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# Enhancing sweetness perception with vanilla extract: Strategy for developing low-sugar food formulations for the elderly

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## Abstract

**Importance of the work**: Excessive sugar consumption can lead to various health problems, especially in the elderly. Vanilla extract can effectively enhance sweetness perception, enabling sugar reduction in food formulations without compromising consumer acceptability.

**Objectives**: To investigate the effect of adding vanilla extract on the sweetness perception and acceptance of three food models (water, milk, and coconut milk) among elderly participants.

**Materials & Methods**: A multi-sensory integration approach was used to reduce the sugar content in three food models. Initially, the sugar content in each model was set based on commercial products and gradually reduced in 0.5% increments, resulting in seven sugar levels. Vanilla extract was added to all samples. Trained panelists evaluated the flavor profiles of the three food models with and without vanilla extract. Elderly consumers assessed the sweetness perception and overall liking of the models.

**Results**: Vanilla extract enhanced the sweetness perception in all three models. In the water models, vanilla enabled a 15% reduction in sugar without compromising the perceived sweet aroma or sweetness. In the coconut milk models, a 13.33% reduction in coconut sugar was achieved while maintaining the perceived sweet aroma and sweetness. However, in the milk models, the reduced-sugar formulation with vanilla was less sweet than the control, although the sweet aroma was not affected. For elderly consumers, vanilla enabled a sugar reduction in all three food models without affecting overall liking.

**Main finding**: Vanilla extract could effectively enhance sweetness perception in various food models, enabling a reduction in sugar content without compromising palatability and overall consumer acceptance. This strategy could be a promising approach to product reformulation without relying on non-nutritive sweeteners.

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## Introduction

The high sugar content of processed foods is a major global health concern, particularly for the elderly population, who are at an increased risk of developing sugar-related health complications such as obesity, Type 2 diabetes, and cardiovascular diseases (Prada et al., 2022). This is due to their increased susceptibility to the adverse health effects of high sugar consumption, such as obesity, diabetes, and heart disease (Anari et al., 2017; Zheng et al., 2017; Jensen et al., 2018; Malik and Hu, 2019; Mojto et al., 2019; Janzi et al., 2020; Prada et al., 2022; Tran et al., 2023).

The global movement towards sugar reduction has necessitated the reformulation of food products to meet the needs of health-conscious consumers, particularly the elderly population. The implementation of sugar taxes, restrictions on the marketing of sugary drinks, and school meal monitoring programs has substantially contributed to reducing sugar consumption, prompting the food industry to reformulate products using a lower sugar content (Yoshida and Simoes, 2018). The COVID-19 pandemic further amplified the focus on healthy eating, particularly among older adults, leading to an increased demand for low-sugar food options (World Health Organization, 2020). World Health Organization (2023) provided a new guideline on non-sugar sweeteners, recommending against the use of non-sugar sweeteners to control body weight or reduce the risk of noncommunicable diseases.

In response to the growing concern over sugar consumption, public health organizations have set strict limits on daily sugar intake (World Health Organization, 2015). This has driven the food industry to reformulate products to meet the needs of health-conscious consumers, especially the elderly population.

One common strategy to reduce the sugar content has been the use of non-nutritive sweeteners (Dubois and Prakash, 2012). However, these sweeteners often have unpleasant aftertastes and have raised potential health concerns (Markey et al., 2015). Additionally, some studies have shown that non-nutritive sweeteners may not be as effective as hoped in preventing weight gain and may even lead to an increased calorie intake (Mattes and Popkin, 2009; Gardner et al., 2012).

Given the limitations of non-nutritive sweeteners, the food industry is increasingly turning to multisensory integration principles as an alternative, more natural approach to reducing sugar content in food products. For example, vanilla, with its inherent health benefits and sweetness-enhancing properties, is at the forefront of this approach. The potential of vanilla to enhance sweetness perception through cross-modal aroma-taste interactions is promising; studies have shown that vanilla aroma can increase the perceived sweetness intensity in plant-based yogurts (Greis et al., 2022). It has also been found that the addition of vanilla aroma to food formulations can lead to an increase in sensory desirable characteristics, such as sweetness and creaminess, especially in overweight individuals (Proserpio et al., 2021). Furthermore, the use of vanilla aroma in combination with non- or low-calorie sweeteners increased the sweetness intensity, particularly for sweeteners perceptually similar to sucrose (Bertelsen et al., 2021). Screening studies have shown that the vanilla aroma can significantly enhance the sweet taste perception in aqueous solutions (Bertelsen et al., 2020). These findings suggest that the vanilla aroma has the potential to enhance sweetness perception through cross-modal interactions in various food and beverage products.

