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Research article

Exploring elderly perception and acceptance: Influence of different sugars and vanilla flavor in different food models

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Abstract

Importance of the work: The cross model of flavor and taste in different food model could be a guideline for the successful development of a reduced-sugar product.

Objectives: To investigate the vanilla recognition threshold and the effect of the presence of vanilla with different sugar types on sweetness perception and acceptance of the elderly toward different food models.

Materials & Methods: The vanilla recognition threshold in water, milk and coconut milk was obtained based on the three-alternative forced-choice test. Descriptive analysis was used to interpret the sensory profiles of different sugars in all three food models. Consumer acceptance tests were conducted to observe the levels of acceptance and perception by the elderly regarding the samples.

Results: The perception by the elderly participants of vanilla flavor varied depending on the food model. The recognition threshold of vanilla in water was 0.2%. Milk required a slightly higher concentration (0.4%) for most participants to perceive the vanilla flavor. Coconut milk, which has a strong and distinctive flavor, required the highest concentration (2.0%) to recognize the vanilla flavor. Descriptive analysis was used to study the flavor profile. The results showed that in all food models, the intensity of sweetness and sweet aromatic tended to decrease with decreasing sugar content. The elderly perceived differences in sweetness between different types of sugar; however, their preference for the sweetness of the samples was not affected by the sugar type used.

Main finding: The recognition thresholds for the vanilla flavor in different food models were obtained and could be applied to attempt to reduce the sugar content by 10–15% in food products based on water, milk or coconut milk.

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Introduction

The United Nations has defined a fully aging society as one when the proportion of the population aged 60 yr and over has increased to 20% (World Health Organization, WHO), 2017). Currently, Thailand is approaching an aging society, with an average elderly population of approximately 9 million people out of 60 million (WHO, 2023). With age, the human body's performance deteriorates, especially regarding taste perception (Alia et al., 2021). This might be a cause of overnutrition that can lead to diabetes and other chronic diseases. Many governments, in both developed and developing countries, have placed increasing emphasis on the quality of life associated with eating, with regulations being introduced for two product categories (Solid Fat and Added Sugar Food) that are increasingly playing a role in consumer health (U.S. Department of Health and Human Services and U.S. Department of Agriculture, 2015). Foods with added sugar can be divided into six categories: sweets, non-alcoholic beverages, bakery products, alcoholic beverages, dairy products and condiments such as ketchup and salad dressings. At present, there are many food and beverage products at use sugar substitutes as sweeteners; however, these may adversely affect the health of consumers in the long term and (unlike sugars) some sweetener have an undesirable aftertaste (Schiano et al., 2021).

Cross-modal interactions have been studied, with the results indicating that the perception of flavor intensity was influenced by taste and aroma interactions, especially when the aroma and taste are closely related (Noble, 1996); for example, a sweet taste is linked to vanilla, which is the most popular flavoring ingredient of food in the world (Gallage and Møller, 2018)). Natural vanilla scent is extracted from pods of orchids in the genus *Vanilla* and consists mainly of vanillin and approximately 200 other molecules (Ehlers and Pfister, 1997; Rao and Ravishankar, 2000). The vanillin content found in most vanilla pods is approximately 2–2.5% (Walton et al., 2003). The effect of vanilla as sweetener, such as the use of vanilla in dairy products, was studied by Mahato et al. (2020), who reported on the research conducted in China and Denmark, where adding vanilla aroma into samples with non-caloric sweeteners boosted the perceived sweetness, particularly for tastes resembling sucrose. These findings suggested that combining the vanilla aroma with non- or low-calorie sweeteners may reduce the sugar content effectively for certain consumers and sweeteners (Bertelsen et al., 2021). The cross model for taste-odor-texture interactions has been explored to reduce sugar in children's milk desserts, with the results showing that increasing the vanilla flavor and viscosity improved the level of liking for most children, suggesting that leveraging cross-modal interactions could aid larger reductions in the sugar content, supporting gradual sugar reduction efforts (Velázquez et al., 2020).

Hence, the current research aimed to investigate the interplay between taste and aroma on sweetness perception, particularly the influence of natural flavor enhancers, such as vanilla extract, with a focus on the cultural context of Thai desserts and beverages. These traditional treats often utilize various sugars (white, brown and coconut) across different food bases (water, milk and coconut milk). The goal was to expand the possibilities for sugar reduction in food and drink items, while still ensuring they retained the sensory characteristics preferred by consumers.

Materials and Methods

Materials

Raw materials

The main raw materials were: natural vanilla extract (McCormick; USA), drinking water (Nestlé; Thailand), full fat pasteurized milk (CP Meiji; Thailand), ultra-high temperature treated coconut milk (Aroy D; Thailand), granulated white sugar (Mitr Phol; Thailand), brown sugar (Mitr Phol; Thailand) and coconut sugar (Lin; Thailand).

Consumer panel

The screening criteria were: age 60 years or older, not residing in a care facility for the elderly, ability to read, listen and write in Thai, capable of independently carrying out daily activities and not suffering from any illness that would prevent participation in the test.

Sample determination and sample preparation.

Sample determination was done according to the market survey of sugar content in food products, with black grass jelly, sweetened milk and pandan noodles with coconut milk ('lod chong' in Thai) as representatives for water, milk and coconut milk models, respectively. The three representatives were selected based on popularity of the product among Thai consumers (The Bangkok Insight, 2018). Five commercial products were sampled from different types of retailers (fresh market,

convenience store and a supermarket) in the Bangkok area. Of the commercial items, the black grass jelly products had sugar contents in the range 5–27%, while the sweetened milk products had a range of 5.5–12% and the highest sugar content was in the lod chong product with the range in sugar being 10–20%. The initial sugar concentrations were determined based on the common sugar content found in the existing products. If the sugar contents varied, the midpoint of the sugar content range found in the commercial products was used as the initial sugar content. As a result, 10% sugar was applied as the initial sugar content for the water and milk models while coconut milk was prepared with 15% sugar. The effect of sugar content was studied by decreasing the sugar concentrations in 0.5% steps to produce six levels from the initial concentration. The treatment conditions are shown in Table 1.

