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Research article

Effect of palm sugar concentration and mixing order on physical properties of coconut milk

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Abstract

The effects were investigated of the palm sugar concentration (10–50 wt%) and mixing order of added sugar (before or after homogenization) on the physical properties of coconut milk (10 wt% fat). The fat droplet size, microstructure, viscosity and creaming index of coconut milk samples were determined after being pasteurized at 72°C for 20 min and then kept overnight. The results showed that the sugar concentration affected the physical properties of the coconut milk. An increase in the palm sugar concentration increased the fat droplet size and viscosity, while the creaming index decreased. The mixing order affected the coconut milk properties. The addition of palm sugar before homogenization resulted in higher stability of the coconut milk than from addition after homogenization. Overall, this study has important implications for the formulation and production of coconut milk products.

Introduction

Coconut milk, obtained from coconut (*Cocos nucifera* L.), is the aqueous extract of coconut meat either with or without the addition of water. It is an oil-in-water emulsion which contains coconut fat droplets stabilized by coconut proteins and phospholipids (Monera and del Rosario, 1982). In many tropical countries, it is widely used as a food ingredient such as in curries and desserts (Seow and Gwee, 1997). For Thai desserts, coconut sugar or palm sugar is usually added to fresh or heated coconut milk and mixed well. Palm sugar is a natural sugar that is widely consumed in Asia and it is produced by heating the sap derived from a species of palm tree (*Borassus flabellifer*) on a wood-fired stove (>100°C) until it becomes a concentrate with a brown color and typical aroma. The unique flavor and color of palm sugar have made it popular as a flavoring agent in desserts (Ho et al., 2007; Naknean and Meenune, 2011).

Emulsion-based foods are compositionally complex and must undergo a variety of different processing operations. Ingredients added to the emulsion may affect the physicochemical properties and its stability. The current study investigated the addition of sugar to coconut milk. Some studies have shown that sucrose affects the thermal stability of protein-stabilized emulsions and can lead to increased fat droplet aggregation (Kulmyrzaev et al., 2000; Kim et al., 2003). The addition of sugar can also slightly increase the fat droplet diameter which could be attributed to the large change in the dispersed:continuous phase viscosity ratio. The influence of various sugars on emulsion properties was studied by Liang et al. (2014) who found that the addition of sugars during emulsification could increase the fat droplet diameter. Since the fat droplet size depends on the viscosity ratio (dispersed:continuous) of an emulsion, the lower the ratio, the smaller the fat droplet size that can be achieved. Moreover, the addition of sugar reduced the heat coagulation time of protein-stabilized emulsion. Adding sugar could decrease the heat coagulation time for protein and the emulsion, suggesting that adding

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sugar decreases the repulsive force between protein particles and between fat droplets (Liang et al., 2014). Maskan and Göğüş (2000) also showed that the addition of sugar (0–8 wt%) could improve the emulsion stability by increasing the emulsion viscosity. This they believed was related to molecular movements, interfacial formation and the physical barriers with ingredients. Jirapeangtong et al. (2008) reported the effects of coconut sugar and stabilizing agents on some physical properties of coconut milk that contained 30% fat and found that both coconut sugar and stabilizing agents affected the emulsion properties such as the stability and rheological properties. Therefore, it is important to understand the effect of the molecular environment and processing conditions on the functionality of emulsions (Kim et al., 2003) and in the production of pasteurized coconut milk with added sugar, it is important to specify the suitable amount of palm sugar and the process. The current study investigated the effect of palm sugar concentration (0–50 wt%) and mixing order (before or after homogenization) on the physical properties of coconut milk. The addition of palm sugar into coconut milk would be expected to alter the coconut milk properties. A preliminary study (data not shown) indicated that the fat content of coconut milk in Thai dessert ranged from 9 to 13 wt% and the mixing order of the added sugar (whether before or after homogenization) affected the coconut milk properties. Therefore, in the current study, the coconut milk was prepared with a final fat concentration of 10 wt% and the effect of palm sugar (10–50 wt%) was investigated as well as the mixing order (before or after homogenization) of the added sugar in the pasteurized coconut milk.

Materials and Methods

Materials

Fresh coconut milk extracted without the addition of water was purchased from a local retailer in Bangkok, Thailand. Palm sugar (10.80 wt% moisture content) was purchased from a local manufacture in Phetchaburi province, Thailand. Sucrose esters (S1170, containing mainly 55% monoester with 45% di-poly-ester and moisture content 3.72 wt%) was purchased from Mitsubishi Kagaku Foods (Tokyo, Japan). Carboxymethyl cellulose (Blanose® 7HF, moisture content 11.38 wt%) was donated by Bronson and Jacobs International (Bangkok, Thailand). All other chemicals were of analytical grade. Distilled, deionized water was used for the preparation of all solutions.

