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Original Research Article

Textural and Physical Properties of Coconut Milk Ice Cream with Bacterial Cellulose

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ABSTRACT

This study aimed to use bacterial cellulose (BC) as a natural stabilizer to replace a synthetic stabilizer in coconut milk ice cream. BC, a cellulose pellicle, was the product from the fermentation of mature coconut water using *Acetobacter xylinum*. Fresh BC pellicle was size reduced prior to mixing with other ingredients. The effect of BC content at either 5, 10 or 15 g per 100 g of ice cream mix on texture, consistency, color, melting rate and overrun of coconut milk ice cream was investigated. Based on the results of texture profile analysis, it was found that hardness, gumminess, and chewiness increased significantly (p<0.05) as the amount of BC increased. Color measurement revealed that an increase in BC content resulted in a significant decrease (p<0.05) in hue angle and chroma. It was also observed that an increase in BC content resulted in a higher overrun but lower melting rate. In addition, an increase in BC content resulted in a significant increase (p<0.05) in consistency of ice cream mix. It was concluded that 15 g of BC per 100 g of ice cream mix was recommended due to higher textural parameters, overrun, melting time and consistency of coconut milk ice cream.

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INTRODUCTION

Ice cream is one of the most popular desserts. The global ice cream market was valued USD 111.58 billion in 2020 and is expected to grow at an annual growth rate of over 5.71% (Research and markets, 2021). Ice creams are physicochemical complexes containing air bubbles that are dispersed in the continuous phase.

Coconut milk ice cream, which contains coconut milk instead of dairy milk, is widely consumed in tropical countries, especially in Thailand. Coconut milk gives a unique flavor (Fuangpaiboon & Kijroongrojana, 2015). According to Vanga & Raghavan (2018), coconut milk can increase the high density lipoprotein (HDL)

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levels, which help in reducing the harmful low density lipoprotein (LDL). For production of coconut milk ice cream, stabilizers, such as carboxy methyl cellulose (CMC) or cellulose gum, are needed. CMC is derived from the cellulose of plant material and commonly used in ice cream formulations as stabilizers. Dietary fibers which are natural hydrocolloids possess several functional properties such as water holding capacity, gelation, thickener and stabilizer in ice cream (Xavier & Ramana, 2021). Thus, they were considered to be a potential replacement for the stabilizing agent in coconut milk ice cream.

Bacterial cellulose (BC) is classified in the category of insoluble dietary fiber and recognized as "generally recognized as safe" food by the U.S. Food and Drug Administration (Azeredo et al., 2019). BC could be obtained from bacterial fermentation of mature coconut water using *Acetobacter xylinum*. Mature coconut water has been considered as waste, especially in coconut processing plants (desiccated coconut factories, coconut milk factories, etc.). BC was produced by some strains of bacteria in the *Acetobacteraceae* family, previously known as genus *Acetobacter* which has recently been renamed *Komagataeibacter (Gluconacetobacter)*. The pure cellulosic thick membrane is preferably formed in the bacterial culture grown in static conditions. It consists of natural cellulose fibers. Although plant cellulose and BC have the same chemical structure, BC does not require extra processes to remove unwanted impurities and contaminants such as lignin, pectin, and hemicellulose and, therefore, can retain a greater degree of polymerization. BC also presents unique properties, including a higher degree of crystallinity, higher water retention, higher tensile strength, and better moldability. BC has been commercialized as high-end products including health food product. BC is indigestible in the human gut, thus it is considered as a dietary fiber (Fontana et al., 2017). Due to various health benefit properties, especially regarding non-communicable diseases, a sufficient intake of dietary fiber could reduce the occurrence of constipation, hemorrhoids, diabetes, improve bowel function, promote weight loss, and prevent heart disease (Anderson et al., 2009). Therefore, the supplement of BC in many foods and drinks has become more popular in Asia. The BC, either mixed with food products or in raw form, has been in demand for worldwide export (Gama et al., 2016).

