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Low-sugar egg-based dessert (sweet egg yolk drops): Characterization, consumer acceptance and driver of liking

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ABSTRACT

The addition of sweeteners and fructooligosaccharides (FOS) to partially reduced-sugar syrup allows for the development of high-sugar egg-based desserts, which are a healthier alternative with good consumer acceptance. This study aimed to analyze the effects of different sweeteners and sugar reductions on physicochemical properties, consumer liking, and emotional responses of sweet egg yolk drops. Five experimental desserts were prepared: four with 25 % low-calorie sweeteners (erythritol, mannitol, sorbitol, and tagatose) combined with 25 % FOS in reduced-sugar syrup (50 %), and one as a control (full-sugar formulation). Substitution of erythritol (E50), mannitol (M50), and tagatose (T50) in the syrup significantly decreased the quality of the desserts. This implies a decrease in the sensory properties, leading to negative emotional responses among consumers. However, the application of external preference mapping (EPM) and hierarchical cluster analysis (HCA) revealed that two of the four commercial desserts and one control sample (F100) included sorbitol desserts (S50). Desserts in this group that are related to specific attributes as drivers of liking, such as appearance, yellowness, sweetness, cohesiveness, and juiciness evoke positive emotional responses in consumers ('Auspicious', 'Glad', 'Attractive', 'Secure', 'Loving', 'Natural'). Therefore, sorbitol and FOS are suitable sweeteners in reduced-sugar syrups for producing egg-based desserts with reduced calories and improved consumer acceptance. This study thus paves the way for the development of healthy dessert products.

1. Introduction

A dessert is one of the most popular and widely consumed products in numerous cultures worldwide [1] because it is easy to eat, and has a pleasing appearance and texture as well as a uniquely pleasant aroma and sweetness. The ingredients in these desserts primarily consist of flour and fat, along with a high amount of sugar, which can lead to health problems if consumed in excess. Carbohydrate foods with high flour and sugar content (high glycemic index) are easily broken down into glucose through the human digestive system and spike blood sugar levels suddenly, leading to type 2 diabetes [2,3]. In this regard, the dessert "Thong Yod" or "sweet egg yolk drops" is a suitable example for developing a healthy product. This traditional Thai dessert is influenced by Portuguese

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cuisine and usually served on various auspicious occasions. The sweet egg-based dessert is made from egg yolks and rice flour, and the mixture is then dropped into boiling high-concentrated sugar syrup to create a teardrop-shaped dessert. However, this dessert has a significantly high degree of sweetness, which causes concern to consumers. Based on the National Food Institute of Thailand [4], the sweet egg yolk drops contain 53.98–54.22 g of sucrose per 100 g, which is approximately two times the recommended daily amount (RDA) of sugar. Based on the latest recommendations by the World Health Organization, adults and children should limit their daily intake of free sugars to no more than 10 % of their total calorie intake or no less than 5 % of their total energy intake, which is approximately 25 g (six teaspoons) daily [5].

A healthy diet has become an intriguing consumer trend over the last several years, particularly with the use of sugar substitutes as low-and/or non-calorie sweeteners in food and beverage products [6]. Sugar consumption has become an increasing concern for consumers owing to obesity and type 2 diabetes caused by excessive consumption of sugar (table sugar, sucrose, fructose, high-fructose corn syrup, and honey). According to the World Health Organization (WHO) [7] mentioned, obesity and being overweight are the leading risk factors for type 2 diabetes. These two conditions are caused by a high intake of energy-dense foods with high fat and sugar content. Over the past few decades, the prevalence of obesity and type 2 diabetes has continued to increase globally [8]. It is estimated that 537 million individuals will be living with diabetes worldwide in 2021, which will increase to 643 and 783 million by 2030 and 2045, respectively [9]. Health issues associated with chronic diseases are some of the leading causes of illness, death, and disability. Therefore, the increasing incidence of diabetes worldwide has increased consumer awareness and changed consumer behavior, which has impacted the development and promotion of healthy food products.

Sugar (sucrose) is a widely used sweetener in the food industry [10]. Along with improving sweetness and aroma, the addition of sugar to food products improves several other essential features, including appearance (browning color), mouthfeel (texture and volume [bulk]), preservation, and crystallization. Although reduced-sugar products offer healthier alternatives for consumers, it can be challenging for manufacturers to maintain consumer satisfaction and acceptance. Several attempts have been made to investigate the use of non-nutritive sweeteners (for example, acesulfame, aspartame, neotame, stevioside, and sucralose) and low-calorie sweeteners (for example, erythritol, fructooligosaccharides [FOS], mannitol, sorbitol, and tagatose) to develop a variety of healthy products, such as soft drinks and fruit juices, alcoholic beverages, bakery products (biscuits, cookies, cakes, muffins), dairy products (milk, ice-cream, yogurt), confectionery and dessert (candies, chewing gum, chocolate, cream caramel desserts, jams/jellies) [11–13]. Low-calorie sweeteners are substances with low energy values that provide a less sweet taste than sucrose, whereas non-nutritive sweeteners contain little or no energy but are potent sweeteners with 30 to 13,000 times greater sweetness than sucrose [14]. At high concentrations, non-nutritive sweeteners are generally undesirable in terms of taste (metallic/bitter) and aftertaste. Furthermore, some low-calorie sweeteners, such as sugar alcohols, produce a cooling sensation in the mouth because of their dissolution in endothermic reactions [15,16]. Some rare sugars, such as tagatose, contain half the amount of calories as sucrose, but are nearly as sweet (0.92 and 1, respectively) [16]. Hence, owing to the variety of sweeteners available and their different sweetness properties and side effects, it is important to select an appropriate sweetener for each food product.