The incorporation of vanilla extract into low-sugar food formulations for the elderly presents a promising strategy to develop healthier and more appealing products that align with current consumer trends and public health initiatives. By enhancing sweetness perception and providing additional health benefits, vanilla extract could contribute to the development of a wide range of low-sugar food products that cater to the specific needs and preferences of the elderly population.

Given the high sugar content in three popular foods, such as black glass jelly in brown sugar syrup, sweetened milk, and the Thai dish 'lod chong' (pandan rice noodles with coconut milk), there is promising potential for vanilla to enhance sweetness perception through cross-modal aroma-taste interactions (Poinot et al., 2013). Therefore, the current research explored this potential, investigating whether manipulating the concentration of vanilla could lead to healthier (yet equally delectable) alternatives to these high-sugar foods. In this context, the aim was to evaluate the use of cross-modal aroma-taste interactions as a way of reducing the sugar content in these three food models.

## Materials and Methods

### *Raw materials*

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

### *Methods*

#### *Sample determination and sample preparation*

Water, milk and coconut milk were selected as representative bases for desserts and sweetened beverages in Thailand. Each food model was paired with a sugar type commonly used in typical dessert items. For example, water was paired with brown sugar, as it is found in syrups for Thai desserts, while coconut milk was paired with coconut sugar. Milk represented a sweetened beverage model typically formulated with granulated white sugar.

Black grass jelly, sweetened milk, and pandan rice noodles with coconut milk (lod chong) were chosen to represent water models with brown sugar, milk with granulated white sugar, and coconut milk with coconut sugar, respectively.

The determination of samples was based on a market survey assessing the sugar content in various food products. Black grass jelly, sweetened milk and lod chong were selected to represent the water, milk and coconut milk models, respectively. Five commercial products for each category were sampled from diverse retailers, including fresh markets, convenience stores and supermarkets in the Bangkok area.

The sugar content analysis revealed that the black grass jelly products and sweetened milk had sugar contents in the ranges 5–27% and 5.5–12%, respectively, while the highest sugar content was in lod chong with a range 10–20%. Based on this survey, an initial sugar content of 10% was applied for the water and milk models, while the coconut milk model was formulated with 15% sugar, as detailed in Table 1. Six levels were studied by reducing sugar concentrations at 0.5% intervals to investigate the impact of the sugar content.

#### *Assessing effect of vanilla extract on sweetness perception in various food models*

The three base food models (water, milk and coconut milk) with varying sugar and vanilla extract concentrations, as shown in Table 1, were assessed for their flavor profiles using a descriptive analysis method adapted from several studies (Keane, 1992; Cherdchu et al., 2013; Ledeker et al., 2014; Rosales and Suwonsichon, 2015; Rosales et al., 2018; Noidad et al., 2019). Nine trained panelists from the Kasetsart University Sensory and Consumer Research Center (KUSCR), Bangkok, Thailand developed a vocabulary set to describe flavor related to basic taste and flavor conditions. The attributes, along with their definitions and corresponding references, were detailed in Table 2.

Four attributes were evaluated in the water model samples: sweet aromatic, vanilla, brown sugar and sweet taste. Four attributes were evaluated in the milk model samples: sweet aromatic, vanilla, milk identity and sweet taste. Five attributes were evaluated in the coconut milk model: sweet aromatic vanilla, coconut milk identity, coconut sugar identity and sweet taste.

An orientation session was held for estimating the intensity rating using reference samples to ensure consistent ratings within a 1.0-point difference. The test session involved rating the flavor intensity of test products on a 0–15 linear scale (where 0 indicated none and 15 indicated extremely high).

To ensure the consistency of vanilla extract quality, commercial natural vanilla extract (McCormick) was used in all samples throughout the study. The final evaluation was conducted in two replicates after training.

**Table 1** Treatment arrangement of food models for sensory evaluation by trained panelists and elderly consumers

| Model | Type of sugar | Sugar (%) | Vanilla extract (%) |
|---|---|---|---|
| Water | Brown sugar | 10.0 | 0.0 |
| | | 10.0 | 0.2 |
| | | 9.5 | 0.2 |
| | | 9.0 | 0.2 |
| | | 8.5 | 0.2 |
| | | 8.0 | 0.2 |
| | | 7.5 | 0.2 |
| | | 7.0 | 0.2 |
| Milk | Granulated white sugar | 7.0 | 0.0 |
| | | 7.0 | 0.4 |
| | | 6.5 | 0.4 |
| | | 6.0 | 0.4 |
| | | 5.5 | 0.4 |
| | | 5.0 | 0.4 |
| | | 4.5 | 0.4 |
| | | 4.0 | 0.4 |
| Coconut milk | Coconut sugar | 15.0 | 0.0 |
| | | 15.0 | 2.0 |
| | | 14.5 | 2.0 |
| | | 14.0 | 2.0 |
| | | 13.5 | 2.0 |
| | | 13.0 | 2.0 |
| | | 12.5 | 2.0 |
| | | 12.0 | 2.0 |