However, there is rare information on BC addition in coconut milk ice cream available in the literature. The aim of this study was to investigate the effect of BC addition on textural properties and other physical properties (i.e., color, melting rate, consistency and overrun) of coconut milk ice cream.

MATERIALS AND METHODS

Materials

BC pellicle was produced and autoclaved at 120 °C at 15 psi for 20 min and stored at 4 °C until further use. It was obtained from Prince of Songkla University. Fresh coconut milk, skimmed milk powder, glucose syrup, sucrose was procured from a local market.

BC preparation

BC was size reduced using a blender (Waring, Model 31BL92-7011, USA) at a speed of 8,000 rpm for 5 min. Blended BC was passed through a 40mesh sieve. The prepared BC was then added in homogenized ice cream mix.

Ice cream preparation

Based on the preliminary study, the control formulation/treatment (a sample without addition of BC) was not feasible to produce coconut milk ice cream. Therefore, it was not included in Table 1. Ice cream ingredients as shown in Table 1 were mixed in a container. For each experiment, 500 g batch size of ice cream mix was prepared. Ice cream mix was pasteurized in a water bath (Memmert GmbH + Co.KG, Schwabach, Germany) at 70 °C for 15 minutes. After pasteurization, ice cream mix was cooled using 4°C cooling water until the temperature distribution of ice cream mix was approximately 25°C. Then, it was homogenized using a homogenizer (Velp Scientifica, model OV5, Italy) at 18,000 rpm for 5 min. After homogenization, the prepared BC was added at ratios of 5, 10 and 15 g to 100 g of ice cream mix. The ice cream mix was aged in a refrigerator at 4°C for 24 hours. Sampling the aged ice cream mix for color and consistency measurement. The aged ice cream mix was subsequently churned using an ice cream maker (Homemate, model HOM-122050) for approximately 50 min and measured the overrun. The churned ice cream was finally packed in the plastic cups and stored in a freezer at -18 °C for texture profile analysis and melting rate measurement.

Table 1 Formulations of coconut milk ice cream with different ratios of BC addition

BC addition (g of BC per 100 g of ice cream mix)	Coconut milk (g)	Glucose syrup (g)	Sucrose (g)	Water (g)	Skimmed milk powder (g)
5	37	6	12	40	5
10	37	6	12	40	5
15	37	6	12	40	5

Texture Profile Analysis (TPA)

TPA was carried out at 25 °C using a texture analyzer (TA.XT Plus, Stable Micro Systems, UK). The hardness, gumminess, and chewiness of sample were determined by compression of the sample in two consecutive cycles. For BC sample, TPA was performed according to the modified method of Feng et al. (2015). The 0.5 g load cell was used and the test speed was 1 mm/s. But for coconut milk ice cream sample, TPA was performed according to the modified method of Pon et al. (2015). The 5 g load cell was used and the test speed was 3.3 mm/s.

Moisture Content Measurement

The procedure was followed AOAC (2000). The moisture can was cleaned and dried in a hot air oven for 2 hours, then cooled in a desiccator for 30 minutes and weighed using a digital balance (RC 250S, Sartorious, Germany) with accuracy of ±0.0001 g. The moisture can weight (W_1) was recorded. The sample was placed in a moisture can and weighed (W_2). The moisture can was placed in a hot air oven at temperature of 105 °C for 3 hours. After that the moisture can containing sample was placed and cooled down in a desiccator, and then weighed (W_3). Moisture content was calculated using Equation 1.

$$\text{Moisture content (\%w.b.)} = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \qquad (1)$$

where W_1 is initial weight of moisture can, g

W_2 is weight of moisture can containing sample before drying, g

W_3 is weight of moisture can containing sample after drying, g

Color Measurement

The color of sample was measured using a Colorimeter (ColorQuest XE, Hunter Associates Lab., Japan). Illuminant D65 was used as a light source. A 50 mm cuvette containing sample was placed above the light source and covered with a lid. Five parameters, namely *L** (Lightness), *a** (Redness/Greenness), *b** (Yellowness/Blueness), Hue, and Chroma were determined. According to McGuire (1992), Hue and Chroma were reported along with chromatic coordinates (*L* a* b**) because they both gave more information about spatial distribution of color.