Pasteurized coconut milk preparation

Fresh coconut milk was extracted from coconut white meat without the addition of water. The initial fat content of the fresh coconut milk was determined using the Babcock method for determination of the fat content in dairy products (AOAC Official Method 989.04; AOAC 2006). A weighed amount (0.5 wt%) of sucrose esters was added to coconut milk and mixed with carboxymethyl cellulose solution (0.3 wt%). The palm sugar solution was mixed (before or after homogenization) into aliquots of coconut milk to obtain a final fat content of 10 wt% and a palm sugar concentration of 10–50 wt%. Each coconut milk sample was pre-homogenized at 15,000 rpm for 3 min using a high-speed homogenizer (Ultra-Turrax T25; IKA; Staufen, Germany). The coconut milk samples were heated at 70°C for 1 min to prevent deterioration due to microorganism spoilage and chemical change caused by lipase (Seow and Gwee, 1997; Jirapeangtong et al., 2008). Then, the samples were homogenized using a high-pressure valve homogenizer at 200/20 bar for three passes (APV 2000; SPX Flow Technology; Unna, Germany) and pasteurized at 72°C for 20 min. (Seow and Gwee, 1997). Following this, the hot pasteurized coconut milk samples were poured into glass bottles (250 mL; DURAN ® laboratory bottle (143 mm height, 40 mm internal diameter)). Sodium azide (0.02 wt%) was added (Sinaga et al., 2018) as a chemical preservative to the final emulsions in order to prevent microbial growth in the samples which were used to assess the physical characteristics (Hebishy et al., 2013). All pasteurized coconut milk samples (water activity values ranged from 0.901 to 0.994) were stored for 24 hr at room temperature before being analyzed and the experiment was repeated three times with freshly prepared samples.

Fat droplet size measurement

The fat droplet size of the coconut milk samples was determined using a dynamic light scattering instrument (Zetasizer Nano series-Zen 3600; Malvern Instruments; Malvern, UK). To avoid multiple scattering effects during measurement, the coconut milk samples were diluted to approximately 0.001% fat. The diluted samples were poured into disposable capillary cells (DTS0012), and then equilibrated at 25°C in the instrument for 60 s prior to measurement. The refractive indices of 1.33 for water and 1.45 for coconut oil were used to determine the optical properties of the coconut milk samples. Fat droplet sizes were reported as the Z-average diameter.

Optical microscopy

The coconut milk samples were diluted using distilled water at a ratio of 1:25 in glass test tubes and gently agitated to ensure complete homogenization. A drop of each sample was placed on a microscope slide under a cover slip. The microstructure of each coconut milk sample was then observed under 100× magnification using a conventional optical microscope (J/902165; Carl Zeiss; Oberkocken, Germany). Pictures were taken from different fields on each slide and representative micrographs were presented (Tangsuphoom and Coupland, 2008).

Rheological measurement

The rheological properties of the coconut milk samples were measured using a rheometer (MCR 300; Physica; Stuttgart, Germany) operating with a DG26.7 double gap rotational cylinder. Each coconut milk sample (8 mL) was gently mixed and then portions were transferred to the instrument (Tipvarakarnkoon et al., 2010). The instrument had previously been equilibrated at 25°C and the test was run after pre-shearing for 2 min. The shear rate was increased from 10 s^{-1} to 1000 s^{-1}. The apparent viscosity at a shear rate of 50 s^{-1} was selected to present the effect of the palm sugar concentration and mixing order on the pasteurized coconut milk viscosity. The presented data were based on the average of three replicates. The shear stress (τ) data were also used to analyze the consistency index (K) and the flow behavior index (n) according to the power law shown in Equation 1:

$$\tau = K\sigma^n \quad (1)$$

For an ideal Newtonian liquid, $n = 1$, for an emulsion which exhibits shear thinning, $n < 1$ and for an emulsion which exhibits shear thickening, $n > 1$ (Dickinson, 1992).