**Table 2** Terms, definitions, and references of the sample attributes

| No. | Term | Definition | Reference (brand) | Reference preparation | Intensity |
|---|---|---|---|---|---|
| 1 | Sweet aromatic | Overall flavor of the sample that gives a sweet feeling, such as the flavor of fruits or flowers. (None-------High) | Brown sugar (Mitr Phol) | 20 g of brown sugar 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) | 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 identity. | Specific flavor of cow's milk that consists of milk, sweet, and creamy sensation. (None-------High) | Full fat pasteurized milk (CP Meiji) | Full fat pasteurized milk (pure) | 9.0 |
| 4 | Coconut identity | Specific flavor of coconut that consists of sweet, floral, nutty, and may be mixed with brown note. (None-------High) | UHT coconut milk (Aroy-D) | 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, ferment. (None-------High) | Brown sugar (Mitr Phol) | 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) | 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 |

UHT = ultra-high temperature treated

*Assessing effect of vanilla extract on sweetness perception and overall liking in various food models among elderly consumers*

A study was conducted to investigate the influence of vanilla extract on sweetness perception and overall liking in the three food models among elderly consumers. These models were prepared using different food bases (water, milk, coconut milk) and sugars (white sugar, brown sugar, coconut sugar) as outlined in Table 1. In total, 50 healthy participants aged 60 years and above residing in the Bangkok Metropolitan Region were recruited for the study. Participants evaluated the perceived sweetness intensity of each model using a 15-point scale (1 to 15, ranging from not sweet to extremely sweet). In addition, consumer acceptance testing was conducted using a blind sequential monadic format, where participants rated their liking on a 9-point hedonic scale (1 to 9, ranging from dislike extremely to like extremely).

*Assessing effect of vanilla extract on sweetness perception and overall liking in various food products among elderly consumers*

A study investigated the effect of vanilla extract on sweetness perception and overall liking among elderly consumers. In total, 50 participants aged 60 years and over evaluated three food products: black glass jelly in plain water with brown sugar, sweetened milk with granulated sugar, and lod chong in coconut milk with coconut sugar, as detailed in Table 3. The participants rated the sweetness intensity on a 15-point scale (1 to 15, ranging from not sweet to extremely sweet). They also rated their liking for each product in a blind taste test format on a 9-point hedonic scale (1 to 9, ranging from dislike extremely to like extremely).

*Statistical analysis*

In each study, intensity scores and overall liking scores were analyzed using a mixed linear model considering sample as a fixed effect and consumer as a random effect. The obtained data were analyzed using the SPSS 22.0 statistical software (IBM Inc.; Chicago, IL, USA). The analysis calculated descriptive statistics, analysis of variance and a multiple comparison (Tukey's range test) at $\alpha = 0.05$. Results were presented as mean ± SD values.

**Table 3** Treatment arrangement to determine most appropriate level of reduced sugar in different food products

| Food product (Food model) | Sugar (%) | Vanilla extract (%) |
|---|---|---|
| Black glass jelly in water with brown sugar (water) | 10.0 | 0.0 |
| | 8.5 | 0.2 |
| | 7.5 | 0.2 |
| Sweetened milk with granulated white sugar (milk) | 10.0 | 0.0 |
| | 7.5 | 0.4 |
| Lod chong in coconut milk with coconut sugar (coconut milk) | 15.0 | 0.0 |
| | 13.0 | 2.0 |
| | 11.25 | 2.0 |

### *Ethics statements*

This study was approved by the Ethics Committee of Kasetsart University, Bangkok, Thailand (Approval no. COA66/065).

## Results and Discussion

### *Effect of vanilla extract on sweetness perception in various food models*

The inclusion of vanilla extract in various food models, as demonstrated by the trained panel results (Tables 4–6), appeared to maintain the perception of sweetness and sweet aroma, even with reduced sugar concentrations. This effect was particularly evident in the water and coconut milk food models. This observation aligned with other reports, suggesting that vanilla extract enhanced sweetness perception through cross-modal interactions (Alcaire et al., 2017; Bertelsen et al., 2020, 2021; Velázquez et al., 2020).