Samples were prepared according to Table 1 and then stored and served at 8–12°C. The samples were served one sample at a time; during the break between samples, each elderly consumer was asked to mouth rinse with drinking water. The series of water model samples was served first, followed by the milk model samples, with the final servings being the coconut milk model samples due to their complexity in taste, flavor and aftertaste. The serving order within the same type of food model was randomized using William's square design (Wang et al., 2009).

Methods

Investigation of vanilla flavor recognition threshold in different food models

A three-alternative forced-choice approach was conducted using 30 elderly people aged 60 years and over. Vanilla flavor was added on a volume per volume (v/v) basis at 0.00625%, 0.0125%, 0.025%, 0.050%, 0.1%, 0.2%, 0.4% and 0.8% in the water model. In the milk and coconut milk models, vanilla flavor was added on a v/v basis at 0.025%, 0.050%, 0.1%, 0.2%, 0.4%, 0.8%, 1.6% and 3.2%. The concentration of the test substance was doubled in each subsequent sample presentation. Then, the individual best estimation threshold (individual BET) and the group BET at 50% of the population were calculated. Threshold values were log-transformed before analysis, as recommended (International Standard Organization, 2002; ASTM, 2011). In addition, individual elderly BET detection values were calculated to determine the overall elderly sensitivity range. The elderly BET detection values for the vanilla flavor in water, milk and coconut milk were calculated from the average of each elderly BET detection value.

Effect of different types of sugar on sweetness, overall sweet impression and vanilla flavor intensity in different food models.

The effect of the type of sugar (white sugar, brown sugar or coconut sugar) on sweet-related sensory attributes was investigated in different food models (water, milk or coconut milk). A randomized complete block design was applied, with sugar concentration being the independent variable to observe the effect of vanilla flavor and sugar reduction within the same type of food model, while the block parameter was consumer. The details of the tested samples in each food model are shown in Table 1.

The study of sensory profiles was based on a descriptive analysis adapted from Keane (1992) and the same method used in other studies (Cherdchu et al., 2013; Ledeker et al., 2014, Rosales and Suwonsichon, 2015, Pujchakarn et al., 2016, Rosales et al., 2018, Noidad et al., 2019, Soontrunnarudrungsri et al., 2023). The test participants were nine people belonging to the Kasetsart University Sensory and Consumer Research Center (KUSCR), who were trained for 120 hr on conducting descriptive sensory testing and had each accumulated at least 20,000 hr experience in testing various products. The trained panel developed a vocabulary set that was used to describe the flavors of the test samples. Orientation on determining intensity ratings using reference samples was used as the basis for comparison. All panelists were trained until they could provide the consistent scores with different scores in the range of not more than 1.0 point. Each product testing session for flavor profiling used a linear scale with a score of 0–15 (0 = none and 15 = extremely high).

Table 1 Conditions of test samples for each food model

Food model	Vanilla (%)	Sugar type	Sugar content (%)	Note
Water	0	Granulated sugar, Brown sugar, Coconut sugar	10.0	Control sample
	0.2	Granulated sugar, Brown sugar, Coconut sugar	10.0, 9.5, 9.0, 8.5, 8.0, 7.5, 7.0	Test samples
Milk	0	Granulated sugar, Brown sugar, Coconut sugar	10.0	Control sample
	0.4	Granulated sugar, Brown sugar, Coconut sugar	10.0, 9.5, 9.0, 8.5, 8.0, 7.5, 7.0	Test samples
Coconut milk	0	Granulated sugar, Brown sugar, Coconut sugar	15.0	Control sample
	2.0	Granulated sugar, Brown sugar, Coconut sugar	15.0, 14.5, 14.0, 13.5, 13.0, 12.5, 12.0	Test samples

The obtained data were analyzed using the SPSS 22.0 statistical software (IBM Inc.; Chicago, IL, USA). The analysis applied descriptive statistics, analysis of variance and multiple comparisons (Duncan's multiple range test) at $\alpha = 0.05$.

Elderly acceptance and perception towards different food models prepared with different types of sugar.

A study was conducted on the acceptance and sweetness perception of elderly consumers toward different types of sugar (white sugar, brown sugar or coconut sugar) with the presence of vanilla in the food model (water, milk or coconut milk). In total, 50 elderly participants were used, with some of them having also participated in the recognition test. The elderly responded to a self-administered questionnaire. The questionnaire was divided into two parts: demographic questions and product testing. The samples were presented for testing using the blind, sequential monadic method.

The product testing consisted of perceived intensity based on an intensity score from 0 to 15 where 0 = not present and 15 = extremely high. Elderly acceptance toward samples was based on a 9-point hedonic scale where 1 = extremely dislike and 9 = extremely like. The samples were presented for testing using the blind, sequential, monadic method and each consumer was asked to rate each sample using the 9-point hedonic scale.

The data were analyzed using the SPSS 22.0 statistical software (IBM Inc.; Chicago, IL, USA), The analysis applied descriptive statistics, analysis of variance and multiple comparisons (Duncan's multiple range test) at $\alpha = 0.05$.

Ethics statement

This study was approved by the Ethics Committee of Kasetsart University, Bangkok, Thailand (Approval no. COE66/094).

