Impact of Sweetener Substitution and Sterilization Conditions on the Quality of Sweetened Condensed Rice Milk

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***Abstract*—This study aimed to investigate the replacement of sucrose with alternative sweeteners in Sweetened Condensed Rice Milk (SCRM) and to determine the optimal sterilization conditions. Maltitol, isomalt, and sucralose were utilized as substitutes for sucrose in rice-based formula compared with milk-based control. Four formulations were evaluated for sensory properties using Quantitative Descriptive Analysis (QDA) by trained panelists, assessing eight key attributes: brightness, apparent viscosity, rice flavor, coconut milk flavor, soybean flavor, thickness, smoothness, and sweetness. The results showed no significant differences in coconut milk flavor, soybean flavor, or smoothness intensity between the maltitol-sucralose and isomalt-sucralose formulations. The isomalt-sucralose sample achieved a sweetness level comparable to the milk-based control (7.59) with an intensity score of 7.23. To ensure commercial sterility, the SCRM sample was subjected to sterilization using a water spray retort under two temperature-time conditions: 116 °C for 20 min and 121 °C for 8 min. The F-values obtained for the sterilized SCRM samples were 6.25 min at 116 °C and 8.49 min at 121 °C. There were no significant differences in redness (a*) and yellowness (b*) after sterilization between the two conditions. However, the viscosity of the sterilized SCRM sample at 116 °C was higher than that of the 121 °C treatment. Microbiological analysis confirmed that the applied sterilization effectively inactivated pathogenic and spoilage microorganisms. The sensory evaluation demonstrated that overall acceptability scores ranged from slightly to moderately liked on a 9-point hedonic scale.**

***Keywords*—isomalt, QDA, rice milk, sterilization, sweetener**

I. Introduction

Sweetened condensed milk is manufactured by evaporating some part of water from milk and addition of sugar almost 50% to preserve the shelf life. The high sugar content increased the osmotic pressure, inhibiting the growth of microorganisms [1, 2]. Sucrose has water-binding capacity that reduce water activity (a_w), thus it prevents microbial growth and prolongs the product's shelf life. Sweetened condensed milk widely utilized in beverages such as tea and coffee to enhances sweetness, mouthfeel and creamy texture. However, excessive sucrose consumption has been associated with various health concerns like diabetes and obesity. Artificial sweetener or natural sweetener often applied for sugar substitution which create the healthier choice of dessert product. According to the research of [3], the sweetened condensed milk formulated with maltodextrin, 0.5% cinnamon extract and replacement of 50% fructose had functionality in term of antioxidant properties and receive higher sensorial score. The research from [4] reported that the replacement of 40% sucrose in sweetened condensed milk with 20% trehalose, 5% lactulose and 15% erythritol results in similar sensory properties and color variations to pure sucrose (100%). Using single sugar has not match sensory profile to sucrose while the use of two or more natural non-nutritive sweeteners could balance the sweet taste for the food product. The advantage of nutritive sweetener, especially isomalt and maltitol, is heat resistant, tooth-friendly and no cooling effect [5].

The demand for plant-based milk alternative has been steadily increasing due to lactose intolerance and cholesterol issue [6]. The production of cereal-based milk typically involves several key processing steps, including wet milling, filtration, addition of supplementary ingredient, homogenization, sterilization and packaging [6]. In the case of Vietnamese purple rice milk supplemented with various cereal, the homogenization at a pressure 20 MPa for 15 min followed sterilizing at 121.1 ºC for 7 min has been improved emulsion stability and ensure microbiological safety [7]. Among various plant-based options, rice is the dominant cereal grain group which was globally consume. The main composition in rice mainly consists of carbohydrate (starch) which accounted for 78%, followed by protein (6–7%) and fat [6]. Rice also naturally hypoallergenic properties, absence of common allergens and toxicity as well as gluten-free, so it is desirable ingredient for developing alternative dairy product.