In the water food model (Table 4), the addition of vanilla extract increased the sweet aromatic and sweetness intensity attributes. For 10% brown sugar with 0.2% vanilla, the sweet taste score was the highest (8.72), being even higher than the control without vanilla. This indicated that vanilla significantly enhanced sweetness perception.

In the milk food model (Table 5), when vanilla was introduced, a significant sweet aromatic enhancement was observed, even with a 3% sugar reduction, achieving a score (2.55) close to the control (2.78). However, the addition of vanilla extract had no significant effect on the sweetness of the milk food model. The results suggested that the addition of vanilla extract enhanced the sweet aromatic attribute of milk food models without significantly affecting sweetness. This was consistent with the findings of Wang et al. (2017), who reported that vanilla was the most prevalent flavoring in dairy products, because of its association with enhanced perceived sweetness.

In the coconut milk model (Table 6), a reduction in the coconut sugar content from 15% to 13%, corresponding to a 13.33% reduction in the total sugar content, and the addition of vanilla essence resulted in a sweetness level (11.33) that closely approximated that of the control (11.11). A similar result was also found for the sweet aromatic attribute. The treatment conditions with 13.5% and 14% coconut sugar and 2% vanilla extract also had good flavor profiles, with scores that were not significantly different from the control for any of the flavor attributes. These results suggested that these concentrations of coconut sugar could be used to produce coconut milk food models with good flavor without significantly reducing sweetness or the coconut milk flavor.

**Table 4** Flavor profile of water food model incorporated with brown sugar and 0.2% vanilla extract evaluated by trained panel

| Treatment condition | Sweet aromatic | Vanilla | Brown sugar | Sweet taste |
|---|---|---|---|---|
| Control (10.0% brown sugar without vanilla) | $3.78 \pm 0.36^{a}$ | $0.33 \pm 0.83^{d}$ | $3.89 \pm 0.31^{a}$ | $8.39 \pm 0.42^{bc}$ |
| 10.0% brown sugar with 0.2% vanilla | $3.83 \pm 0.47^{a}$ | $3.06 \pm 0.46^{a}$ | $3.58 \pm 0.47^{a}$ | $8.72 \pm 0.36^{a}$ |
| 9.5% brown sugar with 0.2% vanilla | $3.79 \pm 0.39^{a}$ | $2.72 \pm 0.51^{ab}$ | $3.72 \pm 0.51^{a}$ | $8.52 \pm 0.36^{ab}$ |
| 9.0% brown sugar with 0.2% vanilla | $3.60 \pm 0.80^{a}$ | $2.89 \pm 0.65^{ab}$ | $3.06 \pm 0.46^{bc}$ | $8.39 \pm 0.55^{bc}$ |
| 8.5% brown sugar with 0.2% vanilla | $3.59 \pm 0.53^{a}$ | $2.63 \pm 0.44^{ab}$ | $3.17 \pm 0.50^{b}$ | $8.17 \pm 0.43^{cd}$ |
| 8.0% brown sugar with 0.2% vanilla | $3.23 \pm 0.53^{b}$ | $2.47 \pm 0.53^{ab}$ | $2.94 \pm 0.39^{bc}$ | $8.03 \pm 0.31^{d}$ |
| 7.5% brown syrup with 0.2% vanilla | $2.98 \pm 0.44^{bc}$ | $2.39 \pm 0.49^{b}$ | $2.92 \pm 0.53^{bc}$ | $8.06 \pm 0.46^{d}$ |
| 7.0% brown sugar with 0.2% vanilla | $2.76 \pm 0.43^{c}$ | $1.83 \pm 0.46^{c}$ | $2.70 \pm 0.24^{c}$ | $7.87 \pm 0.42^{d}$ |

Mean ± SD with different lowercase superscripts in each column are significantly ($p < 0.05$) different.

**Table 5** Flavor profile of milk food model incorporated with granulated white sugar with 0.4% vanilla extract evaluated by trained panel