Consistency Measurement

A Bostwick Consistometer (model 50 CRi-BC50, UK) with a flow range of 24 cm was used to measure the Bostwick flow distance according to ASTM standard F1080-93 (2008). The measurement was performed at 25 °C. The consistometer chamber was filled up with 75 mL of sample. The gate was then released and the travelling distance of the sample for a period of 30 s was recorded. The sample travelled at a shorter distance resulted in higher consistency.

Overrun Measurement

The procedure was followed the method of Agrawal et al. (2016). A known volume of ice cream mix was weighed and then the same volume of ice cream was weighed. The overrun was calculated using Equation 2.

$$\%\text{Overrun} = \frac{m_1 - m_2}{m_2} \times 100 \qquad (2)$$

where m_1 = weight of ice cream mix, g

m_2 = weight of ice cream,g

Melting Rate Measurement

Melting rate of ice cream was performed according to the modified method of Lee & White (1991). 100 g of sample kept in a plastic container at -18°C for 24 h was placed on a wire mesh attached to a 1000 mL beaker under 25 °C. The dripped weight was measured every 5 min for 45 min. Then weight of melted product was plotted against time. The melting rate was then calculated from the slope of the graph.

Experimental Design

All experiments were carried out in duplicate. One-way analysis of variance (ANOVA) was performed to determine the effects of the BC amount on properties of coconut milk ice cream using Minitab Statistical software (Minitab®19 for Windows, Minitab Inc., Sydney, Australia). All data were presented as mean values with standard deviations. Differences between mean values were determined using Tukey's multiple range tests at a confidence level of 95%.

RESULTS AND DISCUSSION

Physical Properties of BC

The textural properties of BC were determined in terms of hardness, gumminess, and chewiness (Table 2). The results showed that hardness, gumminess, and chewiness of BC were 282.15 ± 29.18 g, 86.59 ± 8.76 g, and 26.64±3.36 g, respectively. The results were not similar to the study of Feng et al. (2015) probably because different strains of bacteria were used for BC production. According to Feng et al. (2015), the hardness, gumminess and chewiness of fresh BC produced by *Gluconacetobacter hansenii* CGMCC3917 were approximately 120 g, 50 g, and 20 g, respectively.

Table 2. Physical Properties of Bacterial Cellulose

Properties	Value
Hardness (g)	282.15 ± 29.18
Gumminess (g)	86.59 ± 8.76
Chewiness (g)	26.64±3.36
*L**	67.02 ± 0.25
*a**	2.28 ± 0.09
*b**	10.11 ± 0.14
Hue (°)	77.26 ± 0.38
Chroma	10.36 ± 0.15
Moisture Content (% w.b.)	96.98 ± 0.07

Values are expressed as mean ± SD (n=2).

In addition, the color parameters, i.e., *L*, a*, b**, Hue and Chroma of BC were 67.02 ± 0.25, 2.28 ± 0.09, 10.11 ± 0.14, 77.26 ± 0.38 and 10.36 ± 0.15, respectively (Table 2). The color tone of BC was pale warm-yellow. Kongruang (2008) reported that color of BC was related to pigment in culture media.

Moisture content of BC was 96.98 ± 0.07 %w.b. (Table 2). The result showed that the main food composition of BC was water. Khan, et al. (2007) reported that BC was highly hydrophilic, holding water over 100 times of its weight. The water trapped in the cellulose matrix is highly useful for its application in food industry as a jelly like food.