Creaming index measurement

Creaming is a form of gravitational separation and is usually regarded as having an adverse effect on the quality of food emulsions (McClements, 2015). The effect of palm sugar and mixing order on the creaming stability of coconut milk samples was examined since each product is unique because it contains different types of ingredients and experiences different environmental conditions during its processing, storage and consumption. Each pasteurized coconut milk sample (10 g) was transferred into a glass test tube (internal diameter 15 mm, height 150 mm), covered and stored for 14 d at room temperature. During storage, each coconut milk sample separated into an opaque cream layer at the top and a transparent serum layer at the bottom. The total heights of the emulsions (H_E) and the height of the serum layer (H_S) were measured. The extent of the phase separation was characterized using the % creaming index = 100 × (H_S/H_E) with the lower the creaming index, the higher the emulsion stability (modified from Tangsuphoom and Coupland, 2008).

Statistical analysis

Data were presented as the mean ± SD of triplicate measurements. One-way analysis of variance and Duncan's multiple range tests were used to evaluate the significance of differences ($p < 0.05$) between the samples. Analyses were conducted using a computer statistical program (version 12; SPSS Inc.; Chicago, IL, USA).

Results and Discussion

Palm sugar is generally used in Thai desserts because of its unique flavor and color. The sugar composition of palm sugar is 79.24–87.72% sucrose, 1.04–5.74% glucose and 0.16–3.05% fructose (Naknean, 2010). The pasteurized coconut milk samples were prepared with varying concentrations (10–50 wt%) of palm sugar as well as varying the mixing order for adding the sugar (either before or after the homogenization step) and the different physical properties were compared. All coconut milk samples had a light brown color attributable to the original palm sugar color.

Fat droplet size and microstructure

The size of fat droplets produced during homogenization is important, because it determines the stability, appearance, texture and taste of the emulsion (McClements, 2015). The fat droplet size of the coconut milk samples was determined using a dynamic light scattering instrument. Fig. 1 shows the average fat droplet size for the pasteurized coconut milk samples with an increase in the palm sugar concentration from 10 to 50 wt% significantly increasing the average of fat droplet size of coconut milk. This may have been due to less effective fat droplet disruption in the homogenizer, probably with some larger fat droplets produced by recoalescence during or after emulsification, as well as some kind of bridging flocculation of sugar (Dickinson and Merino, 2002; McClements, 2015). Similar results were reported by Kim et al. (2003) who found that the presence of sucrose in the aqueous phase of the emulsions had a strong impact on the kinetics of fat droplet aggregation. Increasing the palm sugar concentration could lead to increase the fat droplet aggregation. The mixing order of the added sugar also had a significant influence on the fat droplet size of coconut milk. The addition of palm sugar to the samples before homogenization resulted in a smaller fat droplet size than with the addition after homogenization. The difference in fat droplet size and aggregation of pasteurized coconut milk samples was confirmed by the droplet size distributions and optical microscopy (Fig. 2), which showed a binomial distribution in the samples with added sugar after homogenization, while good dispersion of fat droplets in the aqueous phase was clearly seen for the coconut milk sample with added palm sugar before homogenization. This may have been due to the addition of sugar after homogenization influencing the flocculation behavior of the coconut milk samples. McClements (2004) showed that the addition of sucrose had several effects on emulsions depending on the sucrose concentration and the adding process. A number of physical mechanisms were hypothesized to account for the observed effects of sucrose on the stability of the emulsions to droplet flocculation: 1) sucrose increases the viscosity of the continuous phase, which should slow down the rate of droplet-droplet collisions; 2) sucrose alters the physicochemical properties of the aqueous solution surrounding the droplets which may change the height of the repulsive energy barrier and alter the fraction of collisions leading to aggregation; 3) sucrose puts the proteins under osmotic stress, which may slow down the kinetics of protein surface denaturation; and 4) sucrose increases the attractive interactions between emulsion droplets through a short-range molecular depletion interaction, which may strengthen the bonds between flocculated droplets.