Consumer behavior has changed dramatically in recent years because of their concern for long-term health, resulting in a sharp increase in the demand for low-sugar products [17]. However, most consumers expect that sugar-reduced foods with added sweeteners will be pleasing to their sensory senses, have an optimal level of sweetness, and promote health [18]. Sugar replacement in food products requires careful selection of sweetener type and quantity to maintain consumer acceptance and preferences. Product acceptance is also influenced by attitudes, moods, and emotions, which are crucial factors in consumer decision-making regarding the selection of food [19,20]. Therefore, investigating the relationship between consumer behavior and emotions is necessary to identify the factors that motivate and lead to successful product development [21,22].

External preference mapping (EPM) is a preference mapping technique that uses descriptive and/or instrumental data as well as overall liking scores to identify the key drivers of liking based on the differences in liking between products. Another technique is internal preference mapping (IPM), which relies solely on consumer liking ratings to identify preference patterns [23]. Both the EPM and IPM use principal component analysis (PCA) biplots, which are multivariate data analyses, to reduce the dimensions of feature vectors for improved data visualization and analysis [24,25]. Thus, the use of preference mapping, specifically EPM, allows for the prediction of product placement in the market. It also helps identify new opportunities for product positioning and create products that meet consumer needs [24,26].

The objectives of this study were (1) to analyze the effect of different types of sweeteners (erythritol, mannitol, sorbitol, or tagatose mixed with FOS) on the physicochemical properties, sensory attributes, and emotion responses of sweet egg yolk drops, and (2) to explore the factors influencing consumer preferences for sugar-reduced desserts with sweeteners using external preference mapping (EPM) techniques for selecting appropriate sweeteners for the products.

2. Materials and methods

2.1. Materials

Fresh duck eggs (Kasemchai Food [KCF], Nakhon Pathom, Thailand), rice flour (New grade, Bangkok, Thailand), refined sugar (Lin, Kanjanaburi, Thailand), water (Nestle, Ayutthaya, Thailand), and pandan jasmine flavor (Winner's, Bangkok, Thailand) used to prepare the sweet egg yolk drops were purchased from a local market. Erythritol powder (ERYLITE®, Jungbunzlauer, France), mannitol and sorbitol powders (Shandong Tianli Pharmaceutical Co., Ltd., China), tagatose powder (D-Tagatose, Salus, China), and FOS-P Powder (Meiji, Korea) were used as sweeteners.

2.2. Dessert preparation

The sweet egg yolk drops were produced in two steps based on traditional recipes. In the first step, refined sugar was dissolved in boiling water to prepare two different concentration syrups: The cooking syrup (1:0.6 w/w; 70 °Brix) was used to form the egg yolk batter into the desired size and shape, whereas the soaking syrup (1:1, w/w; 56 °Brix) was used to provide the dessert with a glossy appearance and setting. Artificial flavors (pandan-jasmine flavors) were added to both syrups in small amounts.

In the second step, a dessert was prepared by whipping the duck egg yolks with a wire whip for 8 min at a speed setting of 10 in a mixer (Model 5K5SS, KitchenAid®, USA). The sifted rice flour was mixed with beaten egg yolks for 2 min and allowed to stand for 5 min at room temperature (~30 °C). The mixtures were poured into a hand-held manual batter dispenser with a 16.20 mm wide opening at the bottom. A drop batter was added to the cooking syrup at 90 °C for 15 min (120 pieces per each set of drops). After cooking, the dessert drops were transferred to a diluted syrup at room temperature and soaked for 10 min. The sweet egg yolk drops were then removed from the soaked syrup and stored in sealed plastic containers at 8 °C until further analysis.

2.3. Samples preparation

Among the nine samples examined in this study, four commercial sweet egg yolk drop samples (sample codes A, B, C, and D) were obtained from different retailers in Bangkok, Thailand. Samples were collected from three types of Thai dessert shop: a local market, a traditional shop, and a chain bakery. The selection criteria include appearance, retail positioning (price and location), and establishment type (including well-known dessert stores). For the remaining samples (four experimental desserts), the sugar content in both the cooking and soaking syrups was reduced by 50 % (w/w) from that of the control formulation, as shown in Table 1. The samples were partially substituted with FOS mixed with low-calorie sweeteners (erythritol, mannitol, sorbitol, and tagatose) at a ratio of 25:25 (w/w), using the following sample codes: E50, M50, S50, and T50, respectively. All samples were stored in sealed plastic containers and kept at 8±2 °C until further analysis.

2.4. Measurement of physical properties

The color measurements were performed using a HunterLab colorimeter (ColorFlex 45/0; Hunter Associates Laboratory Inc., Reston, VA., U.S.A.) with a D65 illuminant at 10° observation and reported as the CIELAB parameters (L*, a*, and b* values). Each dessert sample was arranged in a set of five pieces and placed in a glass container. The second measurement was performed by rotating the sample 90° and averaging the two directions. The mean values were calculated and reported based on three replicate measurements.

Water activity (a_w) was determined in triplicate using a water activity meter (Aqualab®, Series 4 TE, Decagon, USA). Dessert diameter (cm) was measured using a digital Vernier caliper (Model 500-150-30; Mitutoyo, Japan) and analyzed in ten replicates. Bulk density was determined using the seed displacement method with five replicate measurements, based on a slight modification of Zhuang et al. (2010) [27]. The weights of the dessert samples (five pieces) and the volume displaced by the extra sesame seeds were calculated as weights per volume (g/cm^3).

The textural properties of the dessert samples were analyzed using a TA-XT Plus Texture Analyzer (Stable Micro System, Texture Technologies Corp., NY, USA). A compression probe (P/35: aluminum cylinder) was used to determine the textural parameters (hardness (N) and cohesiveness). The conditions of texture analysis were as follows: pre-test speed (5.0 mm/s), test speed (2.5 mm/s), post-test speed (5.0 mm/s), distance (8.0 mm), and force 5 g. Ten pieces from each sample were analyzed.

Table 1
Formulation of experimental sweet egg yolk drops.