| Treatment condition | Sweet aromatic | Vanilla | Milk identity | Sweetness |
|---|---|---|---|---|
| Control (7.0% white sugar without vanilla) | $2.55 \pm 0.31^{cd}$ | $0.00 \pm 0.00^{e}$ | $7.52 \pm 0.41^{a}$ | $10.45 \pm 0.66^{a}$ |
| 7.0% white sugar with 0.4% vanilla | $3.18 \pm 0.43^{a}$ | $2.52 \pm 0.52^{a}$ | $7.20 \pm 0.52^{bcd}$ | $9.96 \pm 0.47^{b}$ |
| 6.5% white sugar with 0.4% vanilla | $2.92 \pm 0.57^{ab}$ | $1.91 \pm 0.57^{b}$ | $7.05 \pm 0.30^{d}$ | $9.49 \pm 0.51^{c}$ |
| 6.0% white sugar with 0.4% vanilla | $2.72 \pm 0.49^{bc}$ | $1.55 \pm 0.67^{bcd}$ | $7.06 \pm 0.44^{d}$ | $9.37 \pm 0.50^{cd}$ |
| 5.5% white sugar with 0.4% vanilla | $2.67 \pm 0.46^{bcd}$ | $1.67 \pm 0.46^{bc}$ | $7.27 \pm 0.43^{abcd}$ | $9.03 \pm 0.47^{d}$ |
| 5.0% white sugar with 0.4% vanilla | $2.37 \pm 0.47^{d}$ | $1.27 \pm 0.46^{d}$ | $7.42 \pm 0.42^{ab}$ | $9.21 \pm 0.78^{cd}$ |
| 4.5% white sugar with 0.4% vanilla | $2.54 \pm 0.39^{cd}$ | $1.40 \pm 0.75^{cd}$ | $7.36 \pm 0.48^{abc}$ | $9.08 \pm 0.60^{d}$ |
| 4.0% white sugar with 0.4% vanilla | $2.78 \pm 0.53^{bc}$ | $1.68 \pm 0.51^{bc}$ | $7.11 \pm 0.48^{cd}$ | $8.50 \pm 0.68^{e}$ |

Mean ± SD with different lowercase superscripts in each column are significantly ($p < 0.05$) different.

**Table 6** Flavor profile of coconut milk food model incorporated with coconut sugar with 2.0% of vanilla extract evaluated by trained panel

| Treatment condition | Sweet aromatic | Vanilla | Coconut milk identity | Coconut sugar identity | Sweet taste |
|---|---|---|---|---|---|
| Control (15.0% coconut sugar without vanilla) | 4.28±0.26$^{ab}$ | 0.44±0.68$^{d}$ | 7.33±0.35$^{bc}$ | 2.94±0.39$^{abc}$ | 11.33±0.35$^{ab}$ |
| 15.0% coconut sugar with 2.0% vanilla | 4.52±0.44$^{a}$ | 2.22±0.36$^{a}$ | 7.44±0.30$^{bc}$ | 3.11±0.49$^{a}$ | 11.39±0.49$^{ab}$ |
| 14.5% coconut sugar with 2.0% vanilla | 4.22±0.36$^{abc}$ | 1.48±0.41$^{bc}$ | 7.33±0.35$^{bc}$ | 2.94±0.46$^{abc}$ | 11.33±0.50$^{ab}$ |
| 14.0% coconut sugar with 2.0% vanilla | 4.41±0.43$^{a}$ | 2.24±0.46$^{a}$ | 7.33±0.35$^{bc}$ | 2.98±0.32$^{ab}$ | 11.56±0.39$^{a}$ |
| 13.5% coconut sugar with 2.0% vanilla | 3.94±0.46$^{bc}$ | 1.33±0.43$^{bc}$ | 7.86±0.42$^{a}$ | 2.67±0.50$^{abcd}$ | 10.83±0.50$^{cd}$ |
| 13.0% coconut sugar with 2.0% vanilla | 4.06±0.45$^{bc}$ | 1.64±0.39$^{b}$ | 7.61±0.22$^{ab}$ | 2.61±0.42$^{bcd}$ | 11.11±0.49$^{bc}$ |
| 12.5% coconut sugar with 2.0% vanilla | 3.89±0.49$^{c}$ | 1.39±0.22$^{bc}$ | 7.39±0.42$^{bc}$ | 2.50±0.50$^{cd}$ | 10.56±0.46$^{d}$ |
| 12.0% coconut sugar with 2.0% vanilla | 3.92±0.30$^{c}$ | 1.17±0.29$^{c}$ | 7.08±0.47$^{c}$ | 2.44±0.53$^{d}$ | 10.72±0.57$^{cd}$ |

Mean ± SD with different lowercase superscripts in each column are significantly ($p < 0.05$) different.

### *Effect of vanilla extract on sweetness perception and overall liking in various food models among elderly consumers*

In total, 50 elderly individuals participated in this study. The majority of the participants were female (76%), with the remaining 24% being male. Most of the participants (86%) were in the age range 60–70 yr, while the remaining 14% were in the age range 71–80 yr. The participants' educational backgrounds varied, with 30% having less than a high school diploma, 20% having a high school diploma, 10% having a vocational certificate and 40% having an undergraduate degree or higher. Monthly income was divided into three groups: less than THB 20,000/mth (62%), from THB 20,000/mth to THB 50,000/mth (34%) and more than THB 80,000/mth (4%), where USD 1 = THB 34.59.