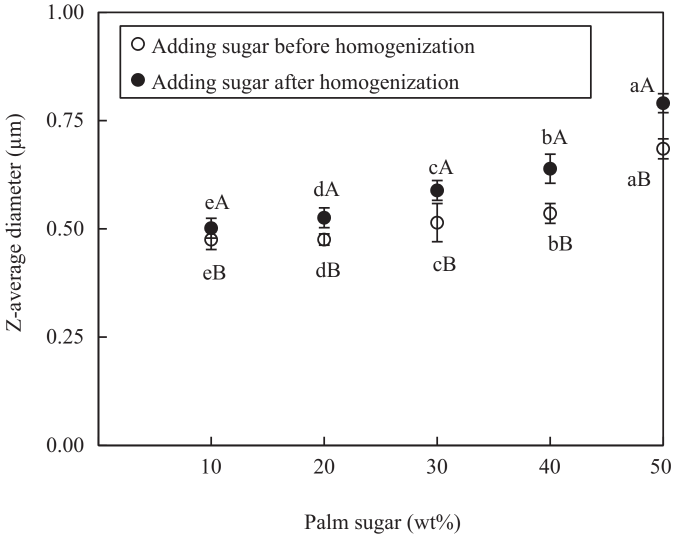

Fig. 1 Average fat droplet size of pasteurized coconut milk with added palm sugar (10–50 wt%) before and after homogenization, where each point represents the mean of three replicates, error bars indicate ±SD and different lowercase letters (palm sugar concentration) and uppercase letters (mixing order) indicate significant differences ($p < 0.05$)

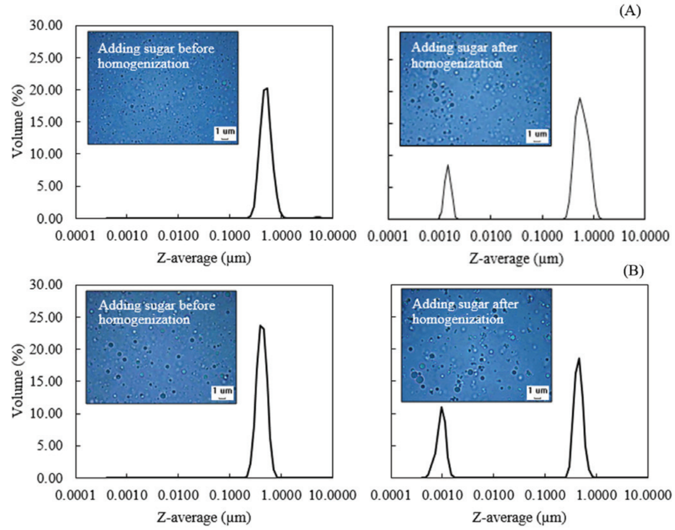

Fig. 2 Droplet size distributions and optical microscopy (inset) of selected coconut milk samples before and after homogenization with: (row A) added palm sugar 10 wt%; (row B) added palm sugar 50 wt%

Rheological properties of pasteurized coconut milk

The rheological properties of the emulsion influence the formation, stability and texture of many food emulsions (McClements, 2015). The pasteurized coconut milk samples provided non-Newtonian samples that exhibited shear thinning behavior at all palm sugar concentrations, whose apparent viscosity decreased with increasing shear rate. Similar flow behavior was reported in previous studies (Simuang et al., 2004; Tangsuphoom and Coupland, 2005; Jirapeangtong et al., 2008). The flow curves were modeled using a power law equation which is a model that is frequently used to describe emulsion rheology (McClements, 2015). Table 1 contains the values for the power law parameter (Equation 1) showing the consistency index (K) and flow behavior index (n). This model can be used to fit the data with a high correlation ($r^2 > 0.99$). The values of flow behavior index (n) were consistently below unity ($n < 1$) indicating a shear thinning behavior of the pasteurized coconut milk samples at all palm sugar concentrations. The consistency index (K) is an indicator of the viscous nature of food (Maskan and Göğüş, 2000) and was observed to increase significantly with increasing palm sugar concentration. K values of the coconut milk samples had values ranging from 44.80 to 591.00 mPa.s, which results suggested that an increase in the palm sugar concentration resulted in an increase in the coconut milk viscosity. Fig. 3 shows the effect of the palm sugar concentration on the coconut milk viscosity (shear rate 50 s^{-1}). It was found that pasteurized coconut milk samples were more viscous when a higher sugar content was added to the samples. Likewise, Maskan and Göğüş (2000) reported that increased sugar concentration increased the viscosity of sunflower oil in water emulsions. In addition, the mixing order of added sugar significantly affected the viscosity of the coconut milk samples. Coconut milk samples with added sugar after homogenization were more viscous than coconut milk samples with added sugar before homogenization, which was consistent with the presence of fat droplet aggregation due to the effective diameter of the fat droplets increasing and leading to increased emulsion viscosity (McClements, 2015).