Ingredient		F100[a]	E50	M50	S50	T50
Duck egg yolk (%)		77.0	77.0	77.0	77.0	77.0
Rice flour (%)		23.0	23.0	23.0	23.0	23.0
Cooking syrup						
	Water (%)	37.5	37.5	37.5	37.5	37.5
	Sugar (%)	62.5	31.25	31.25	31.25	31.25
	Sweeteners[b] (%)	–	15.625	15.625	15.625	15.625
	FOS (%)	–	15.625	15.625	15.625	15.625
Soaking syrup						
	Water (%)	50.0	50.0	50.0	50.0	50.0
	Sugar (%)	50.0	50.0	50.0	50.0	50.0
	Sweeteners[b] (%)	–	25.0	25.0	25.0	25.0
	FOS (%)	–	25.0	25.0	25.0	25.0

Abbreviations: FOS = fructooligosaccharides.
[a] F100 = Full-sugar dessert (control).
[b] Sweeteners: E50, erythritol; M50, mannitol; S50, sorbitol; T50, tagatose.

2.5. Measurement of chemical properties

The moisture content of dessert samples was determined based on method 925.10 of the Association of Official Analytical Chemists (AOAC) [28]. The samples (3 ± 0.0002 g) were initially weighed in pre-dried and pre-weighed aluminum pans, and dried to a constant weigh in a vacuum oven (BINDER VD 115, Tuttlingen, Germany) at 70 °C under pressure ≤100 mm Hg.

The reducing sugar content was determined using a titration method following method 925.36 of the AOAC [29]. The ground dessert samples (10 g) were mixed with 150 mL distilled water, and boiled in a water bath 70 °C for 20 min, then added distilled water to complete the volume to 250 mL, and filtered through a Whatman No. 4 filter paper. After filtration, the water extract was collected for titrated with standard copper sulfate in alkaline tartrate (Fehling's) solution under boiling conditions. The results are expressed as the amount of invert sugar per 100 g of sample.

Sucrose content was analyzed using high-performance liquid chromatography (HPLC) based on method 977.20 of the AOAC, with slight modifications [29]. The ground dessert samples (5 g) was extracted with 25 mL of 1:1 water/ethanol and boiled in a water bath 70 °C for 20 min. The extraction was centrifuged at 3200 g for 4 min. Then, the supernatant was filtered through a 0.45 μm glass microfiber filter before HPLC analysis. The separation was achieved using a HPLC-system (Waters ALLIANCE e2695) consisting of a carbohydrate column (4.6 × 250 mm, 4 μm particle size) with a Carbohydrate Sentry Guard column (60 Å, 3.9 × 20 mm, 4 μm particle size) and refractive index (RI) detector. Elution conditions: A mobile phase of acetonitrile and water (75:25, v/v) was used at an isocratic flow rate of 1.0 ml/min were used. The column was maintained at 30 °C. All analyses were performed in triplicate.

2.6. Sensory and emotional evaluation

The sensory and emotional responses to all the dessert samples were investigated in two stages. The first step was to develop and generate emotional experiences of the dessert samples, whereas the second step was to evaluate the sensory preferences and emotional responses evoked by consumers. This study was approved for ethical clearance by the Ethics Committee for Human Research of Ramkhamhaeng University, Bangkok, Thailand (RU-HRE 63/0058). The recruited consumers (aged 20–60 years) were familiar with the product, had no egg allergies, and had no risk of diabetes. Sensory and emotional evaluations were conducted at Ramkhamhaeng University, Department of Science Service (Bangkok, Thailand), and Sukhothai Thammathirat Open University (Nonthaburi, Thailand).

To generate the emotion lexicons of the dessert samples, focus group discussions and emotion term selection were used as the first steps. Sixteen consumers (untrained panelists) were recruited and divided into two groups: brainstorming and discussion. A sample from each commercial and experimental dessert was served to the panelists. In the focus group, panelists expressed their emotional experiences (before, after, and during dessert consumption), which were evaluated in terms of the EsSence Profile® [30], to develop the initial emotional terms for desserts. All emotions were rechecked and approved by the 50 participants using the check-all-that-apply (CATA) method. As they tested the sample, the participants were asked to evaluate the level of feeling associated with each initial emotional term. Emotions evoked by more than 50 % of the respondents were selected for further consumer study [22, 31].

In the consumer study (n = 150), a sample of commercial desserts (A, B, C, and D) and a control (F100) represented full-sugar desserts, whereas experimental desserts (E50, M50, S50, and T50) represented low-sugar desserts supplemented with sweeteners. A consumer received a dessert set consisting of three different types of dessert (three pieces each), one of which was randomly selected from a full-sugar dessert and/or low-sugar dessert with added sweeteners. For the experimental desserts, consumers were not provided with information regarding the sweeteners used in each sample before testing; rather, they were only informed that the desserts

