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RESEARCH ARTICLE

Skim coconut milk processing by thermal- and ultrasonic-thermal pasteurization

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OBJECTIVES The coconut industry in Indonesia is significant for national income, with the potential for value-added products that could enhance the industry's expansion. Skim coconut milk, a by-product of virgin coconut oil production, is a healthy substitute for dairy milk that can be consumed by people with lactose intolerance. The low-fat and high-protein content of skim coconut milk makes it a healthier alternative to regular coconut milk and cow milk. This study compares ultrasonic-assisted pasteurization of skim coconut milk to conventional pasteurization technique in terms of contamination reduction efficacy and energy efficiency with minimum characteristic change. METHODS The process consisted of thawing frozen skim coconut milk, homogenization of liquid skim coconut milk and pasteurization in a shaking water bath or ultrasonic bath. Total cell counting was conducted, D-value and z-value were estimated to measure the effectiveness of pasteurization in reducing the number of harmful microorganisms in skim coconut milk. RESULTS The study found that ultrasonic-assisted pasteurization reduced the number of microorganisms more effectively than conventional pasteurization with a lower energy consumption. The study showed the removal efficiency of ultrasonic-assisted pasteurization and conventional pasteurization at 70 °C and 15 minutes were 28.74% and 12.33%, respectively. At that condition, energy consumption for every microbial cell being removed was approximately 3 times lower in ultrasonic-assisted pasteurization than the conventional one (0.13 kWh vs. 0.36 kWh). Skim coconut milk processed by ultrasonic-assisted pasteurization at 75 °C for 15 minutes featured homogeneous white liquid with shelf time of 11.2 h, which was 2.65 times longer than the unprocessed coconut skim milk. CONCLUSIONS The research suggests that ultrasonic-assisted pasteurization can be a feasible and sustainable processing technology for skim coconut milk, with potential commercial value for small companies and farmers in Indonesia.

KEYWORDS Pasteurization; preservation; shelf life; skim coconut milk; ultrasonication

1. INTRODUCTION

Coconut (*Cocos nucifera* L.) is one of socioeconomically important agricultural crops in Indonesia. Followed by the Philippines and India, Indonesia has supplied the most coconut-based commodities, contributing to national income of more than USD 1.17 billion in 2020 (Directorate General of Estates Crops 2022). As concerns about health and the environment continue to grow rapidly in global society, it is a big opportunity for the coconut industry in Indonesia, which is currently about 98% handled by small companies and farmers to expand through the creation of value-added products within an integrated agroindustry ecosystem (Alouw and Wulandari 2020). The coconut industry offers a plethora of potential creative products such as coconut coir, coir yarn, coco-peat, mats, as well as various food products such as coconut water drinks, nata de coco, coconut vinegar, coconut sauce, coconut flour, coconut milk, coconut butter, virgin coconut oil (VCO), copra, and young coconuts.

Skim coconut milk is the aqueous by-product of VCO production from coconut milk or cream. This by-product may reach up to 51.9% of the coconut milk mass. Skimmed coconut milk has a mild coconut flavor and is often used in cooking and baking as a substitute for dairy milk since it is safe to be consumed by people with lactose intolerance. Moreover, less fat and higher protein content in the skim coconut milk may assign good branding to skim coconut milk as healthier alternative to the original coconut milk and cow milk (Table 1).

Research on skim coconut milk processing was previously done in various methods such as ultra-high tempera-

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TABLE 1. Nutritional composition of coconut milk, skim coconut milk and cow milk (Deshapriya et al. 2019; Naik et al. 2013).