There were distinct trends in the influence of vanilla extract on sweetness perception among elderly consumers (Tables 7–9). For the plain water models with brown sugar (Table 7), a decrease in brown sugar content from 10% to 7% in the presence of 0.2% vanilla extract produced a reduction in sweetness intensity from 10.34 to 7.45, yet the overall liking remained within a close range. The sweetness intensity of the plain water decreased with decreasing concentrations of the brown sugar, from 9.0% to 7.0%.

**Table 7** Average overall liking score and sweetness intensity of plain water model with brown sugar and 0.2% vanilla extract evaluated by elderly consumers

| Sample | Sweetness intensity | Overall liking |
|---|---|---|
| Control (10% brown sugar without vanilla) | 10.34±2.91$^{a}$ | 5.48±2.15$^{b}$ |
| 10.0% brown sugar with 0.2% vanilla | 9.93±3.08$^{ab}$ | 5.50±2.20$^{b}$ |
| 9.5% brown sugar with 0.2% vanilla | 10.07±3.26$^{a}$ | 5.54±2.22$^{b}$ |
| 9.0% brown sugar with 0.2% vanilla | 9.24±2.85$^{bc}$ | 5.78±2.07$^{ab}$ |
| 8.5% brown sugar with 0.2% vanilla | 8.46±2.88$^{cd}$ | 5.78±2.03$^{ab}$ |
| 8.0% brown sugar with 0.2% vanilla | 8.77±3.13$^{cd}$ | 5.90±2.08$^{ab}$ |
| 7.5% brown sugar with 0.2% vanilla | 8.21±2.91$^{de}$ | 6.14±1.90$^{a}$ |
| 7.0% brown sugar with 0.2% vanilla | 7.45±3.43$^{e}$ | 5.40±2.15$^{b}$ |

Mean ± SD with different lowercase superscripts in each column are significantly ($p < 0.05$) different.

Similar observations were found in the milk model with granulated sugar (Table 8) and coconut milk with coconut sugar (Table 9). The sweetness intensity of the milk decreased with decreasing concentrations of the granulated sugar from 9.0% to 7.0%. These results highlighted the potential of vanilla extract to maintain taste preferences among elderly consumers, even with a reduced sugar content.

According to the sensory test (Tables 7–9), there were high variations in the SD scores for sweetness intensity and

**Table 8** Average sweetness intensity and overall liking score of milk model with granulated sugar and 0.4% vanilla extract evaluated by elderly consumers

| Sample | Sweetness intensity | Overall liking |
|---|---|---|
| Control (10.0% white sugar without vanilla) | 11.62±3.27$^{bc}$ | 5.70±2.61$^{a}$ |
| 10.0% white sugar with 0.4% vanilla | 12.71±2.83$^{a}$ | 5.04±2.64$^{b}$ |
| 9.5% white sugar with 0.4% vanilla | 12.08±2.89$^{ab}$ | 5.10±2.43$^{b}$ |
| 9.0% white sugar with 0.4% vanilla | 12.11±2.89$^{ab}$ | 5.40±2.50$^{ab}$ |
| 8.5% white sugar with 0.4% vanilla | 12.12±2.94$^{ab}$ | 5.36±2.59$^{ab}$ |
| 8.0% white sugar with 0.4% vanilla | 11.79±3.05$^{bc}$ | 5.40±2.60$^{ab}$ |
| 7.5% white sugar with 0.4% vanilla | 11.46±3.10$^{bc}$ | 5.48±2.47$^{ab}$ |
| 7.0% white sugar with 0.4% vanilla | 11.35±3.10$^{c}$ | 5.28±2.47$^{ab}$ |

Mean ± SD with different lowercase superscripts in each column are significantly ($p < 0.05$) different.