Results and Discussion

Investigation of vanilla flavor recognition threshold in different food models

The group BET at 50% of the population was 229.09, or a concentration of 0.2% vanilla flavor in the water samples. In addition, nine elderly participants were unable to correctly distinguish between these samples, even those at the highest concentration. The findings from milk model showed that the group BET at 50% of the population was 436.52, or a concentration of 0.4% vanilla flavor in the milk samples. Three elderly participants were unable to correctly distinguish between these samples at the highest concentration. The group BET at 50% of the population for the coconut milk model was 2,041.7, or a concentration of 2.0% vanilla flavor in the coconut milk samples, as shown in Table 2. Thirteen elderly participants were unable to distinguish between these samples at the highest concentration.

Table 2 Comparison of best estimate threshold (BET) value and elderly BET range values of vanilla concentration between different food models

Food model	Elderly BET range	BET	Concentration (%)
Water	4.42–1,131.37	229.09	0.2
Milk	17.68–4,525.48	436.52	0.4
Coconut milk	282.84–4,525.48	2,041.70	2.0

These results suggested that elderly people perceived vanilla flavor differently, depending on the type of food model it is presented in. This variability may be attributed to the complexity of flavors and the interaction between the vanilla flavor and the inherent taste and aroma of the specific food model (Gaonkar and McPherson, 2005). Water, being neutral in flavor and aroma, allowed for the perception of vanilla flavor even at a low concentration (0.2%). Milk, with its mild flavor, required a slightly higher concentration (0.4%) for most participants to perceive the vanilla flavor, while coconut milk, which has a strong and distinctive flavor, required the highest concentration (2.0%) for perception, and even then, a large portion of the elderly participants had difficulty distinguishing between samples. These findings highlighted the importance of considering the food matrix (the type of food and its properties) when studying flavor perception, especially in specific demographics such as the elderly.

Comparison of sweetness, overall sweet impression and vanilla flavor intensity of different food models prepared using different types of sugar.

The first step in the descriptive sensory testing was to define the terms that describe the sensory characteristics being tested. The definitions of each characteristic, along with reference samples used in the test, are shown in Table 3.

Table 3 Lexicon and definition of sample attributes

No.	Term	Definition	Reference	Reference preparation	Intensity
1	Sweet aromatic	Overall flavor of sample that gives a sweet feeling, such as flavor of fruits or flowers. (None-------High)	Brown sugar, Mitr Phol brand	20 g. of brown sugar 20 in 200 mL of water	3.5
				Brown sugar	5.5
2	Vanilla flavor	Specific flavor that consists of brown, sweet, and dry wood note. (None-------High)	Vanilla flavor, Winner brand	0.3 g of vanilla flavor in 200 ml of water	4.0
				0.8 g of vanilla flavor in 200 ml of water	6.5
3	Milk I.D.	Specific flavor of cow's milk that consists of milk, sweet and creamy sensation (None------High)	Full fat pasteurized milk, CP Meji brand	Full fat pasteurized milk (pure)	9.0
4	Coconut I.D.	Specific flavor of coconut that consists of sweet, floral, nutty, and may be mixed with brown note. (None-------High)	UHT coconut milk, AROY-D brand	UHT coconut milk (pure)	9.0
5	Brown sugar	Specific flavor of brown sugar that consists of sweet, aromatic, brown, caramel, molasses and may be mixed with dark brown, fermented. (None-------High)	Brown sugar, Mitr Phol brand	Brown sugar (pure)	7.0
6	Coconut sugar	Specific flavor of coconut sugar that consists of sweet, aromatic, brown, floral, caramel, coconut milk, and may be mixed with sour. (None-------High)	Coconut sugar, Lin brand	Coconut sugar (pure)	5.5
7	Sweetness	Fundamental taste when stimulated by sugar or sweeteners. (None-------High)	Granulated sugar, Mitr Phol	5.0% Sucrose solution	5.0
				10.0% Sucrose solution	10.0
				16.0% Sucrose solution	15.0

For the water models with added brown sugar, a brown sugar concentration of 8.5% and vanilla at the lowest sugar concentration was not significantly different in sweet aromatic and sweetness intensity from the control solution, which contained 10% brown sugar. For the water models with added coconut sugar, 10% coconut sugar solution was the lowest concentration with added vanilla that had the same sweetness intensity as the control sample (10% coconut sugar), as shown in Table 4.

Table 5 presents the flavor profile of the cow's milk models with vanilla (0.4%) and varying sugar types (white, brown or coconut) at concentrations in the range 7–10%. With decreasing white sugar concentration, samples with added vanilla maintained higher sweetness and aroma intensity compared to the control samples with a higher sugar content. Significant sweetness differences were noted between the control and vanilla-added samples. Milk models with vanilla and brown sugar matched the control samples for sweetness and aroma at the 9.5% brown sugar concentration. Similarly, samples with vanilla and 9.5% coconut sugar had sweetness parity with the control samples, with no significant difference in aroma intensity.

Descriptive sensory testing of the coconut milk samples with various types of sugar, was prepared with 15% sugar (based on a survey of sugar content in market products) and was reduced by 0.5% increments to a minimum sugar concentration of 12%. The results of the study of the flavor profile of the coconut milk model showed that the samples of the model with added white sugar had an intensity of the sweetness of the sample with 13% sugar that was not significantly different from the sweetness of the control sample. The sweetness of the control sample prepared with brown sugar was not significantly different from the sample at a concentration of 14%. However, when coconut sugar was added to the coconut milk model, no significant differences were recorded in the intensity of sweet aromatic and sweetness of the sample with 13% sugar, as shown in Table 6.