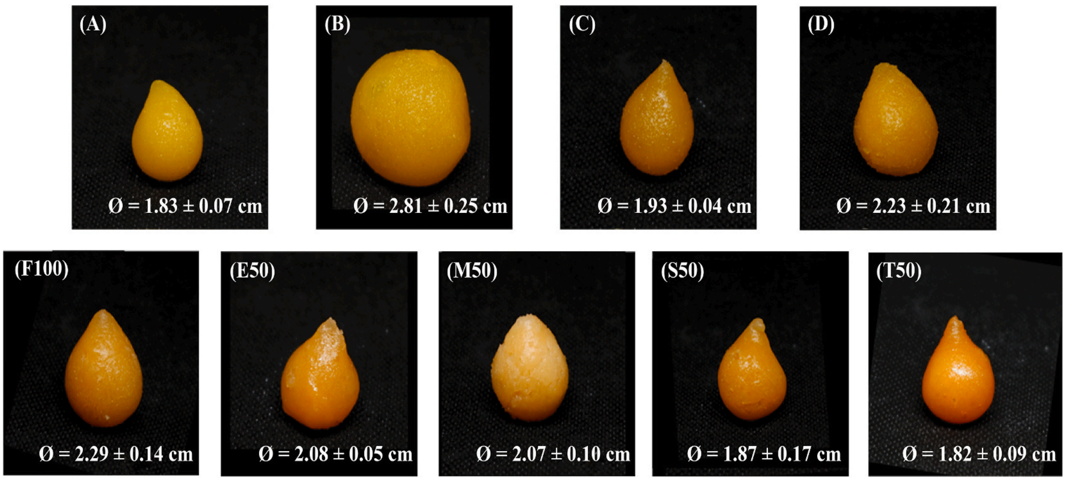

Fig. 1. Photograph of commercial (A–D) and experimental desserts: 25 % low-calorie sweeteners (erythritol: E50, mannitol: M50, sorbitol: S50, and tagatose: T50) combined with 25 % FOS in reduced-sugar syrup (50 %) and full-sugar formulation (F100).

contained reduced sugar and substitute sweeteners. For the product acceptance tests, consumers were asked to rate the samples on a 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely) for seven attributes: appearance, color, overall flavor, sweetness, juiciness, firmness, and overall liking. Consumers' emotional responses were assessed using a five-point intensity scale (1 = not at all, 3 = moderate, 5 = extremely) based on the emotion terms acquired from the first step.

2.7. Statistical analysis

Experimental data were analyzed using analysis of variance (ANOVA) in the SPSS© statistical package (version 12.0; SPSS (Thailand) Co., Ltd., Bangkok, Thailand). Duncan's Multiple Range Test was used to determine multiple comparisons of mean values, with statistically significant differences established at $p \leq 0.05$. For PCA and hierarchical cluster analysis (HCA) were performed using XLSTAT® software (XLSAST® 2021, a trial version from Addinsoft Inc., NY, USA).

3. Results and discussion

3.1. Physicochemical properties

The characteristics of the nine sweet egg yolk drops (commercial and experimental) are shown in Fig. 1(A–D). The images show the differences in the shapes and sizes of the samples. The most common shape in commercial desserts (samples A, C, and D) was a teardrop shape, but some brands created spherical shapes (sample B) with mean diameters ranging 1.83–2.81 cm. The substitution of sucrose with different sweeteners (erythritol (E50), mannitol (M50), sorbitol (S50), or tagatose (T50) mixed with FOS) resulted in a decrease in the size of the experimental samples compared to the control (F100). It is possible that the reduced sugar content and the differences in physicochemical properties of the sweeteners in the syrup changed the size of the dessert, as well as its formation and setting during cooking. In general, desserts are teardrop-shaped and have a smooth, soft, and glossy texture on the inside and outside, without a fishy odor. Thus, all the experimental samples were intended to have characteristics similar to those of most commercial dessert samples.

The physicochemical properties of sweet egg yolk drops are listed in Table 2. The color of all the dessert samples was yellowish-orange, which could be due to the pigment contained in the duck egg yolks (some commercial samples contained both duck and chicken egg yolks in varying ratios). The lightness values of the desserts ranged from 41.61 to 54.66 The redness values were from 10.43 to 24.85, and the yellowness values ranged from 35.36 to 50.63. The control dessert (F100) and desserts containing low-calorie sweeteners and partially reduced sugar had different color values ($p \leq 0.05$), which may be due to the characteristic property of non-reducing sugars in polyol sweeteners [32]. The highest browning color was observed in the T50 samples containing tagatose sweeteners. The color of T50 was dark red-brown, with the lowest L* (41.61) and the highest a* (24.85) values. This color change is caused by the chemical properties of tagatose, a reducing sugar that readily undergoes the Maillard reaction at elevated temperatures [32].

Reducing sugars, mainly mono- and disaccharides containing terminal aldehydes or ketone groups, react with amino acids to produce Maillard reaction products, leading to progressive browning. Because sucrose is a non-reducing sugar and a polyol sweetener [33], changes in pH and/or temperature during food production can hydrolyze sucrose into glucose and fructose [34], which are both reducing sugars. As shown in Table 2, the four commercial desserts contain different amounts of reducing sugar (0.58–2.76 g/100 g) and sucrose (39.10–54.27 g/100 g) due to the differences between the ingredients of the desserts. In contrast, the partial substitution of sugar with polyols and FOS resulted in higher levels of reducing sugars (0.71–0.78 g/100 g) due to a lower content of sucrose (20.23–23.47 g/100 g), compared to a control (F100: 0.70 g/100 g and 41.80 g/100 g, respectively). This was because the FOS can be degraded into monomers (i.e., glucose, fructose) and dimers (sucrose) at a temperature of 90–100 °C and a pH of 2.7–3.3 [35,36]. Tagatose provides desserts with the highest levels of reducing sugars (11.23 g/100 g) because of its unique properties as a reducing

Table 2
Physicochemical properties of commercial and experimental sweet egg yolk drops.