**Table 9** Average overall liking score and sweetness intensity of coconut milk model with coconut sugar and 2.0% vanilla extract evaluated by elderly consumers

| Sample | Sweetness intensity$^{ns}$ | Overall liking$^{ns}$ |
|---|---|---|
| Control (15.0% coconut sugar without vanilla) | 12.66±2.72 | 5.00±2.65 |
| 15.0% coconut sugar with 2.0% vanilla | 12.44±2.67 | 4.80±2.66 |
| 14.5% coconut sugar with 2.0% vanilla | 12.64±2.57 | 4.94±2.63 |
| 14.0% coconut sugar with 2.0% vanilla | 12.54±2.84 | 4.90±2.64 |
| 13.5% coconut sugar with 2.0% vanilla | 12.69±2.82 | 4.86±2.79 |
| 13.0% coconut sugar with 2.0% vanilla | 12.26±2.81 | 5.00±2.47 |
| 12.5% coconut sugar with 2.0% vanilla | 12.30±2.82 | 5.24±2.54 |
| 12.0% coconut sugar with 2.0% vanilla | 12.42±2.85 | 5.00±2.72 |

Values shown as mean ± SD.

$^{ns}$ = non-significant ($p > 0.05$) difference acceptance perhaps because of the sweetness threshold and individual preferences. These factors involve physiological influences, such as age-related changes in taste bud sensitivity and chemical reception. Psychological aspects, including past experiences and cognitive processes, could also shape sweetness preferences. The interaction between threshold and preferences influenced liking or disliking sweet foods.

*Effect of vanilla extract on sweetness perception and overall liking in various food products among elderly consumers*

The acceptance and perception of differences among elderly consumers were studied regarding the sweetness in different food products, representing different food models (water, milk, and coconut milk) compared to the sugar types usually added into the product (black glass jelly with plain water and brown sugar, sweetened milk with granulated sugar, and lod chong with coconut milk and coconut sugar). In the study involving elderly consumers, the addition of vanilla extract influenced sweetness perception in various food models, as shown in Tables 10–12. For black glass jelly with brown sugar, a notable decrease in sweetness intensity was observed, from 6.06±3.53 in the control (10% sugar) to 4.24±3.05 with 7.5% brown sugar (25% sugar reduction) and 0.2% vanilla. Similarly, for sweetened milk with granulated sugar, the sweetness intensity reduced from 9.78±3.18 in the control (10% sugar) to 8.60±2.84 with 7.5% sugar (25% sugar reduction) and 0.4% vanilla. In the lod chong coconut milk model, the sweetness intensity decreased from 8.60±3.05 (15% sugar) to 6.70±3.16 with 11.5% sugar (25% sugar reduction) upon vanilla addition. Despite 25% sugar reductions, the overall liking remained relatively consistent for all three products, highlighting vanilla's role in enhancing perceived sweetness, even when the sugar content was reduced. According to Alcaire et al. (2017), sugar reduction strategies that focus on preserving sweet taste perception are more conservative than those that focus on product acceptance. In their study, sugar reduction impacted perceived sweetness but did not affect product acceptance, suggesting that even if consumers perceive a slight reduction in sweetness, sugar reduction could be implemented without compromising product acceptability, especially given the high sugar content of currently available products. Reducing the sugar content in processed products is one of the main challenges facing industries due to changes in the sensory characteristics of products and may undermine consumer acceptance (Markey et al., 2015). Nevertheless, the current results showed that reducing sugar with the addition of vanilla did not compromise the acceptability of the food model by consumers, although the trained panelists described the samples as less sweet.

**Table 10** Average sweetness intensity and liking score of black grass jelly samples with 0.2% vanilla extract (plain water model with brown sugar)

| Treatment condition | Sweetness intensity | Sweetness liking $^{ns}$ | Overall taste liking $^{ns}$ | Overall liking |
|---|---|---|---|---|
| Control (10.0% brown sugar without vanilla) | 6.06±3.53$^{a}$ | 6.06±2.22 | 6.42±1.88 | 6.52±1.91$^{a}$ |
| 8.5% brown sugar with 0.2% vanilla | 5.02±3.37$^{ab}$ | 5.88±1.85 | 6.12±1.62 | 5.94±1.91$^{b}$ |
| 7.5% brown sugar with 0.2% vanilla | 4.24±3.05$^{b}$ | 5.36±1.99 | 5.52±1.84 | 5.62±1.98$^{b}$ |

Mean ± SD with different lowercase superscripts in each column are significantly ($p < 0.05$) different.
$^{ns}$ = non-significant ($p > 0.05$) difference.