Table 4 Average intensity score obtained from descriptive analysis of water model with different concentrations of granulated sugar, brown sugar and coconut sugar

Type of sugar	% Sugar	Attribute				
		Sweet aromatic	Vanilla flavor	Sweetness	Brown sugar I.D.	Coconut sugar I.D.
Granulated sugar	Control	0.00±0.00^{b}	0.00±0.00^{b}	9.33±0.43^{a}	-	-
	10%	2.70±0.43^{a}	2.64±0.60^{a}	9.00±0.50^{ab}	-	-
	9.5%	2.70±0.50^{a}	2.89±0.49^{a}	8.56±0.46^{cd}	-	-
	9.0%	2.61±0.65^{a}	2.89±0.48^{a}	8.61±0.70^{ab}	-	-
	8.5%	2.44±0.53^{a}	2.41±0.38^{a}	8.44±0.53^{cde}	-	-
	8.0%	2.30±0.67^{a}	2.87±0.60^{a}	8.39±0.42^{cde}	-	-
	7.5%	2.56±0.53^{a}	2.72±0.57^{a}	8.11±0.49^{de}	-	-
	7.0%	2.36±0.59^{a}	2.89±0.70^{a}	8.00±0.35^{e}	-	-
Brown sugar	Control	3.78±0.36^{a}	0.33±0.83^{d}	8.39±0.42^{bc}	3.89±0.31^{a}	-
	10%	3.83±0.47^{a}	3.06±0.46^{a}	8.72±0.36^{a}	3.58±0.47^{a}	-
	9.5%	3.79±0.39^{a}	2.72±0.51^{ab}	8.52±0.36^{ab}	3.72±0.51^{a}	-
	9.0%	3.60±0.80^{a}	2.89±0.65^{ab}	8.39±0.55^{bc}	3.06±0.46^{bc}	-
	8.5%	3.59±0.53^{a}	2.63±0.44^{ab}	8.17±0.43^{cd}	3.17±0.50^{b}	-
	8.0%	3.23±0.53^{b}	2.47±0.53^{ab}	8.03±0.31^{d}	2.94±0.39^{bc}	-
	7.5%	2.98±0.44^{bc}	2.39±0.49^{b}	8.06±0.46^{d}	2.92±0.53^{bc}	-
	7.0%	2.76±0.43^{c}	1.83±0.46^{c}	7.87±0.42^{d}	2.70±0.24^{c}	-
Coconut sugar	Control	3.19±0.47^{a}	1.37±1.07^{ab}	8.41±0.35^{a}	-	3.30±0.36^{a}
	10%	2.94±0.51^{ab}	1.44±0.46^{ab}	8.11±0.33^{abc}	-	2.98±0.44^{ab}
	9.5%	2.83±0.43^{bc}	1.67±0.61^{ab}	7.78±0.24^{c}	-	2.47±0.37^{cd}
	9.0%	2.63±0.48^{bcd}	1.74±0.51^{a}	7.80±0.45^{c}	-	2.64±0.43^{bc}
	8.5%	2.63±0.36^{cd}	1.72±0.30^{bc}	7.86±0.42^{bc}	-	2.74±0.23^{bc}
	8.0%	2.58±0.39^{cd}	0.00±0.00^{c}	8.17±0.43^{ab}	-	2.72±0.44^{bc}
	7.5%	2.44±0.46^{d}	1.78±0.26^{a}	7.44±0.30^{d}	-	2.44±0.59^{cd}
	7.0%	2.28±0.42^{d}	1.11±0.42^{b}	7.22±0.36^{d}	-	2.20±0.24^{d}

Values (mean ± SD) in same column and same food model, superscripted with different lowercase letters are significantly ($p < 0.05$) different.
Control sample prepared with 10% sugar and no vanilla added.
Brown sugar I.D. and coconut sugar I.D. refer to specific flavor of brown sugar and coconut sugar, respectively.

Table 5 Average intensity score obtained from descriptive analysis of milk model with different concentrations of granulated sugar, brown sugar and coconut sugar

Type of sugar	% Sugar	Attribute					
		Milk I.D.	Sweet aromatic	Vanilla flavor	Sweetness	Brown sugar I.D.	Coconut sugar I.D.
Granulated sugar	Control	7.83±0.50^{a}	3.06±0.46^{c}	0.28±0.57^{b}	12.61±0.42^{a}	-	-
	10%	7.41±0.50^{b}	3.53±0.50^{bc}	2.31±0.56^{a}	11.39±0.49^{bc}	-	-
	9.5%	7.00±0.35^{c}	4.14±0.51^{a}	2.76±0.50^{a}	11.29±0.53^{bcd}	-	-
	9.0%	7.17±0.50^{bc}	3.83±0.55^{ab}	2.78±0.57^{a}	11.61±0.55^{b}	-	-
	8.5%	7.28±0.28^{bc}	3.50±0.61^{bc}	2.42±0.54^{a}	10.78±0.51^{ef}	-	-
	8.0%	7.48±0.53^{b}	3.50±0.57^{bc}	2.48±0.47^{a}	11.11±0.60^{cde}	-	-
	7.5%	7.22±0.44^{bc}	3.94±0.50^{ab}	2.81±0.61^{a}	10.61±0.42^{f}	-	-
	7.0%	7.31±0.46^{bc}	3.67±0.55^{ab}	2.84±0.60^{a}	10.94±0.58^{def}	-	-
Brown sugar	Control	6.61±0.42^{a}	3.69±0.50^{b}	0.00±0.00^{c}	11.28±0.36^{a}	4.06±0.53^{a}	-
	10%	6.44±0.45^{a}	4.27±0.48^{a}	2.83±0.50^{a}	11.00±0.25^{ab}	3.83±0.56^{abc}	-
	9.5%	6.24±0.32^{a}	4.22±0.34^{a}	2.67±0.55^{ab}	11.00±0.56^{ab}	3.89±0.55^{ab}	-
	9.0%	6.56±0.39^{a}	3.98±0.48^{ab}	2.46±0.54^{ab}	10.39±0.49^{cd}	3.53±0.48^{bcd}	-
	8.5%	6.50±0.50^{a}	3.72±0.49^{b}	2.33±0.56^{b}	10.56±0.53^{bc}	3.56±0.58^{bcd}	-
	8.0%	6.39±0.55^{a}	3.86±0.55^{ab}	2.67±0.57^{ab}	10.56±0.46^{bc}	3.44±0.39^{bcd}	-
	7.5%	6.33±0.43^{a}	3.69±0.40^{b}	2.61±0.55^{ab}	10.00±0.56^{d}	3.08±0.34^{d}	-
	7.0%	6.37±0.52^{a}	3.94±0.46^{ab}	2.50±0.56^{ab}	10.22±0.57^{cd}	3.39±0.49^{cd}	-