Therefore, this study aimed to investigate the replacement of sucrose with alternative sweeteners in Sweetened Condensed Rice Milk (SCRM) and to determine the optimal sterilization process.

II. Materials and Methods

A. Materials

The ingredients used in the preparation of Sweetened Condensed Rice Milk (SCRM) were sourced from various suppliers. Almonds (Heritage Snacks & Food Co., Ltd.), white sesame (Thanya Farm Co., Ltd.), coconut milk (Thai Agri Foods Public Co., Ltd.), soybean milk (Tofusan Co., Ltd.), and rice bran oil (King Rice Oil Group Co., Ltd.) were obtained from local supermarkets. Additionally, white rice (RD 43 variety) was supplied by Pkakan Co., Ltd., while prebiotic syrup was obtained from Rajburi Sugar Co., Ltd. Inulin powder (DP 2-60) and isomalt were purchased from DPO (Thailand) Ltd. Food-grade sucralose and xanthan gum were provided by Chemipan Corporation Co., Ltd. Flexible retort pouches were supplied by Meiwa Pax Co., Ltd.

B. Preparation of Sweetened Condensed Rice Milk (SCRM)

The production of SCRM followed the method from [8] with minor modifications. Four formulations were prepared: (1) milk-based control, (2) rice milk with sucrose, (3) rice milk with maltitol-sucralose, and (4) rice milk with isomalt-sucralose. After mixing and homogenizing all ingredients, sucrose in the SCRM formulations was replaced with alternative sweeteners. Maltitol (relative sweetness: 80%) and isomalt (relative sweetness: 40%) were incorporated at 6.93%, with a small amount of sucralose added to match the sweetness level of the milk-based control and sucrose-containing rice milk [9, 10]. The mixtures were packaged in retort pouches and sterilized using a water spray retort (Owner Food Machinery, PP500, Thailand). The final products were then evaluated using quantitative descriptive sensory analysis.

C. Quantitative Descriptive Sensory Analysis

Quantitative Descriptive Analysis (QDA) was conducted to assess the sensory properties of SCRM samples, following the methodologies of [11, 12]. The evaluation was performed by 10 trained panelists (aged 24–27 years) from the Food Science and Technology program at Thammasat University, Thailand. Panelists developed descriptive terms and identified reference standards for evaluating the SCRM samples. The assessed attributes included appearance (brightness, apparent viscosity), flavor (rice, coconut milk, soybean), texture (thickness, smoothness), and taste (sweetness). Samples were rated on a 15 cm line scale, with "not detected" at one end and "high" at the other. Each panelist received all four SCRM formulations, along with a glass of water at room temperature for palate cleansing between evaluations.

D. Heat Penetration Evaluation

The optimal sucrose-substituted SCRM formulation was packaged in a flexible retort pouch (PET13/NY15/CPP70) with dimensions of 160×270 mm and a net weight of 500 g. Sterilization was performed on a pilot-scale water spray retort system under two temperature-time conditions: 121 °C for 8 min (high-temperature, short-time sterilization) and 116 °C for 20 min (low-temperature, long-time sterilization). A thermocouple probe (3.5 cm in length) was inserted into the geometric center of the pouch to monitor the core temperature of the SCRM sample, with real-time temperature recordings taken at one-minute intervals using a data logger (E-Val Pro, Ellab, Denmark). The come-up time (CUT), defined as the interval between the initial temperature (25 °C) and the target sterilization temperatures (116 °C and 121 °C), was determined. The accumulated lethality (F-value) was calculated based on the lethal rate (L) using the following equation:

$$F^{T}_{z} = \sum L(\Delta T)$$

$$\text{where } L = 10^{((T-Tref)/z)}$$

The Temperature (T) was measured at the slowest-heating zone within the food package, with a reference temperature (Tref) of 121.1 °C and a z-value of 10 °C [13].