**Table 11** Average sweetness intensity and liking score of sweetened milk samples with 0.4% vanilla extract (milk model with granulated sugar)

| Treatment condition | Sweetness intensity | Sweetness liking$^{ns}$ | Overall taste liking $^{ns}$ | Overall liking$^{ns}$ |
|---|---|---|---|---|
| Control 10% granulated white sugar without vanilla | 9.78±3.18$^{a}$ | 5.78±2.30 | 5.78±2.35 | 5.78±2.35 |
| 7.5% granulated white sugar with 0.4% vanilla | 8.60±2.84$^{b}$ | 5.84±2.00 | 6.08±1.73 | 6.20±1.85 |

Mean ± SD with different lowercase superscripts in each column are significantly ($p < 0.05$) different.
$^{ns}$ = non-significant ($p > 0.05$) difference

**Table 12** Average sweetness intensity and liking score of Lod Chong samples with 2.0% vanilla extract (coconut milk model with coconut sugar)

| Treatment condition | Sweetness intensity | Sweetness liking $^{ns}$ | Overall taste liking $^{ns}$ | Overall liking $^{ns}$ |
|---|---|---|---|---|
| Control 15.0% coconut sugar | 8.60±3.05$^{a}$ | 6.58±1.49 | 6.46±1.64 | 6.74±1.57 |
| 13.0% coconut sugar with 2.0% vanilla | 7.94±2.97$^{a}$ | 6.32±1.69 | 6.50±1.69 | 6.60±1.52 |
| 11.5% coconut sugar with 2.0% vanilla | 6.70±3.16$^{b}$ | 6.08±1.88 | 6.34±1.52 | 6.54±1.50 |

Mean ± SD with different lowercase superscripts in each column are significantly ($p < 0.05$) different.
$^{ns}$ = non-significant ($p > 0.05$) difference

Investigations into the interplay between taste and flavor are often conducted using food matrix models to gain better control over food composition. However, the flavor-taste interaction is heavily influenced by the food matrix; consequently, findings from model studies may not be directly applicable to real foods (Poinot et al., 2013). Therefore, further research is crucial to thoroughly assess the behavior of flavors (such as vanilla) in enhancing sweetness perception in products with varying compositions. Furthermore, research in this area could contribute to the development of healthier food products with reduced free-sugar contents.

Primarily, the study focused on the positive impact of vanilla extract. However, it should be recognized that there are potential drawbacks associated with its use, such as the possibility of overpowering other flavors in certain dishes or adding an unwanted sweetness. Additionally, the quality of vanilla extract could vary greatly, which could impact its flavor profile and overall effect on food products.

A decrease in the brown sugar and coconut sugar contents in the food model not only resulted in decreasing overall sweetness but also diminished the distinctive characteristics of the coconut sugar and brown sugar flavors. Potentially, this could amplify the discernment of differences in samples, as these unique characteristics are closely linked to sweetness perception. Additionally, the reduction in the sugar content could impact the mouthfeel attributes of the liquid samples, introducing lighter body and lower viscosity, making it more challenging to lower the sugar content since it would be more perceptible by the elderly regarding changes in product characteristics.

The multisensory interaction approach was effective, wherein vanilla flavor was used to enhance the sweet taste to facilitate sugar reduction in products. However, a challenge arises because the elderly consumers can be emotionally connected to their lifelong perceived sweetness and the rewarding feeling post-consumption. Another potential method to alter consumer sweetness perception is through repeated exposure. Research, such as the study by Griffioen-Roose et al. (2013), indicated that repetitive consumption of a non-caloric sweetened beverage, instead of a sugar-sweetened version, may not lead to changes in reward value. This might be a more effective approach, since the product would provide fewer calories without affecting the consumer's perception and satisfaction.

Reducing the sugar content is a major challenge that must be addressed to improve consumer health. Various strategies can address this issue. An effective approach is cross-modal aroma-taste interactions; however, their potential detectability by consumers necessitates further enhancement. Therefore, studying food additives that can compensate for sweetness and satisfaction becomes crucial to improving the method's effectiveness. Another promising approach is repeated exposure. Investigating how repeated exposure influences the associations between sensory attributes and the satiating capacity of food developed over time is particularly intriguing, as well as considering how it would impact the perceived reward value of products. Leveraging nudging strategies has proven effective in encouraging healthier eating habits, employing cognitive nudges through nutritional labeling, affective nudges with visually appealing packaging and behavioral nudges that prioritize convenience. A viable approach to further advance the promotion of healthier eating behaviors involves comparing the effectiveness of various nudging techniques, specifically focusing on sugar intake reduction. This comparative analysis could provide valuable insights for shaping new behaviors conducive to healthy eating.

The current research suggested that vanilla extract could be a valuable tool for product developers who are aiming to reduce the sugar content in food products while preserving sweetness perception and maintaining overall liking among consumers. These current findings underscored the potential for vanilla extract as a valuable ingredient in formulating low-sugar food products and the opportunity for food developers to cater to health-conscious consumers without compromising on taste and overall product appeal.

## Conflict of Interest

The authors declare that there are no conflicts of interest.

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