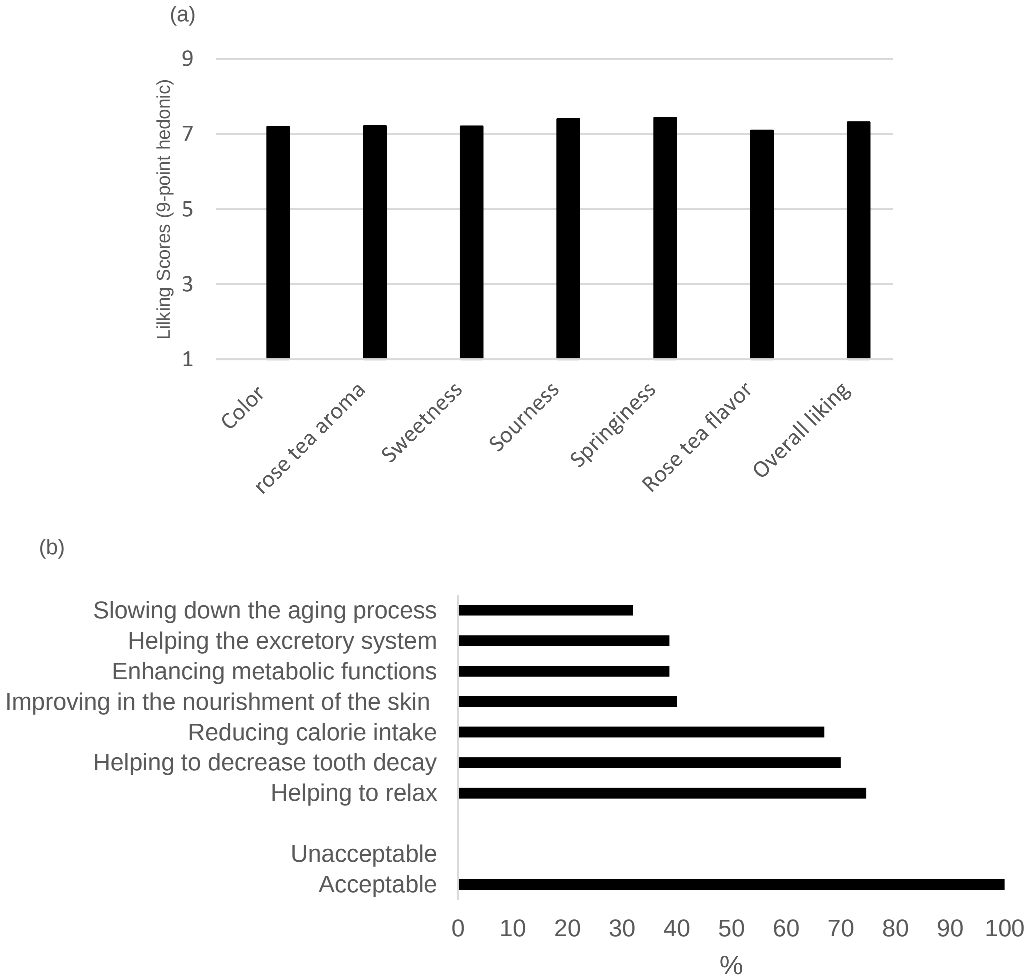

Figure 2. Liking scores of RTGJ with 100% SC **(a)**; and consumer attitude and acceptance test toward RTGJ with 100% SC **(b)** by consumer testing.

only. Future studies should examine consumer health and safety effects as well as additional industrial applications.

Conclusion

The present work demonstrated the physical properties, antioxidant activity, TPC, and TFC of formulated RTGJ with increasing levels of SC. All RTGJ with SC samples were not significantly different from the control sample in terms of a_w, TPC, and TFC. Sensory analysis revealed that RTGJ with 100% SC had a higher liking score than the other samples, but it was not statistically different from the control sample. Most participants indicated that their reasons and expectations regarding consuming RTGJ with 100% SC (sugar-free) was to help them relax and decrease tooth decay. They also expressed complete agreement with the acceptability of gummy jellies made by replacing sucrose with 100% SC, and including antioxidants from natural sources like rose tea to improve mood, among other benefits. Future studies should examine consumer health and safety effects as well as industrial applications for this new functional confectionery product.

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