E. Color

The finished product was analyzed color properties using a colorimeter (ColorFlex CX2687, Hunter Lab, USA). The parameters included lightness (L*), red-green intensity (a*), and yellow-blue intensity (b*).

F. Viscosity Measurement

Viscosity was measured following the method adapted from [14] using a Brookfield viscometer (DV-II+, SA, USA) equipped with a small sample adapter. A 12 mL sample was placed in an SC4 sample chamber and measured using an SC4-28 spindle. The viscosity was recorded at a shear rate of 28 s^{-1} under a controlled temperature of 25±0.1 °C, with results expressed in centipoise (cP).

G. Microbiology Analysis

The microbiological quality and safety of sucrose-substituted SCRM samples were assessed through Total Plate Count (TPC), yeast and mold count, and coliform enumeration (MPN method). Pathogenic bacteria, including *Salmonella* spp., *Clostridium perfringens*, *Staphylococcus aureus*, and *Bacillus cereus*, were also analyzed. Additionally, mesophilic and thermophilic anaerobic spore-formers were evaluated as indicators of heat-treated food stability. All analyses followed the Ministry of Public Health Notifications No. 355 and No. 364 [15, 16].

H. Sensory Evaluation

Sensory evaluation was conducted with 60 untrained panelists to assess SCRM samples treated under different sterilization conditions. Each 15 g sample was presented in a sealed, clear plastic cup labeled with a three-digit random code and served at room temperature. White bread and water were provided for palate cleansing. Panelists rated appearance, color, rice flavor, sweetness, oiliness, viscosity, and overall acceptability using a 9-point hedonic scale (1 = "dislike extremely," 9 = "like extremely").

I. Statistical Analysis

Data were expressed as mean ± Standard Deviation (SD) from at least three replicates. Statistical analysis was performed using SPSS v.20.0, with one-way ANOVA to determine significant differences ($p < 0.05$). Duncan's multiple range test was applied for mean comparisons.

III. Results and Discussion

A. Quantitative Descriptive Analysis

Quantitative Descriptive Analysis (QDA) was conducted to evaluate the key sensory attributes of four SCRM formulations with different sugar substitutions: a milk-based control, rice milk with sucrose, rice milk with maltitol-sucralose, and rice milk with isomalt-sucralose. A panel of 10 trained panelists assessed brightness, apparent viscosity, rice flavor, coconut milk flavor, soybean flavor, thickness, smoothness, and sweetness (Fig. 1).

The results (Table 1) showed no significant differences in the intensity of coconut milk flavor, soybean flavor, and smoothness across formulations. However, both maltitol-sucralose and isomalt-sucralose formulations exhibited lower viscosity and thickness scores compared to the milk-based control, likely due to differences in their bulking properties. Especially, the isomalt-sucralose formulation achieved a sweetness intensity of 7.23, comparable to the control (7.59) (Table 1). Isomalt interacts synergistically with other sweeteners, particularly intense sweeteners like sucralose, resulting in a more balanced sweetness perception [17].

According to [18], the combination of isomalt and sucralose enhances sweetness balance and enables sugar reduction in cocoa beverages. Additionally, isomalt functions as both a sugar substitute and a bulking agent, helping to maintain key physical characteristics such as viscosity, texture, and consistency.

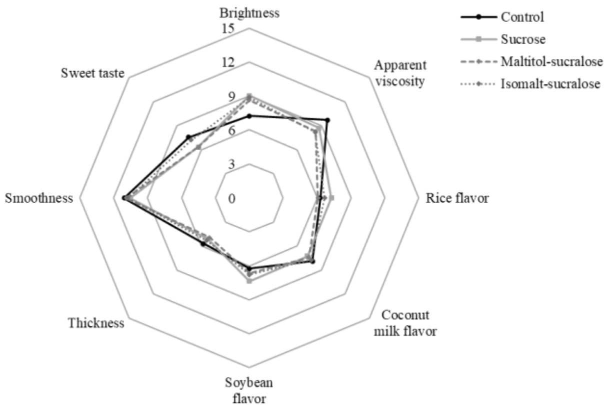


Fig. 1. Quantitative descriptive profile of SCRM samples with different sugar substitution.