Component	Coconut milk (%)	Skim coconut milk (%)	Cow milk (%)
Water	49,6	85,7	87.5
Protein	3,7	4,2	2.9
Sugar	5.1	7.3	4.1
Fat	33,2	0,8	4.5
Minerals	0,6	0,8	0.8

ture (UHT) sterilization (Khuenpet et al. 2016), spray drying (Naik et al. 2012) and ultrafiltration (Ng et al. 2014). Such technologies are quite modern and effective yet require large investment and complex processing equipment, which are not preferred by small companies and farmers in Indonesia. Moreover, certain drawbacks, such as protein loss caused by heat denaturation, nozzle blockage and membrane fouling, make it infeasible to apply these technologies for long term operation. Similar problem was also found in pasteurization, a generally used simple processing technique for liquid food products. Deposition of denatured coconut milk protein on the heated surface followed by adsorption of fat, carbohydrate and minerals as the pasteurization goes further could cause more nutrition loss in the product as well as more difficult cleaning in industry (Saikhwan et al. 2022).

Recent studies found that ultrasonic treatment could provide significant advantages for the processing of milk including enhanced quality factors, such as yield, extraction, cloudiness, rheological properties, and color as well as the shelf life with lower processing temperature and time (Balthazar et al. 2019; Maghsoudlou et al. 2015; Ragab et al. 2019). However, to the best of our knowledge, application of ultrasonics for skim coconut milk still cannot be found anywhere. Hence, we introduce ultrasonic-assisted pasteurization as a new approach to pasteurizing the skim coconut milk. This study compared ultrasonic-assisted pasteurization of skim coconut milk to the conventional pasteurization technique in terms of contamination reduction efficacy. Moreover, energy efficiency of each technique was discussed. Shelf-time of original and processed skim coconut milk at room temperature were also monitored.

2. RESEARCH METHODOLOGY

2.1 Materials

Frozen skim coconut milk was obtained from a VCO producer in Malang, East Java, Indonesia. ISO/APHA standard plate count agar (PCA) powder was obtained from Pronadisa, Spain. Endospore staining dyes such as safranin and malachite green were purchased from Merck, USA.

2.2 Procedures

Frozen skim coconut milk was thawed in a water bath at room temperature for 1 h and then homogenized by a stirring mixer at 1500 rpm for 5 minutes. A 250 mL glass flask with 100 mL skim coconut milk as working volume was used for each batch. In conventional pasteurization process, the flask was put into a shaking water bath at 70-85 °C under continuous agitation at 300 rpm for 15 minutes. The ultrasonic assisted pasteurization was conducted by putting the flask inside an ultrasonic bath (40 kHz) at 50-75 °C for 15 minutes to pasteurize the skim coconut milk. Total energy consumption for both pasteurization techniques were measured by kWh meter connected to the instruments.

After pasteurization, 1 mL of pasteurized skim coconut milk was taken for total cell counting by pour plate method and endospore staining. Briefly, 1 mL of sample was diluted in series by 0.85 $g.L^{-1}$ NaCl solution then mixed into liquid PCA. Samples in solidified agar were incubated at 37 °C for 12 h prior to colony forming unit (CFU) counting. The average values of CFU of each mL sample were processed further to estimate D-value and z-value according to a previous study (Vatankhah et al. 2019). D-value is the decimal reduction time and Z-value is the temperature sensitivity indicator. Remained diluted samples were objected to endospore staining procedure using malachite green-safranin dyes sequentially.

The process that resulted in the skim coconut milk that potentially met the Indonesian Food and Drug Authority regulation (Peraturan Badan POM No. 13 Tahun 2019) was further evaluated by prolonging the processing time up to 1 hour. Furthermore, shelf life of standard-passed product was determined by pouring 12 mL of each sample into several 15 mL

TABLE 2. Total cell number (log $CFU.mL^{-1}$), D-value and z-value of skim coconut milk.