Properties		Commercial dessert samples				Experimental dessert samples[a]				
		A	B	C	D	F100	E50	M50	S50	T50
Color:	L*	54.66^{a}	43.50^{de}	44.70^{cd}	46.38^{bc}	47.88^{b}	48.31^{b}	54.08^{a}	52.04^{a}	41.61^{e}
	a*	13.04^{g}	10.43^{h}	15.38^{f}	10.70^{h}	21.31^{c}	17.68^{e}	19.58^{d}	23.35^{b}	24.85^{a}
	b*	50.63^{a}	43.92^{b}	37.91^{cde}	35.64^{de}	38.03^{cd}	35.36^{e}	38.70^{c}	44.50^{b}	36.36^{cde}
a_w		0.895^{ab}	0.835^{d}	0.822^{e}	0.857^{c}	0.898^{a}	0.862^{c}	0.889^{b}	0.894^{ab}	0.892^{b}
Diameter (cm)		1.83^{d}	2.81^{a}	1.93^{d}	2.23^{b}	2.29^{b}	2.08^{c}	2.07^{c}	1.87^{d}	1.82^{d}
Bulk density (g/cm^3)		0.99^{d}	1.52^{a}	0.87^{e}	0.75^{f}	1.02^{d}	1.19^{c}	1.31^{b}	1.07^{cd}	1.10^{cd}
Texture:	Hardness (N)	4.66^{ef}	9.69^{cd}	4.34^{f}	5.34^{ef}	9.35^{d}	12.89^{bc}	21.18^{a}	13.28^{b}	8.12^{de}
	Cohesiveness	0.56^{a}	0.43^{bc}	0.42^{bc}	0.62^{a}	0.45^{b}	0.37^{c}	0.24^{d}	0.36^{c}	0.42^{bc}
Moisture content (%wb)		32.96^{c}	34.12^{b}	30.32^{d}	34.87^{ab}	35.87^{a}	34.28^{b}	32.08^{c}	34.82^{ab}	32.24^{c}
Reducing sugar (Invert sugar g/100 g)		0.58^{f}	2.76^{b}	1.04^{d}	1.20^{c}	0.70^{ef}	0.78^{e}	0.77^{e}	0.71^{ef}	11.23^{a}
Sucrose content (g/100 g)		39.10^{d}	54.27^{a}	53.40^{b}	52.73^{b}	41.80^{c}	23.47^{e}	22.50^{f}	20.23^{g}	23.76^{e}

The technical terms of the color parameters in the CIELAB system are L* (lightness), a* (redness), and b* (yellowness).
Means with different superscript letters in the same row are significantly different ($p \leq 0.05$).
[a] Experimental dessert samples: full-sugar dessert, F100; desserts reduced in sugar by 50 % and containing 25 % erythritol, E50; mannitol, M50; sorbitol, S50; and tagatose, T50 mixed with 25 % FOS.

sugar [37].

Moisture content, which is related to the a_w value, is a crucial factor in assessing the shelf life of desserts. Commercial desserts and desserts containing sugar substitutes had a_w between 0.822 and 0.895, and moisture contents ranged from 30.32 to 35.87 % wet basis, (wb), which are classified as intermediate moisture foods (IMF: a_w = 0.6–0.9 and moisture content = 10–50 % [38,39].

3.2. Textural properties

The hardness and cohesiveness values were used to describe the textural characteristics of the samples. All commercial samples exhibited hardness values in the range 4.34–9.69 N as shown in Table 2. There are several textures of different dessert samples, depending on their size, shape, and ingredients (for example, flour is either rice flour, tapioca flour, or arrowroot flour; egg yolks are duck and/or chicken egg yolks, as well as sweeteners and sugar solution concentrations). Generally, sweet egg yolk drops are distinguished by their unique appearance, owing to the use of an egg yolk batter that is dropped into boiling, teardrop shaped sugar syrups. During immersion cooking in sugar-water solutions, the starch and protein in the egg yolk batter droplets expand and swell as they absorb water molecules. Sucrose exhibits a significant interaction with starch and proteins because of the decrease in the adsorbed water content, leading to an increase in both the starch gelatinization temperature and protein denaturation temperature [40,41]. An increase in both temperatures restricts starch granule swelling and prematurely inhibits the unfolding of protein molecules [42,43]. This results in a more stable expansion of the batter, allowing the outer layers to gradually form before the dessert shape begins to set under the influence of high sucrose concentrations (approximately 70 ± 2 °C , 95 ± 2 °C).

The replacement of sucrose with erythritol and sorbitol (E50 and S50) tended to increase the hardness values more than the control (F100). M50 had the highest hardness value (21.18 N), and there was no significant difference between the hardness values of T50 and F100 ($p > 0.05$), as shown in Table 2. Partial substitution of sugar with low-calorie sweeteners may alter the textural properties of the dessert product, leading to differences in their physicochemical properties, including molecular weight (MW), number of equatorial and exocyclic hydroxyl groups, molar volume density of effective hydroxyl groups ($N_{OH,s}/v_s$), and hygroscopicity. The polyol sweeteners used in this experiment were erythritol (MW = 122 g/mol; $N_{OH,s}/v_s = 0.0327$ mol/cm^3), sorbitol (MW = 182 g/mol; $N_{OH,s}/v_s = 0.0280$ mol/cm^3), and mannitol (MW = 182 g/mol; $N_{OH,s}/v_s = 0.0292$ mol/cm^3), which have lower molecular weight and higher $N_{OH,s}/v_s$ than sucrose (MW = 342 g/mol; $N_{OH,s}/v_s = 0.0214$ mol/cm^3) [44–46]. Thus, polyol sweeteners are capable of forming intermolecular hydrogen bonds and penetrating starch granules/protein molecules more effectively than sucrose, resulting in delayed gelatinization and denaturation temperatures owing to restricted water accessibility to starch-protein mixtures [47]. A similar phenomenon occurs with sucrose, but polyol sweeteners have a significant impact (depending on their type, concentration, amount, and processes of use), resulting in smaller droplets and a harder texture because the batter droplets do not fully expand before setting. Owing to its nearly identical physicochemical properties (MW and $N_{OH,s}/v_s$) to sorbitol, mannitol has relatively low water solubility and is easily crystallized [48]. Mannitol crystallizes rapidly upon cooling, resulting in desserts with the hardest outer surfaces. Tagatose, a low-calorie rare sugar, has hygroscopicity and viscosity similar to sucrose [49,50], and desserts containing tagatose are likely to have the same textural properties as controls. Moreover, the presence of FOS in syrup is associated with an increase in soluble dietary fiber, which has a high-water retention capacity, as well as reduced starch water absorption and protein matrix mobility [51,52]. Renuka et al. [53] reported that Gulab Jamun desserts, which have a production process similar to that of sweet egg yolk drops, exhibit increased hardness when soaked in FOS syrups.