Table 1. The intensity score of SCRM samples with different sugar substitution by quantitative descriptive analysis

Attributes	Control	Sucrose	Maltitol-sucralose	Isomalt-sucralose
Brightness	7.2±1.48^{b}	9.0 1±1.78^{a}	8.63±1.74^{a}	8.89±1.84^{a}
Apparent Viscosity	9.74±1.43^{a}	8.70±2.30^{b}	8.30±2.14^{b}	8.22±1.86^{b}
Rice flavor	6.26±095^{ab}	5.83±1.40^{b}	6.06±1.34^{ab}	6.65±1.38^{a}
Coconut milk flavor ^{ns}	7.91±1.48	7.26±1.61	7.44±1.52	7.73±1.43
Soybean flavor ^{ns}	6.24±3.64	7.35±3.51	6.67±3.08	6.78±3.41
Thickness	5.72±1.40^{a}	5.15±1.60^{ab}	4.96±1.19^{b}	5.31±1.76^{ab}
Smoothness ^{ns}	11.06±1.06	10.53±1.45	10.87±1.31	10.74±1.40
Sweetness	7.59±0.75^{a}	6.37±1.15^{b}	6.35±1.03^{b}	7.23±1.09^{a}

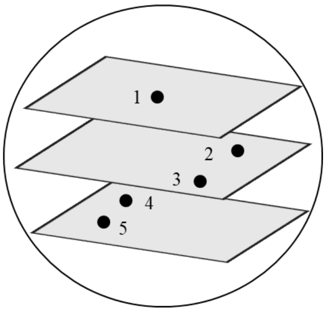
^{a,b,c} Different letters in the same row indicate that values are significantly different (p<0.05)
ns: not significant different.

B. Sterilization Process on Quality of SCRM

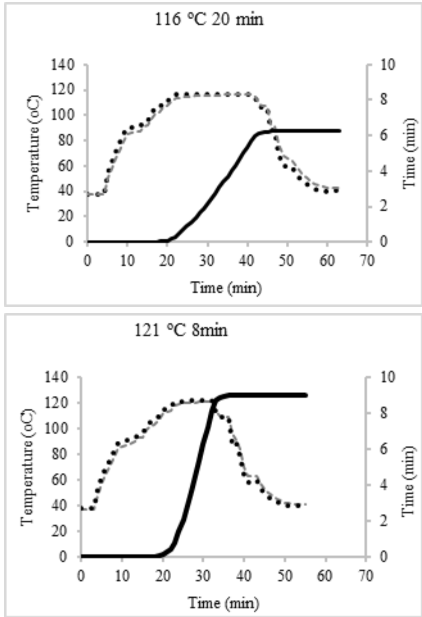
1) Heat penetration test

The heat penetration test was carried out under two sterilizing conditions: 116 °C for 20 min (LTLT sterilization) and 121 °C for 8 min (HTST sterilization). The isomalt-sucralose SCRM samples were positioned at five different locations within a water spray retort to monitor temperature variations during the sterilization process (Fig. 2). The results revealed a steady temperature increase in the SCRM samples that nearly matched the retort temperature, demonstrating efficient heat transfer within the product.

The Come-up Time (CUT), defined as the duration required for the retort to reach the target processing temperature, was recorded as 20.75±0.64 min for 116 °C and 23.10±0.14 min for 121 °C (Table 2). The F-value, representing accumulated lethality, varied across different positions in the retort. For 116 °C, F-values ranged from 6.16 to 6.45 min, while for 121 °C, F-values ranged from 7.67 to 9.27 min.



(a)



(b)

Fig. 2. The position of SCRM (a) and heat penetration test in the water spray retort at different condition (b).