Color of Coconut Milk Ice Cream Mix after Aging

Table 3 presents the effect of BC addition on color characteristics of coconut milk ice cream mix after aging. The results revealed that all color values (*L**, *a**, *b**, Chroma, Hue) were significantly affected by the BC addition ($p < 0.05$). Increasing the BC content decreased *L** (lightness-darkness) and *b** (blueness-yellowness) but increased *a** (greenness-redness). The differences in lightness related to the amount of BC in coconut milk ice cream. It was found that BC addition had significant difference on *L** (lightness) ($p < 0.05$). The lightness of ice cream with 5 g of BC per 100 g of ice cream was 78.45±0.29 and when the BC content was increased to 10 g and 15 g per 100 g of ice cream, the lightness of ice cream was decreased to 77.42±0.31 and 75.52±0.25, respectively. Thus, the addition of BC resulted in decreased lightness. Furthermore, BC addition had significant difference on *b** ($p < 0.05$). The *b** of ice cream with 5 g of BC per 100 g of ice cream was 6.87±0.10 and when the BC content was increased to 10 g and 15 g per 100 g of ice cream, the *b** of ice cream was decreased to 6.46±0.10 and 5.75±0.21, respectively. The *b** value with negative numbers towards blue and positive towards yellow. Thus, the addition of BC resulted in decreased yellowness. In addition, BC addition had significant difference on *a** ($p < 0.05$). The a* of ice cream with 5 g of BC per 100 g of ice cream was -1.41±0.01 and when the BC content was increased to 10 g and 15 g per 100 g of ice cream, the *a** of ice cream was increased to -1.20±0.03 and -0.83±0.01, respectively. Thus, the addition of BC resulted in increased greenness.

Table 3. Color properties of coconut milk ice cream mix with different ratios of BC addition

BC addition	*L**	*a**	*b**	Hue (°)	Chroma
5 g of BC	78.45±0.29[a]	-1.41±0.01[c]	6.87±0.10[a]	101.59±0.18[a]	7.01±0.09[a]
10 g of BC	77.42±0.31[b]	-1.20±0.03[b]	6.46±0.10[b]	100.53±0.32[b]	6.58±0.09[b]
15 g of BC	75.52±0.25[c]	-0.83±0.01[a]	5.75±0.21[c]	98.25±0.39[c]	5.81±0.21[c]

Values are expressed as mean ± SD (n=2). Different letters in the same column indicate significant difference (p<0.05)

For hue and chroma, it was found that BC addition had significant difference on hue angle ($p < 0.05$). The hue angle of ice cream with 5 g of BC per 100 g of ice cream was 101.59±0.18° and when the BC content was increased to 10 g and 15 g per 100 g of ice cream, the hue angle of ice cream was decreased to 100.53±0.32° and 98.25±0.39°, respectively. The chroma of ice cream with 5 g of BC per 100 g of ice cream was 7.01±0.09 and when the BC content was increased to 10 g and 15 g per 100 g of ice cream, the chroma of ice cream was decreased to 6.58±0.09 and 5.81±0.21, respectively. It can be explained that color tone of BC itself was pale warm-yellow (as mentioned earlier) and increasing of BC in ice cream resulted in pale cool-yellow. Nevertheless, the little ranges in hue (98.25-101.59°) and chroma (5.81-7.01) of coconut milk ice cream mix samples with different amounts of BC addition were not noticeable by human eyes.

Consistency of Coconut Milk Ice Cream Mix after Aging

Bostwick flow distance of each coconut milk ice cream mixture after aging is shown in Table 4. As mentioned earlier, the sample travelled at a shorter distance resulted in higher consistency. The coconut milk ice cream with 5 g of BC per 100 g of ice cream mix reached maximum travelling distance as soon as the gate of the Bostwick Consistometer was released. Because its consistency is too low to be detected using a Bostwick Consistometer with a full flow range of 24 cm. In addition, the results revealed that higher amount of BC (i.e., 10 and 15 g/100 g of ice cream mix) caused an increase in the consistency of ice cream mix. The coconut milk ice cream mix with 15 g of BC per 100 g of ice cream contained the highest consistency (due to the shortest flow distance) among the three BC addition. This likely due to the fact that web-like microfibrous structures of BC were able to interact with water. The water molecules become immobilized and unable to move freely among other molecules resulted in increasing consistency of ice cream mix (Azeredo et al., 2019).