Table 5 Coutinued

Type of sugar	% Sugar	Attribute					
		Milk I.D.	Sweet aromatic	Vanilla flavor	Sweetness	Brown sugar I.D.	Coconut sugar I.D.
Coconut sugar	Control	6.72±0.36^{a}	3.73±0.23^{a}	0.00±0.00^{c}	10.94±0.30^{ab}	-	3.26±0.30^{a}
	10%	6.33±0.56^{abc}	3.97±0.19^{a}	2.13±0.33^{a}	11.17±0.56^{ab}	-	2.94±0.38^{ab}
	9.5%	6.50±0.50^{ab}	3.81±0.31^{a}	1.81±0.52^{ab}	10.78±0.57^{bc}	-	2.73±0.55^{a}
	9.0%	6.09±0.51^{abc}	3.77±0.41^{a}	1.84±0.48^{ab}	10.44±0.39^{cd}	-	2.28±0.28^{d}
	8.5%	6.03±0.40^{c}	3.70±0.35^{a}	1.52±0.50^{b}	10.44±0.53^{cd}	-	2.72±0.51^{bc}
	8.0%	6.17±0.50^{bc}	3.73±0.48^{a}	2.14±0.55^{a}	10.33±0.43^{d}	-	2.63±0.55^{bcd}
	7.5%	6.33±0.50^{abc}	3.72±0.42^{a}	1.99±0.38^{a}	10.22±0.57^{d}	-	2.73±0.56^{bc}
	7.0%	6.37±0.44^{abc}	3.68±0.22^{a}	2.13±0.40^{a}	10.39±0.49^{d}	-	2.53±0.40^{cd}

Values (mean ± SD) in same column and same food model, superscripted with different lowercase letters are significantly ($p < 0.05$) different.
Control sample prepared with 10% sugar and no vanilla added.
Brown sugar I.D. and coconut sugar I.D. refer to specific flavor of brown sugar and coconut sugar, respectively.

Table 6 Average intensity score obtained from descriptive analysis of coconut milk model with different concentrations of granulated sugar, brown sugar and coconut sugar

Type of sugar	% Sugar	Attributes					
		Coconut milk I.D.	Sweet aromatic	Vanilla flavor	Sweetness	Brown sugar I.D.	Coconut sugar I.D.
Granulated sugar	Control	8.06±0.39^{a}	4.33±0.35^{abc}	0.00±0.00^{d}	11.70±0.43^{a}	-	-
	15%	7.94±0.39^{ab}	4.44±0.39^{ab}	2.26±0.47^{a}	11.50±0.56^{ab}	-	-
	14.5%	7.67±0.43^{b}	4.06±0.37^{c}	1.47±0.40^{c}	11.50±0.50^{ab}	-	-
	14.0%	7.78±0.44^{ab}	4.61±0.22^{a}	2.11±0.33^{ab}	11.42±0.53^{ab}	-	-
	13.5%	7.83±0.43^{ab}	4.17±0.50^{bc}	1.83±0.43^{bc}	11.28±0.51^{ab}	-	-
	13.0%	7.91±0.40^{ab}	4.59±0.24^{a}	1.78±0.26^{bc}	11.48±0.47^{ab}	-	-
	12.5%	7.83±0.25^{ab}	4.41±0.35^{ab}	2.00±0.50^{ab}	11.22±0.57^{b}	-	-
	12.0%	7.89±0.49^{ab}	4.42±0.49^{ab}	1.98±0.52^{ab}	11.22±0.51^{b}	-	-
Brown sugar	Control	6.64±0.35^{a}	4.17±0.35^{a}	0.41±0.50^{c}	11.78±0.44^{a}	3.63± 0.51^{a}	-
	15%	6.67±0.55^{a}	4.30±0.35^{a}	1.52±0.46^{a}	11.80±0.35^{a}	3.30±0.49^{bc}	-
	14.5%	6.48±0.44^{a}	4.09±0.28^{a}	1.37±0.46^{ab}	11.31±0.52^{bc}	2.87±0.48^{cd}	-
	14.0%	6.59±0.31^{a}	4.30±0.21^{a}	1.37±0.68^{ab}	11.44±0.30^{ab}	2.83±0.35^{d}	-
	13.5%	6.67±0.43^{a}	4.11±0.41^{a}	1.59±0.51^{ab}	11.17±0.43^{bcd}	3.28±0.44^{b}	-
	13.0%	6.50±0.43^{a}	4.26±0.25^{a}	1.17±0.79^{ab}	11.00±0.50^{cd}	2.92±0.54^{bcd}	-
	12.5%	6.28±0.51^{a}	4.11±0.18^{a}	1.02±0.71^{b}	10.94±0.46^{d}	2.76±0.43^{d}	-
	12.0%	6.28±0.51^{a}	4.03±0.31^{a}	1.39±0.49^{ab}	10.83±0.43^{d}	2.90±0.17^{bcd}	-
Coconut sugar	Control	7.33±0.35^{bc}	4.28±0.26^{ab}	0.44±0.68^{d}	11.33±0.35^{ab}	-	2.94±0.39^{abc}
	15%	7.08±0.47^{c}	3.92±0.30^{c}	1.17±0.29^{c}	10.72±0.57^{cd}	-	2.44±0.53^{d}
	14.5%	7.44±0.30^{bc}	4.52±0.44^{a}	2.22±0.36^{a}	11.39±0.49^{ab}	-	3.11±0.49^{a}
	14.0%	7.33±0.35^{bc}	4.22±0.36^{abc}	1.48±0.41^{bc}	11.33±0.50^{ab}	-	2.94±0.46^{abc}
	13.5%	7.33±0.35^{bc}	4.41±0.43^{a}	2.24±0.46^{a}	11.56±0.39^{a}	-	2.98±0.32^{ab}
	13.0%	7.61±0.22^{ab}	4.06±0.45^{bc}	1.64±0.39^{b}	11.11±0.49^{bc}	-	2.61±0.42^{bcd}
	12.5%	7.39±0.42^{bc}	3.89±0.49^{c}	1.39±0.22^{bc}	10.56±0.46^{d}	-	2.50±0.50^{cd}
	12.0%	7.86±0.42^{a}	3.94±0.46^{bc}	1.33±0.43^{bc}	10.83±0.50^{cd}	-	2.67±0.50^{abcd}