Skim coconut milk	T (°C)	log CFU.mL-1	D-value (minutes)	z-value (°C)
Original	30	6.21 ± 0.15	NA	NA
Conventionally Pasteurized (15 minutes)	70	5.44 ± 0.02	19.50	131.12
	80	5.42 ± 0.04	19.01	
	85	5.17 ± 0.08	14.44	
Ultrasonicated (15 minutes)	50	5.04 ± 0.24	12.83	34.33
	70	4.42 ± 0.37	8.38	
	75	2.81 ± 0.09	4.41	

NA : not available

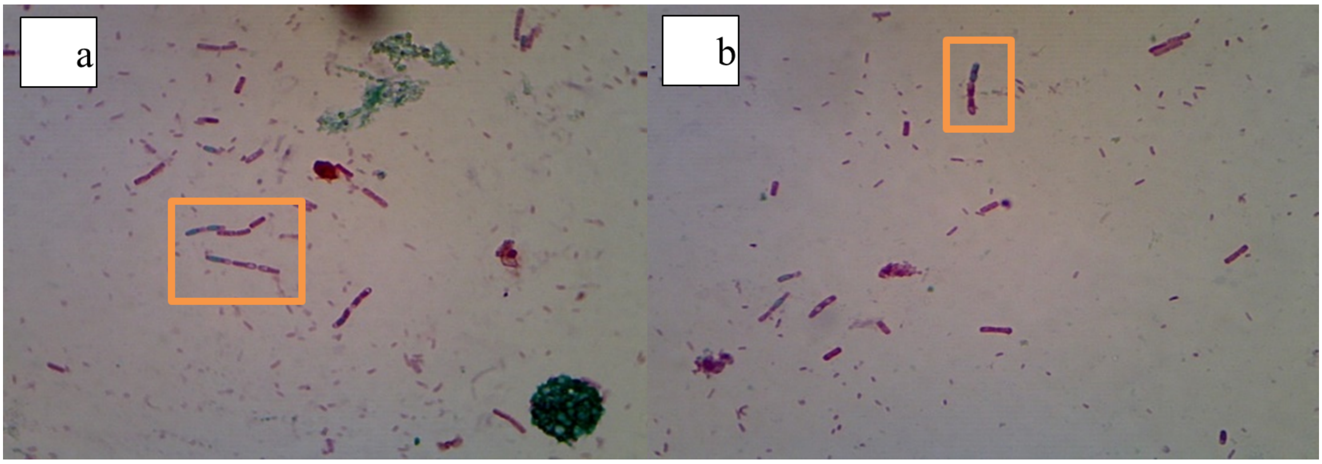

FIGURE 1. Endospore staining of pasteurized skim coconut milk by (a) conventional pasteurization at 85 °C for 15 minutes and (b) sonicated pasteurization at 70 °C for 15 minutes.

Falcon tubes. The tubes were then placed into incubator at 30 °C. The pH of samples was measured every hour. The measurement was stopped when the pH was below 5.9, which indicated product spoilage (Codex Alimentarius CXS 240-2003 standard). The shelf life of the unprocessed skim coconut milk was used to contrast the processing effect on the product storage lifetime. All analyses were conducted at least in duplicate and the average value was expressed as the results.

3. RESULTS AND DISCUSSION

In this study, z-value and D-value are used to measure the effectiveness of pasteurization in reducing the number of harmful microorganisms in skim coconut milk (Table 2). At the same temperature and time (70 °C, 15 minutes), ultra-

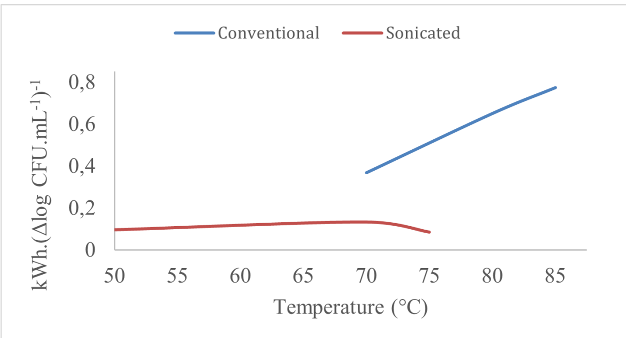

FIGURE 2. Energy economy of conventional and sonicated pasteurization.