Table 4. Consistency of the coconut milk ice cream mix with different ratios of BC addition

BC addition	Distance within 30s (cm)
5 g of BC	nd*
10 g of BC	15.75±1.04[a]
15 g of BC	11.75±0.61[b]

Values are expressed as mean ± SD (n=2). Different letters in the same column indicate significant difference (p<0.05). * nd = not detected

Overrun of Coconut Milk Ice Cream

Table 5 illustrates the effect of BC addition on the overrun of the coconut milk ice cream. Higher amount of BC resulted in an increase of the overrun. The overrun of ice cream with 5 g of BC per 100 g of ice cream was 51.78±2.95% and when the BC content was increased to 10 g and 15 g per 100 g of ice cream, the overrun of ice cream was increased to 62.00±2.20% and 69.40±2.37%, respectively. However, no significant differences ($p > 0.05$) on the overrun of the coconut milk ice cream with 10 and 15 g of BC per 100 g of ice cream. According to Flores & Goff (1999), it was suggested that the amount of air cells at 70% was optimum value of overrun to prevent collisions among ice crystals. Thus, coconut milk ice cream with 15 g of BC per 100 g of ice cream mix was the nearest optimum overrun value.

Texture of Coconut Milk Ice Cream

It was found that BC addition had significant difference on hardness ($p \leq 0.05$) (Table 6). The hardness of ice cream with 5 g of BC per 100 g of ice cream was 488.21±45.90 g and when the BC content was increased to 10 g and 15 g per 100 g of ice cream, the hardness of ice cream was increased to 882.60±84.38 and 1088.95±52.59 g, respectively.

Table 5. Overrun of coconut milk ice cream with different ratios of BC addition

BC addition	Overrun (%)
5 g of BC	51.78±2.95[b]
10 g of BC	62.00±2.20[a]
15 g of BC	69.40±2.37[a]

Values are expressed as mean ± SD (n=2). Different letters in the same column indicate significant difference (p<0.05).

Table 6. Textural properties of coconut milk ice cream with different ratios of BC addition

BC addition	Hardness (g)	Gumminess (g)	Chewiness (g)
5 g of BC	488.21±45.90[c]	20.29±2.89[c]	14.28±1.99[b]
10 g of BC	882.60±84.38[b]	35.04±2.38[b]	33.55±2.76[a]
15 g of BC	1088.95±52.59[a]	42.75±4.08[a]	35.24±3.96[a]

Values are expressed as mean ± SD (n=2). Different letters in the same column indicate significant difference (p<0.05).

Gumminess refers to the energy required in disintegrating the ice cream before swallowing. It was found that BC addition gave a significant increase ($p \leq 0.05$) in gumminess of the coconut milk ice cream (Table 6). The gumminess values of ice cream with 5, 10 and 15g of BC per 100 g of ice cream were 20.29±2.89 g, 35.04±2.38 and 42.75±4.08 g, respectively. It was also observed that increasing BC from 5 g to 10 g per 100 g of ice cream resulted in higher increment in gumminess than increasing BC from 10 g to 15 g per 100 g of ice cream.

Chewiness refers to viscoelastic behavior of the ice cream while chewing. It was found that BC addition had significant difference ($p < 0.05$) on chewiness of the coconut milk ice cream (Table 6). The chewiness of ice cream dramatically increased from14.28±1.99 to 33.55±2.76 g as BC addition increased from 5 to 10 g of BC per 100 g of ice cream. However, when the BC content was increased from 10 g to 15 g per 100 g of ice cream mix, the chewiness of ice cream was slightly increased from 33.55±2.76 to 35.24±3.96 g which was not statistically significant ($p > 0.05$).