Values (mean ± SD) in same column and same food model, superscripted with different lowercase letters are significantly ($p < 0.05$) different.
Control sample prepared with 10% sugar and no vanilla added.
Brown sugar I.D. and coconut sugar I.D. refer to specific flavor of brown sugar and coconut sugar, respectively.

The sweetness profile of sugars can be described in terms of their perceived sweetness level and any distinctive flavors they may have. According to the findings from the descriptive analysis, granulated sugar tended to be most intense in sweet taste since it was considered as the standard of sweetness without any distinctive flavors or aftertastes. The second most intense sweetness was brown sugar that was slightly less sweet than granulated sugar perhaps due to the presence of molasses. The least sweet samples were prepared from coconut sugar that provided a more subtle and complex sweetness. The coconut sugar had a unique flavor profile with a hint of caramel and a mild, nutty undertone, as evidenced in the descriptive analysis result of the sweet aromatic characteristic of brown sugar samples being the strongest overall. The difference in sweetness intensity might have been caused by the simple sugar content as well as the combination of sugar types, since the granulated sugar consisted mostly of sucrose (relative sweetness = 1.0) while the coconut sugar contained about 4.6% glucose (relative sweetness = 0.6; Colonna et al., 2006).

Elderly acceptance and perception towards different food models prepared with different types of sugar.

The participants in the acceptance test were 50 elderly people, consisting of 38 females (76%) and 12 males (24%), with most of them (42 people or 84%) being aged 61–70 yr and 6 people (12%) aged 71–80 yr. The level of education was evenly distributed across all types: secondary education (13 people, 26%), secondary education (10 people, 20%), vocational education (8 people, 16%) and bachelor's degree or higher (19 people, 38%). The monthly income for most of the participants was in the range THB 20,001–25,000 (19 people, 38%), followed by below THB 9,000 (13 people, 26%) and THB 9,000–15,000 (10 people, 20%), where USD 1 = THB 36 at March 2024. Elderly people who participated in the product test were mostly from Bangkok (35 people, 70%) and its metropolitan area (9 people, 18%).

The average intensity scores for sweetness and the average preference scores for the water model samples are shown in Tables 7, 8 and 9 for added white sugar, brown sugar and coconut sugar, respectively. For the samples with added white sugar at different levels, the elderly consumers began to notice a difference in the intensity of sweetness at a concentration of 8%, with no significant difference in the overall preference scores compared to the control sample. For the samples prepared from brown sugar, the consumers began to notice less sweetness than the control sample when the sugar content was reduced by 1%; however, there was no significant difference in the overall preference scores. However, the sample with 7.5% brown sugar was more preferred than the control sample, which have been due to this sample containing the optimum level of brown sugar that the elderly preferred. For the water model with added coconut sugar, there was no significant difference in the preference scores when the sugar content was reduced; however, the elderly could perceive reduced sweetness when the coconut sugar was reduced by 1.5% (15% of the initial sugar content).

The average sweetness intensity scores and preference ratings for water samples are shown in Tables 7, 8, and 9 for white sugar, brown sugar and coconut sugar, respectively. Notably, discernible differences in sweetness intensity were noted among samples with added white sugar at concentrations starting from 8%, while the overall liking scores remained consistent with the control sample. For the brown sugar samples, a decrease in sweetness perception compared to the control was observed at a 1% reduction in sugar content, although no significant difference was recorded in the overall liking scores. Intriguingly, the sample containing 7.5% brown sugar was more preferred than the control, suggesting this was the optimal sweetness level for elderly consumers. For the water models with added coconut sugar, the liking scores remained consistent despite reductions in the sugar content; nonetheless, the elderly participants perceived decreased sweetness at a reduction of 1.5% (15% of the initial sugar content).

Table 7 Average sweetness intensity and overall liking toward water model with 0.2% vanilla extract at different concentrations of granulated sugar

Sample	Sweetness intensity	Overall liking
Control (no vanilla added with 10% sugar)	8.89±3.02^{ab}	6.04±1.97^{ab}
10% Granulated sugar	9.37±3.07^{a}	5.92±2.11^{ab}
9.5% Granulated sugar	9.24±3.21^{ab}	5.92±2.06^{ab}
9.0% Granulated sugar	9.22±3.29^{ab}	5.84±2.0^{b}
8.5% Granulated sugar	9.03±2.92^{ab}	6.18±1.79^{ab}
8.0% Granulated sugar	8.46±3.37^{bc}	5.98±2.11^{ab}
7.5% Granulated sugar	8.06±2.36^{c}	6.46±1.76^{a}
7.0% Granulated sugar	7.93±2.71^{c}	6.34±1.59^{ab}

Values (mean ± SD) in same column superscripted with different lowercase letters are significantly ($p < 0.05$) different.