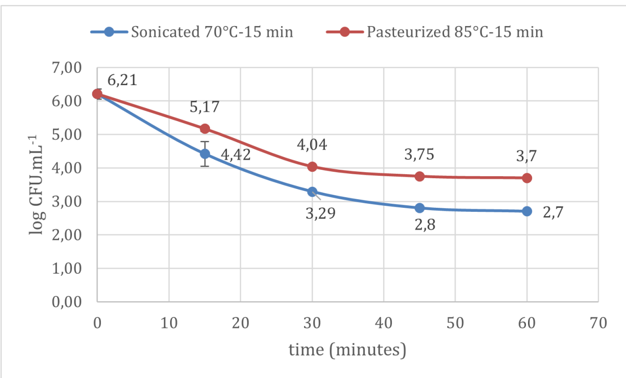

FIGURE 3. Total cell count in sonicated pasteurization and pasteurized coconut milk.

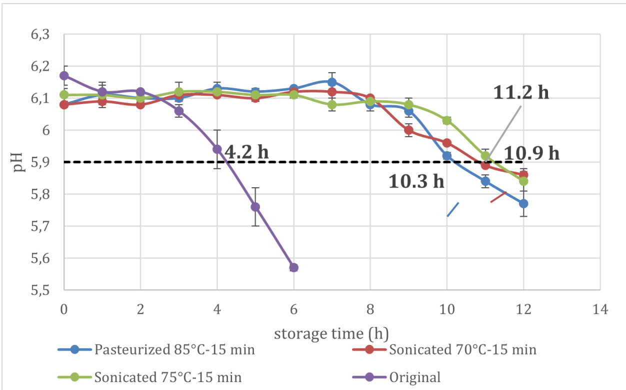

FIGURE 4. Acidity profile of skim coconut milk samples at 30 °C storage.

sonic assistance successfully lowered total cell count approximately to 1-log than that of conventional pasteurization. Higher temperature processing showed steady decrease of total cell count for both processes. However, increasing temperature in conventional pasteurization did not show meaningful impact as the ultrasonicated one. Since two processes worked in different temperature range, z-value was used to fairly assess the effect of increasing temperature and processing time.

Z-value is a measure of heat (energy) required to achieve a tenfold reduction of D-value, which represents the time required to reduce the number of microorganisms by one logarithmic unit at a specific temperature. A higher z-value indicates that more heat is required to reduce the number of microorganisms, which could indicate heat resistance of the microbial cells. In the case of pasteurization, the z-value was found to be 131.1 °C. However, the z-value for ultrasonication was found to be only 34.3 °C. On the other hand, the D-value of pasteurization was found to be between 14.4-19.5 minutes, whereas the D-value for ultrasonicated pasteurization was between 4.4-12.8 minutes. This suggests better heat penetration of ultrasonicated pasteurization than that of conventional one.

This was also in conform to the observed results in the previous study of Sukasih et al. (2009). In that study, heat resistant bacteria presence was indicated by high z-value and D-value, which had quite similar values compared to this study. Based on the microscopic analysis, it was found that heat resistance characteristic of the microbes was the result of the microbial capability to form endospores during pasteurization (Figure 1). When these endospores were exposed to a conducive growth environment, including the availability of nutrients, water, growing temperature, and other suitable physical parameters, the endospores would germinate and begin their metabolic activity, ultimately causing the spoilage of skim coconut milk.

Energy consumption of both processes were depicted in Figure 2. It was observed that sonication consumed 3-8 times of the energy used to lower down the microbes in conventional pasteurization. Such advantages lead to better energy economy and less environmental impact. Lower energy consumption was related to the efficacy of sonication to transfer the heat that damaged the cells. Relatively flat energy consumption with increasing temperature in ultrasonicated system showed that energy was transferred efficiently and utilized effectively through cavitation to eliminate microbial cells in the system. Increasing energy consumption per eliminated microbes in conventional pasteurization reflected ineffective heat utilization to eliminate heat resistant microbes as well as less efficient energy transfer due to protein coagulation.