Table 2. F value of sweetened condensed rice-milk treated by different condition

Condition	Come up time (min)	Process time (min)	Position	F value (min)
116 °C 20 min	20.75±0.64	64.50±0.71	1	6.25±0.54
			2	6.21±0.11
			3	6.16±0.12
			4	6.45±0.00
			5	6.17±0.06
			Average	6.25±0.12
121 °C 8 min	23.10±0.14	54.76±3.17	1	7.67±0.13
			2	8.60±0.60
			3	8.96±1.58
			4	9.27±1.45
			5	7.98±0.12
			Average	8.49±0.67

The F-values in this study comply with the Ministry of Public Health Notification No. 355 [15], which mandates that low-acid foods (pH > 4.6, aw > 0.85) must achieve an F-value of at least 3 min to ensure effective *Clostridium botulinum* spore inactivation. Therefore, the SCRM product met commercial sterility standards.

According to [19], sterilized rice and cereal-based products, such as rice porridge mixed with legumes and Job's tears in retort pouches, achieved an F-value of 4.02 at 122 °C with no detection of thermophilic anaerobic bacteria or total plate count. Similarly, Vietnamese purple rice milk supplemented with sesame, soybean, and water caltrop, when sterilized at 121.1 °C for 7 min, maintained acceptable microbial safety while preserving its sensory characteristics [7].

2) Effect of sterilization condition on SCRM color

The color parameters of SCRM before and after sterilization are presented in Table 3. The lightness (L*) of all samples tended to decrease whereas redness (a*) and yellowness (b*) was increased after sterilization process. The 121 °C treatment for 8 min resulted in more pronounced color changes compared to the 116 °C treatment for 20 min, leading to a more intense yellow-brown appearance (Fig. 3). This change is primarily attributed to the Maillard reaction, which occurs between reducing sugars and proteins during thermal processing.

However, the differences in redness (a*) and yellowness (b*) between the two sterilization conditions were not statistically significant (Table 3). Higher temperatures and prolonged heating can accelerate the Maillard reaction, protein denaturation, and degradation of food components, ultimately altering the color of final product [20]. Similarly, previous studies have reported that heat treatment at 135 °C for 15 sec enhances color development in camel milk, demonstrating the influence of thermal processing on color changes [21].

Table 3. Color value of SCRM treated by different sterilization condition

Color value	Before sterilization	After sterilization	
		116 °C 20 min	121 °C 8 min
L*	84.76 ± 1.07^{a}	82.52 ± 0.47^{b}	81.36 ± 0.24^{c}
a*	-0.26 ± 0.02^{b}	0.65 ± 0.07^{a}	0.96 ± 0.04^{a}
b*	8.16 ± 0.29^{b}	10.15 ± 0.61^{a}	10.41 ± 0.09^{a}

^{a,b,c} Different letters in the same row indicate that values are significantly different (p<0.05).

Before sterilization 116 °C 20 min 121 °C 8 min

Fig. 3. Appearance of SCRM before and after sterilization.

3) Effect of sterilization condition on SCRM viscosity

The viscosity of SCRM under different sterilization conditions is presented in Table 4. During sterilization, amylose and amylopectin in rice and cereal starch undergo gelatinization, followed by retrogradation during cooling and storage. This structural rearrangement of starch molecules changes viscosity [20]. The 116 °C for 20 min treatment allowed for a longer water absorption period in starch granules, leading to greater gelatinization and subsequently higher viscosity in the final product [19].

Sterilization temperature was the most influential factor affecting product quality, followed by sterilization time and product composition [22]. According to [22], viscosity may be correlated with the F-value obtained during sterilization. Higher viscosity in soups or similar products can slow down heat penetration, leading to a lower apparent F-value. However, a higher sterilization temperature (121 °C for 8 min) with a shorter processing time can minimize thermal effects on the fluid properties of sauces and other liquid-based foods [23].