Table 8 Average sweetness intensity and overall liking toward water model with 0.2% vanilla extract at different concentration of brown sugar

Sample	Sweetness intensity	Overall liking
Control (no vanilla added with 10% sugar)	10.34±2.91^{a}	5.48±2.15^{b}
10% Brown sugar	9.93±3.08^{ab}	5.50±2.20^{b}
9.5% Brown sugar	10.07±3.26^{a}	5.54±2.22^{b}
9.0% Brown sugar	9.24±2.85^{bc}	5.78±2.07^{ab}
8.5% Brown sugar	8.46±2.88^{cd}	5.78±2.03^{ab}
8.0% Brown sugar	8.77±3.13^{cd}	5.90±2.08^{ab}
7.5% Brown sugar	8.21±2.91^{de}	6.14±1.90^{a}
7.0% Brown sugar	7.45±3.43^{e}	5.40±2.15^{b}

Values (mean ± SD) in same column, superscripted with different lowercase letters are significantly ($p < 0.05$) different.

Table 9 Average sweetness intensity and overall liking toward water model with 0.2% vanilla extract at different concentrations of coconut sugar

Sample	Sweetness intensity	Overall liking
Control (no vanilla added with 10% sugar)	10.43±3.10^{ab}	5.62±2.34
10% Coconut sugar	10.56±2.92^{a}	5.62±2.23
9.5% Coconut sugar	10.14±2.97^{abc}	5.94±2.05
9.0% Coconut sugar	9.64±2.81^{bc}	5.68±1.80
8.5% Coconut sugar	9.51±3.08^{c}	5.72±2.15
8.0% Coconut sugar	8.47±3.38^{d}	5.52±2.29
7.5% Coconut sugar	8.44±2.98^{d}	6.10±1.90
7.0% Coconut sugar	8.05±2.76^{d}	6.12±1.73

Values (mean ± SD) in same column, superscripted with different lowercase letters are significantly ($p < 0.05$) different.

Tables 10, 11 and 12 present the average scores of the intensity of sweetness and overall liking of the milk model samples with the different levels of white sugar. The elderly felt the sweetness increased when vanilla was added to the samples with the same amount of sugar (control sample, 10% white sugar versus sample with 10% white sugar and 0.4% vanilla). The liking scores of the samples decreased when vanilla was used with samples with high sugar levels (10% and 9.5%), though the change was not significant. For samples with different levels of brown sugar, the elderly still felt the level of sweetness was the same as if the sugar had been reduced by no more than 1%. However, regarding acceptance by the elderly, the preference did not change when the brown sugar in the sample was reduced. The results for the test of the intensity of sweetness using samples that were added with coconut sugar, were similar to those found in brown sugar, with the elderly still considering that the level of sweetness was the same if the sugar were reduced by no more than 1% (10% of the initial sugar content). There was a significant difference in preference between the control sample and the test sample with 7.5% coconut sugar.

Table 10 Average sweetness intensity and overall liking toward milk model with 0.4% vanilla extract at different concentrations of granulated sugar

Sample	Sweetness intensity	Overall liking
Control (no vanilla added with 10% sugar)	11.62±3.27^{bc}	5.70±2.61^{a}
10% Granulated sugar	12.71±2.83^{a}	5.04±2.64^{b}
9.5% Granulated sugar	12.08±2.89^{ab}	5.10±2.43^{b}
9.0% Granulated sugar	12.11±2.89^{ab}	5.40±2.50^{ab}
8.5% Granulated sugar	12.12±2.94^{ab}	5.36±2.59^{ab}
8.0% Granulated sugar	11.79±3.05^{bc}	5.40±2.60^{ab}
7.5% Granulated sugar	11.46±3.10^{bc}	5.48±2.47^{ab}
7.0% Granulated sugar	11.35±3.10^{c}	5.28±2.47^{ab}

Values (mean ± SD) in same column, superscripted with different lowercase letters are significantly ($p < 0.05$) different.

Table 11 Average sweetness intensity and overall liking toward milk model with 0.4% vanilla extract at different concentrations of brown sugar

Sample	Sweetness intensity	Overall liking
Control (no vanilla added with 10% sugar)	11.93±3.12^{a}	4.92±2.57^{b}
10% Brown sugar	12.08±3.02^{a}	5.14±2.46^{ab}
9.5% Brown sugar	11.69±3.11^{ab}	5.12±2.46^{ab}
9.0% Brown sugar	11.08±2.91^{bc}	5.46±2.34^{a}
8.5% Brown sugar	11.62±2.99^{ab}	5.08±2.53^{ab}
8.0% Brown sugar	11.24±3.19^{bc}	5.36±2.31^{ab}
7.5% Brown sugar	10.82±3.17^{c}	5.38±2.38^{ab}
7.0% Brown sugar	10.73±3.01^{c}	5.38±2.36^{ab}

Values (mean ± SD) in same column, superscripted with different lowercase letters are significantly ($p < 0.05$) different.