According to Peraturan Badan POM No. 13 Tahun 2019, a safe batch of coconut milk should not have more than 2 samples containing a total cell count between 4-5 log CFU.mL^{-1}. To ensure consumer safety, it is further suggested that all samples have a total cell count lower than 4 log CFU.mL^{-1}. Longer processing of skim coconut milk containing a total cell count close to that limit resulted in a lower microbial cell count to a certain extent (Figure 3). Prolonging the process for 15 minutes more ideally lowered the CFU count by 1-log as indicated by the D-value of the corresponding process. However, prolonged process more than 30 minutes did not result in further reduction in microbial count. Interestingly, sonicated pasteurization could produce a lower cell count than conventional pasteurization, despite the lower temperature used. This confirms the resistance of microbial cells, which tend to suppress heat penetration more than the ultrasonic wave.

Pasteurized skim coconut milk that met the limit set by the Indonesian Food and Drug Authority was obtained from sonicated pasteurization at 75 °C for 15 minutes. The lower cell count in sonicated skim coconut milk at 75 °C for 15 minutes caused its shelf life to be longer than the unprocessed and pasteurized ones when stored at room temperature (Figure 4). This suggests that the sonication process harnesses mechanical shearing waves through the liquid and denatured protein (the white clumps in Figure 5), allowing better heat penetration to the cells and possibly inactivation of intracellular function (Nunes et al. 2022). Although a lower cell count was achieved, the shelf life of sonicated skim coconut milk at 75 °C for 15 minutes differed slightly compared to that of 70 °C for 15 minutes, indicating disproportionality between total cell count and shelf life. A more homogeneous product appearance of sonicated skim coconut milk compared to the pasteurized one in Figure 5 showcased the ultrasonic ability to homogenize fat/oil emulsion in cow milk and plant-based milks as reported in previous studies (Munir et al. 2019; Sarangapany et al. 2022). A higher processing temperature also resulted in a more yellowish color than the lower one, which conforms to the result of thermal processing of coconut milk in a previous study (Khuenpet et al. 2016).

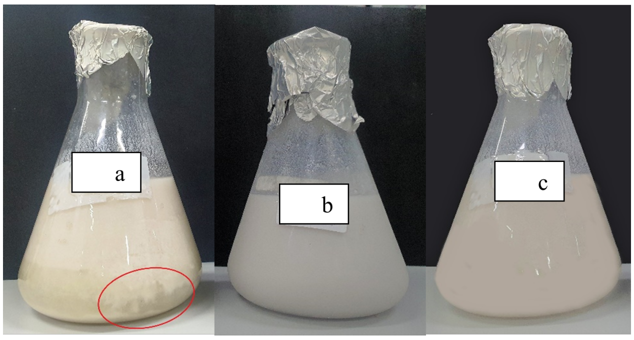

FIGURE 5. Pictures of (a) conventionally pasteurized at 85 °C and ultrasonicated skim coconut at (b) 70 °C and (c) 75°C for 15 minutes.

4. CONCLUSIONS

Ultrasonication is a promising method for microbial decontamination of food products. It requires less energy compared to conventional pasteurization and has a lower D-value, indicating better efficiency. This is due to the ability of ultrasonication to penetrates the body of liquid and breaking the solid clumps. The same ability also improved the visual property of pasteurized coconut milk. Longer processing time by D-value scale could compensate the shortcoming of lower temperature or ineffective pasteurization mode at certain extent. The advantages of ultrasonication may be further used to increase the product value of small coconut industry in Indonesia. According to the findings of the study, the removal efficiency of ultrasonic-assisted pasteurization was 28.74 percent while the removal effectiveness of traditional pasteurization at 70 °C and 15 minutes was 12.33 percent. When performed under these conditions, ultrasonic-assisted pasteurization had an energy consumption that was roughly three times lower than traditional pasteurization for each and every microbial cell that was eliminated (0.13 kWh vs. 0.36 kWh). The unprocessed coconut milk had a shelf life that was 2.65 times shorter than the shelf life of the skim coconut milk that had been processed using ultrasonic-assisted pasteurization at 75 °C for 15 minutes. This processing method produced a homogenous white liquid with a shelf life of 11.2 hours. According to the findings of the research, ultrasonic-assisted pasteurization may be an option for a practicable and long-term processing technology for skim coconut milk.

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