Table 4. Viscosity value of SCRM treated by different sterilization condition

Sterilization condition	Viscosity (cp)
116 °C 20 min	2387.22 ± 187.13^{a}
121 °C 8 min	2158.33 ± 107.06^{b}

^{a,b,c} Different letters in the same column indicate that values are significantly different (p<0.05).

4) Effect of sterilization condition on microbiology quality of SCRM

The SCRM under both sterilization conditions showed no detectable microbial growth at 37 °C and 55 °C, including pathogenic bacteria, coliforms, and *E. coli*. Furthermore, the total plate count was less than 10,000 CFU per gram, complying with the standards set by the Ministry of Public Health Notification on commercially sterile foods [15, 16]. These findings confirm that the applied sterilization processes were sufficient to inactivate pathogenic and spoilage microorganisms, ensuring the product is safe for consumption (Table 5).

Table 5. Microbiological analysis of SCRM treated by different sterilization condition

Microbiology analysis	Sterilization condition	
	116 °C 20 min	121 °C 8 min
Total plate count (CFU/g)	< 10	< 10
Yeast and mold (CFU/g)	< 10	< 10
Coliform (MPN/g)	< 3	< 3
Staphylococcus aureus (CFU/g)	Not detect in 0.1 g	Not detect in 0.1 g
Salmonella spp.	Not detect in 25 g	Not detect in 25 g
Clostridium perfringens (CFU/g)	Not detect in 25 g	Not detect in 25 g
Bacillus cereus (CFU/g)	Less than 100 in 1 g	Less than 100 in 1 g
Thermophilic anaerobic spore former	Not detect in 25 g	Not detect in 25 g
Mesophilic anaerobic spore former (CFU/g)	< 10	< 10

5) Effect of sterilization condition on sensory characteristic of SCRM

The sensory evaluation of SCRM under different sterilization conditions is presented in Table 6. The results showed no significant differences in appearance, color, rice flavor, sweetness, oiliness, viscosity, and overall acceptability among the samples. The overall acceptability scores ranged from slightly to moderately liked, indicating that the sterilization process did not negatively impact consumer preference. However, the 121 °C for 8 min treatment demonstrated greater processing efficiency, requiring a shorter batch processing time compared to sterilization at 116 °C for 20 min while maintaining similar sensory attributes.

Table 6. Sensorial scores of SCRM treated with different sterilization condition by 9-point hedonic scale

Attributes	116 °C 20 min	121 °C 8 min
Appearance ^{ns}	7.37±1.03	7.33±1.17
Color ^{ns}	7.37±1.09	7.17±1.22
Rice flavor ^{ns}	6.73±1.27	6.77±1.58
Sweetness ^{ns}	6.37±1.37	6.53±1.47
Oiliness ^{ns}	7.03±0.84	7.03±1.09
Viscosity ^{ns}	6.40±1.53	6.53±1.60
Overall acceptability ^{ns}	7.20±1.05	6.93±1.49

ns: not significant different.

IV. Conclusion

The evaluation of different sweetener combinations demonstrated that the isomalt-sucralose formulation effectively replaced sucrose in the milk-based control while maintaining desirable sensory characteristics. The sterilization processes at 116 °C for 20 min and 121 °C for 8 min successfully achieved commercial sterility, effectively inactivating pathogenic and spoilage microorganisms. Among the tested conditions, sterilization at 121 °C for 8 min was identified as the optimal treatment, as it resulted in a visually appealing yellow-brown color, shorter processing time, and lower energy consumption. These advantages make it a more efficient option for large-scale production while maintaining product quality and safety.

Conflict of Interest

The authors declare that they have no conflicts of interest.

Author Contributions

Rawiporn Polpued designed the experiments, conducted laboratory analyses, and performed data collection and statistical analysis. Krittiya Khuenpet conceptualized the study, contributed to manuscript writing and revisions, provided methodological guidance and assisted in data interpretation. She also contributed to the critical review and editing of the manuscript. All authors participated in discussions and approved the final version.

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