Table 12 Average sweetness intensity and overall liking toward milk model with 0.4% vanilla extract at different concentrations of coconut sugar

Sample	Sweetness intensity	Overall liking
Control (no vanilla added with 10% sugar)	11.94±3.16^{a}	5.34±2.64^{b}
10% Coconut sugar	11.76±3.03^{ab}	5.36±2.31^{b}
9.5% Coconut sugar	11.73±2.90^{ab}	5.30±2.46^{b}
9.0% Coconut sugar	11.46±2.93^{abc}	5.42±2.34^{ab}
8.5% Coconut sugar	11.20±2.87^{bc}	5.30±2.37^{b}
8.0% Coconut sugar	11.15±2.74^{bc}	5.52±2.35^{ab}
7.5% Coconut sugar	10.89±3.23^{c}	5.84±2.19^{a}
7.0% Coconut sugar	11.01±2.89^{c}	5.48±2.26^{ab}

Values (mean ± SD) in same column, superscripted with different lowercase letters are significantly ($p < 0.05$) different.

The test results for the perception of the intensity of sweetness and overall preference for model coconut milk samples with different types of sugar at different concentrations showed that the elderly could not perceive a difference in the intensity of sweetness in samples using regular cane sugar and coconut sugar. In addition, there was no difference in the overall liking scores of the elderly for samples using regular cane sugar and coconut sugar. For coconut milk model samples with brown sugar, the test samples with 2.0% vanilla and different sugar levels were not significantly different from the control sample in terms of both the intensity of sweetness and overall preference, as shown in Tables 13, 14 and 15.

Overall, the sweetness perception of the elderly participants regarding all presented food model was influenced by the presence of vanilla flavor in the samples. Most of the findings showed that vanilla flavor induced a perception of sweetness, which might have been caused by congruent odor (Schifferstein and Verlegh, 1996), which is the extent to which two stimuli interact in combination in a food or cross-modal interactions, or the interaction of different sensory modalities, especially flavor. Taste-flavor interactions are the ones most commonly described between sensory modalities, occurring as a result of physical, physiological, cognitive and psychological effects (Blake, 2004). The findings from the milk and the coconut milk models reflected a more complex experience that involved the integration of multiple sensory modalities, including smell, taste and touch (Wang et al., 2018). In a study conducted to investigate the use of cross-modal interactions to reduce sugar in vanilla milk desserts targeted at children (Velázquez et al., 2020), the addition of a vanilla aroma and a creaminess mouthfeel to the desserts resulted in a significant reduction in the amount of sugar that was perceived to be present, without affecting the overall liking of the desserts by the children.

The findings of the current study suggested that it is possible to reduce the amount of added sugar in water, milk and coconut milk without significantly affecting the elderly's acceptance of these products. This was achieved by using cross-modal techniques that leveraged the vanilla flavor, which could help to enhance the sweetness of the sugar, making it less noticeable. This approach could be used to gradually reduce the amount of sugar in these products over time, which could help to reduce the elderly's preference for excessively sweetened products. Notably, the sweetness level was not the only factor affecting the taste of food, with the distinctive flavors and aromas of different sugars also playing a role. Overall, this study suggested that cross-modal techniques can be a promising way to reduce sugar in food without compromising the taste.

Table 13 Average sweetness intensity and overall liking toward coconut milk model with 2.0% vanilla extract at different concentrations of granulated sugar

Sample	Sweetness intensity^{ns}	Overall liking^{ns}
Control (no vanilla added with 15% sugar)	12.15±3.15	4.96±2.54
15% Granulated sugar	12.38±3.15	4.80±2.55
14.5% Granulated sugar	12.32±2.98	4.88±2.69
14.0% Granulated sugar	12.36±2.99	4.68±2.60
13.5% Granulated sugar	12.47±2.72	4.94±2.49
13.0% Granulated sugar	12.26±3.14	4.82±2.46
12.5% Granulated sugar	12.04±3.10	4.84±2.33
12.0% Granulated sugar	12.17±3.16	5.00±2.57

Values are mean ± SD.

^{ns} = no significant ($p \geq 0.05$) difference among means in the same column.

Table 14 Average sweetness intensity and overall liking toward coconut milk model with 2.0% vanilla extract at different concentrations of brown sugar

Sample	Sweetness intensity	Overall liking
Control (no vanilla added with 15% sugar)	12.22±3.25^{ab}	4.78±2.51^{ab}
15.0% Brown sugar	12.20±3.17^{ab}	4.72±2.44^{ab}
14.5% Brown sugar	12.15± 3.54^{ab}	4.62±2.51^{b}
14.0% Brown sugar	12.58 ±2.92^{a}	4.58±2.70^{b}
13.5% Brown sugar	12.41±2.78^{a}	4.92±2.52^{ab}
13.0% Brown sugar	12.16±3.40^{ab}	4.72±2.50^{ab}
12.5% Brown sugar	12.20±2.98^{ab}	4.80±2.41^{ab}
12.0% Brown sugar	11.75±2.88^{b}	5.18±2.30^{a}

Values (mean ± SD) in same column, superscripted with different lowercase letters are significantly ($p < 0.05$) different.

Table 15 Average sweetness intensity and overall liking toward coconut milk model with 2.0% vanilla extract at different concentrations of coconut sugar

Sample	Sweetness intensity^{ns}	Overall liking^{ns}
Control (no vanilla added with 15% sugar)	12.66±2.72	5.00±2.65
15% Coconut sugar	12.44±2.67	4.80±2.66
14.5% Coconut sugar	12.64±2.57	4.94±2.63
14.0% Coconut sugar	12.54±2.84	4.90±2.64
13.5% Coconut sugar	12.69±2.82	4.86±2.79
13.0% Coconut sugar	12.26±2.81	5.00±2.47
12.5% Coconut sugar	12.30±2.82	5.24±2.54
12.0% Coconut sugar	12.42±2.85	5.00±2.72

Values are mean ± SD.

^{ns} = no significant ($p \geq 0.05$) difference among means in the same column.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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