The presence of polyol sweeteners, especially mannitol, in the syrup affects the cohesiveness of desserts (Table 2). The different physicochemical characteristics (for example, hygroscopicity and crystallization) of polyol sweeteners may lead to reduced cross-linking or enhanced interference between network structures, resulting in a decrease in product cohesiveness. A similar result was observed in a study using mannitol and soluble wheat fiber to create low-calorie gummy candies [48], and in a study using erythritol and sorbitol to replace sucrose in muffins [40].

3.3. Sensory evaluation

The sensory acceptability of all the desserts was evaluated using a 9-point hedonic scale (Table 3). Samples A and C received high

Table 3
Sensory properties of commercial and experimental sweet egg yolk drops.

Attributes	Commercial dessert samples				Experimental dessert samples[a]				
	A	B	C	D	F100	E50	M50	S50	T50
Appearance	7.2^{a}	5.5^{bcd}	7.1^{a}	5.7^{bc}	6.3^{ab}	4.6^{de}	4.2^{e}	6.8^{a}	5.2^{cd}
Color	7.3^{a}	5.8^{cd}	6.8^{ab}	6.4^{bc}	6.6^{abc}	5.2^{de}	4.8^{e}	7.1^{ab}	5.0^{de}
Odor	7.0^{a}	5.5^{b}	7.0^{a}	6.2^{b}	6.8^{a}	4.5^{c}	5.3^{bc}	6.0^{b}	5.5^{b}
Sweetness	6.3^{ab}	5.2^{bc}	6.4^{a}	6.0^{abc}	6.0^{abc}	3.7^{d}	5.1^{c}	6.0^{abc}	5.0^{c}
Juiciness	7.3^{a}	5.5^{c}	6.6^{ab}	5.9^{bc}	6.1^{bc}	3.9^{d}	5.3^{c}	6.6^{ab}	5.3^{c}
Firmness	6.7^{a}	5.3^{c}	6.9^{a}	5.6^{bc}	6.3^{ab}	3.5^{d}	4.7^{c}	6.9^{a}	5.3^{d}
Overall liking	7.3^{a}	5.5^{de}	7.1^{ab}	5.9^{cd}	6.7^{ab}	4.1^{f}	4.8^{ef}	6.4^{b}	5.7^{cd}

Means with different superscript letters in the same row are significantly different ($p \leq 0.05$).

[a] Experimental dessert samples: full-sugar dessert, F100; desserts reduced in sugar by 50 % and containing 25 % erythritol, E50; mannitol, M50; sorbitol, S50; and tagatose, T50, mixed with 25 % FOS.

scores for all liking-related qualities, including appearance, color, odor, sweetness, juiciness, firmness, and overall liking. These attributes were rated by consumers as 'like slightly' to 'like moderately'. Notably, samples A and C (relatively high-priced products), obtained from a store chain with multiple branches (selling bakery items/Thai desserts) and an authentic Thai dessert shop, respectively, satisfied consumers. This may be due to the use of high-quality ingredients and a meticulous process to produce desserts with an attractive appearance, optimal sweet taste, and desirable texture. On the other hand, samples B and D (relatively low product prices), obtained from market stalls and dessert shops (which did not make their own products), had poor liking scores for all attributes.

When comparing sample F100 with samples E50, M50, and T50, which were partially sugar-substituted with a low-calorie sweetener, the liking scores significantly ($p \leq 0.05$) decreased in all sensory attributes, except for sample S50 (Table 3). In the case of erythritol, mannitol, and tagatose sweeteners, all the dessert attributes received the lowest scores, indicating that they are inappropriate for desserts. Consumers dislike desserts containing sugar substitutes because tagatose produces darker products. Insufficient sweetness was observed in erythritol products, whereas the use of mannitol in desserts led to crystallization in the crust and produced a rough texture. Additionally, these sweeteners alter the textural characteristics of desserts from traditional perception, which may negatively impact consumer preference. In terms of appearance, color, odor, sweetness, and overall liking, sorbitol was assessed as being more comparable to the control. The consumer ratings of samples F100 and S50 were similar to those of commercial samples A and C for all sensory qualities, except for odor and overall liking for sample S50 ($p \leq 0.05$).

3.4. Emotional responses to products

Based on the focus group discussion with 16 panelists, emotion terms related to the consumption of desserts with reduced sugar and sweetener substitutes were generated and screened. Before the consumer survey, the preliminary emotional terms from the panelists were reduced and cut-off pointed out by 50 consumers (terms with ≥50 % frequently mentioned) to obtain meaningful and unambiguous wording. A consumer survey was conducted by 150 consumers consisting of 30 emotions: 17 terms from the focus group, such as 'Ancient', 'Attractive', 'Auspicious', 'Disappointed', 'Healthy', 'Mysterious', 'Unhealthily', and 13 terms from the ESP template, such as 'Active', 'Bored', 'Disgusting', 'Friendly', 'Good', 'Happy', 'Secure', 'Worried', as shown in Table 4. These emotions can be categorized into 20 positive terms, such as 'Auspicious', 'Happy', 'Healthy', 'Natural', 'Sucre', and 10 negative terms, such as 'Averse', 'Bored', 'Disgusting', 'Unhealthy', 'Worried'. The aforementioned terms were measured using a 5-point intensity scale to evaluate consumers' expressed preferences regarding dessert consumption and collect their feelings and emotions.