Table 1 Effects of palm sugar concentration and mixing order on consistency index and flow behavior index

Palm sugar	Consistency index (mPa.s)		Flow behavior index		r^2	
(wt%)	Before	After	Before	After	Before	After
10	44.80±18.95^{dA*}	53.20±3.39^{dA}	0.775±0.004^{dA}	0.778±0.008^{dA}	1.00	1.00
20	64.10±6.65^{dA}	67.10±7.50^{dA}	0.803±0.015^{dA}	0.808±0.019^{dA}	1.00	1.00
30	93.90±24.89^{cA}	107.35±7.00^{cA}	0.808±0.011^{cA}	0.829±0.001^{cA}	1.00	1.00
40	191.30±17.54^{bB}	220.45±27.29^{bA}	0.810±0.015^{bA}	0.872±0.006^{bA}	1.00	1.00
50	367.75±60.46^{aB}	591.00±37.89^{aA}	0.861±0.000^{aA}	0.888±0.041^{aA}	0.99	1.00

Means ± SD are shown (n = 3); r^2 = Coefficient of determination

* In each tested parameter, different uppercase, superscript letters indicate significant differences between means in the same row ($p < 0.05$), and different lowercase, superscript letters indicate significant differences between means in the same column ($p < 0.05$).

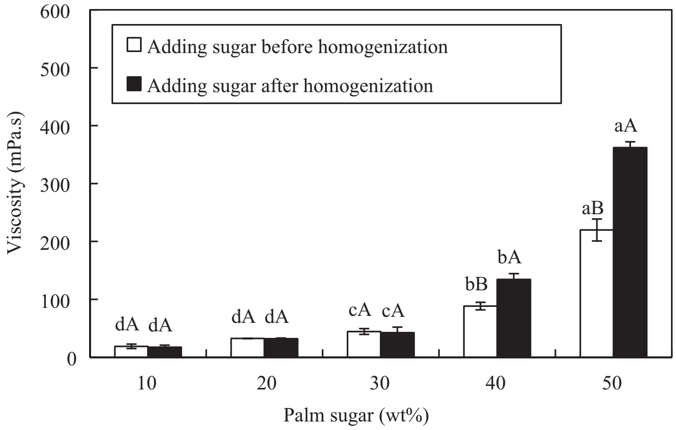

Fig. 3 Viscosity of pasteurized coconut milk with added palm sugar (10–50 wt%) before and after homogenization (error bar = ±SD) where different lowercase letters (palm sugar concentration) and uppercase letters (mixing order) indicate significant differences ($p < 0.05$)

Stability in pasteurized coconut milk

This study observed the creaming stability of coconut milk samples during storage. A consumer expects to see a product that appears homogeneous (McClements, 2015). Generally, creaming provides indirect information about the extent of fat droplet aggregation in an emulsion; the higher the creaming index, the faster the fat droplets move, and therefore the greater the amount of fat droplet aggregation that has occurred (McClements, 2015). The creaming index of the pasteurized coconut milk samples with different palm sugar concentrations are shown in Fig. 4. The sugar concentration had a significant effect on the creaming index and the creaming index of coconut milk decreased as the sugar concentration increased. These results agreed with published studies (Maskan and Göğüş, 2000; Jirapeangtong et al., 2008) that reported an increase in the sugar content increased the stability of an emulsion system, which may have been because the sugar could be used as a stabilizer (Maskan and Göğüş, 2000; Kim et al., 2003; Jirapeangtong et al., 2008; Liang et al., 2014). Better stability of the coconut milk after storage for 14 d was obtained for the coconut milk containing 50 wt% palm sugar. The results implied that sugar plays a significant role in the stability of coconut milk because the sugar can increase the viscosity of the continuous phase and retard fat droplet aggregation (Kim et al., 2003; McClements, 2004). Jirapeangtong et al. (2008) also reported an increase in coconut milk stability due to the amount of sugar added. In the current study, the influence of the mixing order of added palm sugar was also related to the stability of the coconut milk samples ($p < 0.05$). The creaming index (after 1 d and 7 d storage time) of coconut milk samples with added sugar before homogenization (Fig. 4A) was lower than that of coconut milk samples with added sugar after homogenization (Fig. 4B).

The current study revealed that the palm sugar concentration and the mixing order of added sugar can affect the physical properties of pasteurized coconut milk. Increasing the palm sugar concentration increased the fat droplet size and viscosity but decreased the creaming index, because the additional sugar increased the viscosity of the continuous phase and retarded fat droplet aggregation. Therefore, the addition of sugar before the homogenization step could increase the efficacy of the process, while the addition of sugar after the homogenization did not break the flocs and aggregated fat droplets. The results presented in this study are useful for coconut milk product development by facilitating the formulation and process design.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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