It was obvious that the increases in values of hardness, gumminess and chewiness were related to the greater amount of BC in coconut milk ice cream. This may be attributed to the crucial properties of BC that it retained high strength and water-holding capacity (Azeredo et al., 2019). Moreover, stability of emulsion achieved by the addition of BC might be due to the ability of BC to stabilize the network of fat droplets around the air cells (Xavier & Ramana, 2021). The TPA results of 15 g of BC per 100 g of ice cream mix were close to those reported by Pon et al. (2015). According to Pon et al. (2015), the hardness, gumminess and chewiness of ice cream were approximately 1139.26±83.98, 46.62±9.81 and 41.98±11.06 g, respectively. On top of this, as mentioned earlier, the hardness values of ice cream with 10 g and 15 g BC per 100 g of ice cream were 882.60±84.38 and 1088.95±52.59 g, respectively. Both hardness values were close to the range of hardness (847.86 – 1086.28 g) reported by Fuangpaiboon & Kijroongrojana (2015). However, 15 g BC per 100 g of ice cream was preferred due to higher added amount of BC.

Melting Rate of Coconut Milk Ice Cream

The values of melting rate of coconut milk ice cream samples are shown in Table 7. The results showed that higher amount of BC caused a decrease in melting rate of ice cream. The melting rate of ice cream with 5 g of BC per 100 g of ice cream was 1.57±0.14 g/min and when the BC content was increased to 10 g and 15 g per 100 g of ice cream, the melting rate of ice cream was decreased to 0.72±0.04 and 0.54±0.10g, respectively. It was observed that an increase of BC from 5 g to 10 g per 100 g of ice cream mixture resulted in a significant decrease in melting rate. However, an increase in BC from 10 g to 15 g per 100 g of ice cream showed a non-significant decrease (p >0.05) in melting rate. Sofjan & Hartel (2004) found that ice cream with higher overrun (containing a higher amount of air) tended to meltdown slowly due to a decrease in thermal diffusivity. Lower values of thermal diffusivity indicated that the ability of heat to penetrate into the ice cream became less. Furthermore, Xavier & Ramana (2021) reported higher concentration of cellulose fiber may be contributed to a significant increase in the melting time of ice cream. Feizi et al. (2021) reported that high concentration of basil seed gum as stabilizer in ice cream resulted in higher viscosity of the ice cream mix, which provided higher melting resistance.

Table 7. Melting rate of coconut milk ice cream with different ratios of BC addition

BC addition	Melting rate (g/min)
5 g of BC	1.57±0.14[a]
10 g of BC	0.72±0.04[b]
15 g of BC	0.54±0.10[b]

Values are expressed as mean ± SD (n=2). Different letters in the same column indicate significant difference (p<0.05).

CONCLUSIONS

The effect of the addition of 5, 10, and 15 g of BC per 100 g of ice cream mix on texture and other properties of coconut milk ice cream was investigated in this work. It was observed that the consistency of the aged coconut milk ice cream mix and overrun of the churned coconut milk ice cream were higher due to higher BC addition. Furthermore, the higher added amount of BC resulted in a decrease in melting rate but an increase in textural parameters in terms of hardness, gumminess and chewiness of coconut milk ice cream. Consequently, addition of 15 g of BC per 100 g of ice cream mix was recommended based on overall results of the investigated quality attributes, especially texture of coconut milk ice cream. Thus, BC was considered to be a potential replacement for the stabilizing agent in coconut milk ice cream. Final remarks, sensory evaluation of the studied and similar benchmark coconut milk ice cream products should be further performed and correlated with each investigated quality attribute.

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