Fig. 2 shows the results of a study on the intensity of customer emotions as they consume both commercial and experimental desserts with reduced sugar and different substituted sweeteners. The mean emotion intensities were determined at 20 % frequency (based on a 5-point intensity scale), which was used to describe and represent consumer emotions [30]. The results showed that 19 of the 20 terms associated with positive emotions correlated with full-sugar desserts (both commercial and F100 samples). All of these positive emotions had a high frequency of more than 30 % for example, 'Auspicious', 'Glad', 'Fresh', 'Attractive', 'Fancy', 'Loving', and 'Natural'. In contrast, the 9 out of 10 terms related to negative emotions were associated with low-calorie sweetener-containing desserts (e.g., 'Averse', Unattractive', 'Disappointed', 'Resentful', and 'Worried'). Interestingly, the customers expressed feelings of 'Healthy' when they were presented with reduced-sugar desserts containing sweeteners, whereas they expressed feelings of 'Unhealthy' after presented with full-sugar desserts. These results indicate that consumers expressed concern regarding their health when consuming extremely sweet desserts and that it is possible for consumers to feel more comfortable when eating desserts if they know that products contain fewer sugars but are still satisfied. This is consistent with the results of Wardy et al. [18], sensory properties (sweetness, taste, and texture) of muffins made with stevia and reduced sugar levels may directly influence consumer emotion. Reis

Table 4
Emotion terms in both full-sugar desserts[a] and low-sugar desserts supplemented with sweeteners[b] using in the consumer study.

Emotional terms		
Positive		Negative
Active[c]	Happy[c]	Averse[d]
Ancient[d]	Healthy[d]	Bored[c]
Attractive[d]	Humble[d]	Callous[d]
Auspicious[d]	Loving[c]	Disappointed[d]
Calm[c]	Merry[c]	Disgusting [c]
Fancy[d]	Natural[d]	Mysterious[d]
Fresh[d]	Polite [c]	Resentful[d]
Friendly[c]	Proud[d]	Unattractive[d]
Glad[c]	Relaxed[d]	Unhealthily[d]
Good[c]	Secure[c]	Worried[c]

[a] Emotion terms in full-sugar sweet egg yolk drop samples (Commercial, A–D; F100, control).

[b] Emotion terms in low-sugar sweet egg yolk drops supplemented with sweeteners (E50, M50, S50, and T50).

[c] Thirteen emotion terms were selected from the EsSence Profile® (King and Meiselman, 2010).

[d] Seventeen new emotional terms were created during the focus group discussion.

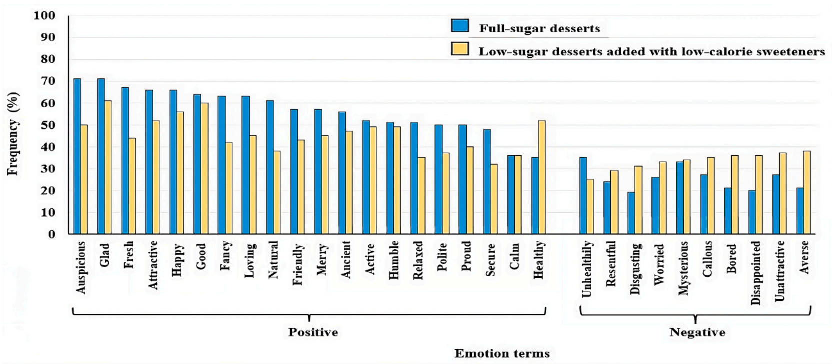

Fig. 2. Comparison of the mean emotion intensities of full-sugar and low-sugar desserts supplemented with sweeteners (n = 150).

et al. [54] also observed that consumer perceptions of physical health and emotional well-being are influenced by information regarding sugar content, statements regarding the absence of added sugar, and the use of natural sweeteners.

3.5. Preference mapping

The external preference mapping (EPM) was developed using PCA to investigate the relationship between dessert qualities and consumer preferences based on physicochemical properties, sensory properties, and emotional responses, as shown in Fig. 3(a). The PCA biplots revealed that the first PC (PC1: 50.25 %) and second PC (PC2: 28.56 %) explained 78.81 % of cumulative variance. Based on the information obtained from the loading factors, the PC1 was associated with some physical properties (L*, b*, a_w, and diameter) and reducing sugar values as well as most positive emotion terms, except for 'healthy' and 'active', which were negatively correlated with the PC1. PC2 correlated positively with the most negative emotional terms and all sensory attributes, including bulk density, texture profile (hardness), moisture content, and sugar content.

Moreover, the HCA method was used to categorize the dessert samples based on their quality and consumer preferences, resulting in the division of the samples into three groups (Fig. 3(b)). The first group consisted of four dessert samples: commercial A and C desserts, full-sugar desserts (F100), and reduced-sugar desserts mixed with sorbitol/FOS (S50), as shown in Fig. 3(a). This group was observed to be the most preferred by consumers, it was closely associated with the following factors that drivers of liking of desserts: e. g., yellowness (b*), cohesiveness, sensory attributes (appearances, sweetness, odor, juiciness) and positive emotion (e.g., 'Auspicious', 'Glad', 'Fresh', 'Attractive', 'Proud', 'Secure', 'Loving', 'Natural'). The second group (commercial desserts B and D) showed a positive correlation between diameter and sucrose content. The sucrose content of commercial dessert C was similar to that of samples B and D. However, the categorical analysis indicated that dessert C was grouped into the first group, which was influenced by consumer preference factors. For the third group (sample E50, M50 and T50) exhibit virtually all characteristics opposite to consumer preferences in terms of hardness, bulk density, reducing sugar, and especially have negative emotions (e.g., 'Averse', 'Disappointed', 'Disgusting', 'Resentful', 'Unattractive').

4. Conclusions

In this study, sugar reduction in syrup formulation and the addition of various types of sweeteners/FOS mixtures affected aspects related to the characteristics, texture, and sugar content, particularly the organoleptic properties of sweet egg yolk drops, which have an impact on emotional responses. The use of erythritol, mannitol, and tagatose (all of which have the same FOS ratio) as substitutes for sucrose does not seem to be an appropriate choice for this type of dessert because they have undesirable characteristics in terms of color, texture, and taste. The quality of the desserts was dramatically reduced when erythritol (E50), mannitol (M50), and tagatose (T50) were substituted in the syrup. These characteristics significantly influenced both the perception of negative emotions and the overall level of customer acceptance of desserts. However, the use of external preference mapping (EPM) and hierarchical cluster analysis (HCA) revealed that sorbitol desserts (S50) were present in two of the four commercial desserts and one control sample (F100). Furthermore, EPM techniques revealed that customers prefer those who have commercialized samples of ideal desserts (A and C) as well as reduced sugar desserts containing both FOS and sorbitol sweeteners. This technique also demonstrated that the main factors influencing customer preferences for desserts are appearance, yellowness, sweetness, cohesiveness, and juiciness, which caused consumers to feel good emotions ('Auspicious', 'Glad', 'Attractive', 'Secure', 'Loving', 'Natural'). Therefore, sorbitol and FOS are recommended as the most suitable sucrose substitutes for sweet egg yolk drops for the healthy dessert industries. In this study, the importance of information and/or claims regarding sweeteners, including detailed information on their use and benefits, led to a shift in emotional responses. This increases the likelihood that consumers will accept healthy dessert products. From this preliminary work, further studies are needed to optimize the ratio of sorbitol to FOS associated with reducing sugar levels to develop healthy and sweet egg yolk drops.

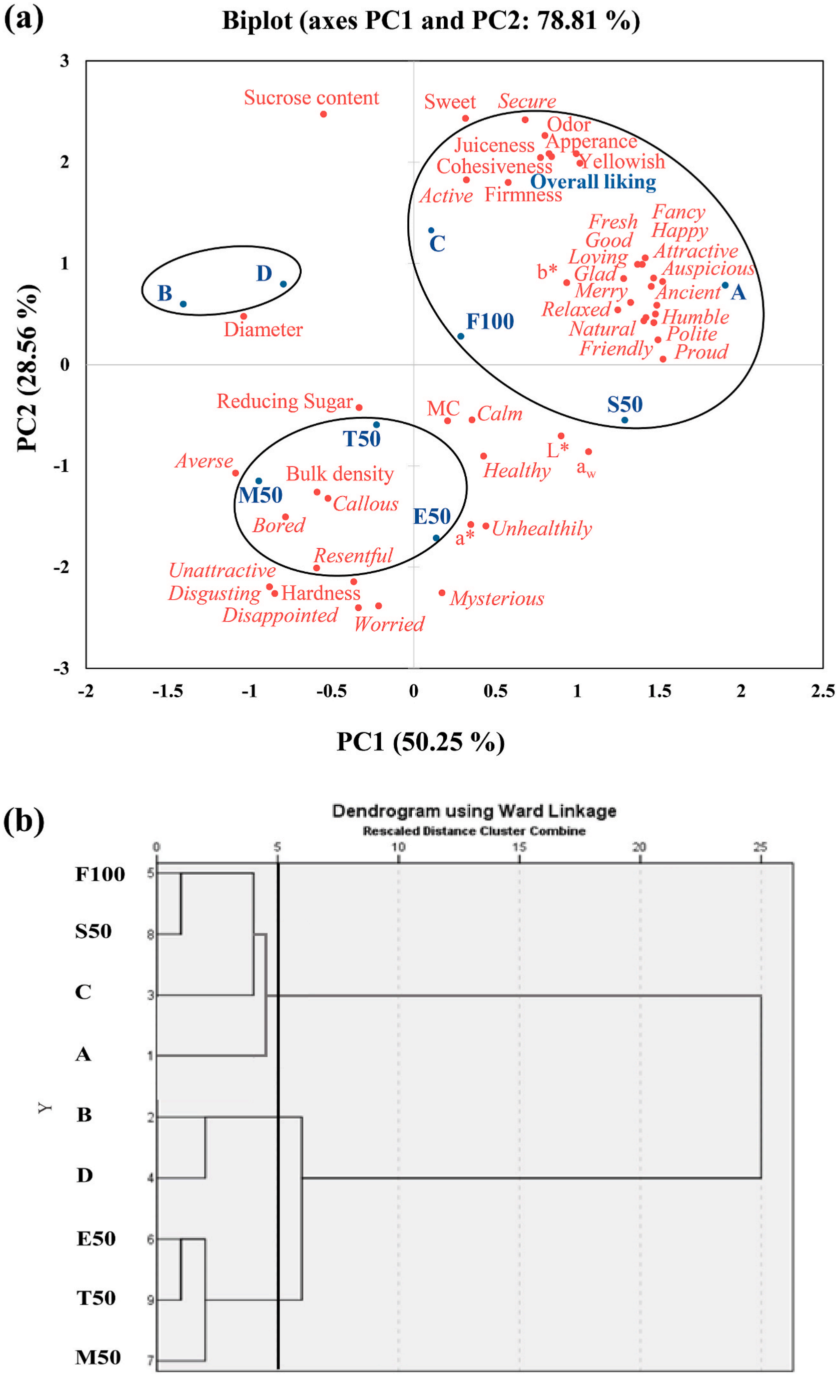

Fig. 3. (a) EPM of the variable properties of commercial desserts (A–D), experimental desserts (E50, M50, S50, and T50), and full-sugar desserts (F100). (b) HCA of the dessert samples.

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Ethics approval

This study was granted the ethics approval RU-HRE 63/0058 by the Ethics Committee for Human Research, Ramkhamhaeng

University, Bangkok, Thailand. All experiments were conducted according to established ethical guidelines. All participants were in agreement to participate in the sensory testing by signing an informed consent form.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

CRediT authorship contribution statement

Phanlert Promsakha na Sakon Nakhon: Writing – review & editing, Writing – original draft, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Montakan Aimkaew:** Validation, Methodology, Investigation, Formal analysis. **Saynamphung Tongsai:** Validation, Methodology, Formal analysis, Conceptualization. **Wannarat Leesuksawat:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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