Heliyon 10 (2024) e29002

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Determining key factors affecting coconut sap quality after harvesting

Jintana Wiboonsirikul [a], Pornthipa Ongkunaruk [b,*], Piyarat Poonpan [c]

[a] Division of Food Science and Technology, Faculty of Agricultural Technology, Phetchaburi, 76000, Thailand
[b] Department of Industrial Engineering, Faculty of Engineering, Kasetsart University, Bangkok, 10900, Thailand
[c] Department of Agro-Industrial Technology, Faculty of Agro-Industry, Kasetsart University, Bangkok, 10900, Thailand

A R T I C L E I N F O

Keywords:
Coconut sap
Factorial design
Preservative type
Taguchi
Temperature
Washing method

A B S T R A C T

The production of coconut sap beverages faces a challenge with the quality of the incoming coconut sap sourced from farmers. The clarification of pivotal factors influencing the quality of coconut sap after harvesting is of paramount importance for fostering mutual benefit between the involved parties. This research focuses on assessing the quality and degradation of coconut sap during the post-harvest stage. It addresses the shortcomings in evaluating coconut sap quality and improper pick-up conditions. To improve these processes, various experiments were designed, including 1) preliminary experiments that explored microbial count, pH, and soluble solids in harvested coconut sap at varying intervals, and 2) the L9 Taguchi Orthogonal Array method. These approaches identify the optimal levels of factors such as cleaning method, storage temperature, and preservative type. By reducing the number of experiments, costs and time were minimized, 3) the 23 factorial design was implemented, reducing the levels of each factor while measuring coconut sap quality based on pH and total soluble solids (representing sweetness) at different post-harvest intervals. The results from the Taguchi method were then used to design the factorial method experiment. The analysis revealed crucial factors influencing coconut sap quality at the 10-h mark. Storage and transportation temperatures, along with the type of preservative, significantly impacted the pH value. However, the washing method and preservative type showed no statistically significant effect on Total Soluble Solids (TSS) value ($p > 0.05$). Recommendations include using tap water for container cleaning, opting for Payom wood as a preservative, and adhering to cold chain practices for transportation exceeding 4 h, with temperatures maintained below or equal to 10 °*C*. Swift sap collection within 4 h post-harvest, coupled with stringent temperature control during transportation (not exceeding 10 °*C*), is advised to ensure optimal quality. Integrating pH with TSS values enhances comprehensive quality assessment, aligning with established best practices in coconut sap handling.

1. Introduction

Coconut sap, also known as neera, is a naturally sweet liquid extracted from the inflorescence flowers of the coconut palm tree. Renowned for its health benefits, it contains amino acids, minerals, vitamins, and antioxidants, making it a suitable option for individuals with diabetes [1–6]. When collected in controlled containers for 10–12 h, unfermented coconut sap exhibits a slightly

* Corresponding author.
E-mail addresses: wiboonsirikul@yahoo.com (J. Wiboonsirikul), pornthipa.o@ku.ac.th (P. Ongkunaruk), pp_piyarat@hotmail.com (P. Poonpan).

https://doi.org/10.1016/j.heliyon.2024.e29002
Received 7 December 2023; Received in revised form 3 March 2024; Accepted 28 March 2024
Available online 7 April 2024
2405-8440/

alkaline, golden-brown color with a mild sweetness. Conversely, traditional sap collection without temperature control leads to microbial fermentation, resulting in an acidic, off-white sap with a distinct fermented odor [1,7]. Microbial growth, encompassing both bacteria and yeast and mold, poses a significant threat to coconut sap quality during harvesting and transportation, emphasizing the necessity for temperature reduction and adherence to hygienic practices [4,8]. To inhibit undesirable microorganisms, various procedures are employed, involving the use of both natural and synthetic preservatives, each with its unique advantages and disadvantages [1,9–14].

Ensuring the safety and quality of coconut sap requires meticulous pretreatment of collecting containers [15]. Community entrepreneurs in Thailand adopt various methods, including washing with tap water, canal water, or boiled water. While boiled water is considered the most hygienic option, its practicality is hindered by cost and time constraints. Canal water, readily available in most fields, emerges as a common and accessible choice [4]. The challenge in maintaining coconut sap beverage quality lies in the quality of incoming sap from farmers. Identifying factors influencing post-harvest sap quality is crucial for fostering mutual benefits, with parameters such as pH, total soluble solids, and bubble formation serving as key indicators for farmers in the coconut fields [1,11,16]. To optimize factors affecting coconut sap quality, both the Taguchi method and factorial experimental design prove valuable. The Taguchi method, utilizing orthogonal arrays, effectively reduces the number of experimental trials, thus saving time and cost [17–19]. On the other hand, factorial design systematically varies factor levels, providing insights into main effects and interactions, albeit potentially requiring more time [20–22]. This study aims to investigate the effects of post-harvest temperature, container cleaning method, and preservative type on coconut sap quality, employing both Taguchi orthogonal design and factorial experimental design.

The primary objective is to establish a model that can serve as a guiding framework for other food and beverage manufacturers in maintaining the high quality of their raw materials. The research structure comprises a comprehensive exploration, beginning with the significance and background of coconut sap beverages and the literature review, emphasizing related research on Taguchi and factorial design. Subsequently, the materials and methods section elucidates the experimental setup, incorporating detailed descriptions of methods and the statistical techniques employed. The results section presents the findings of the statistical analyses, while the discussion section offers a comparative analysis of Taguchi and factorial design, highlighting noteworthy findings, and providing recommendations for farmers and coconut manufacturers. Finally, the conclusion section emphasizes the achievements, findings, and contributions of the study, proposing potential avenues for future research.

2. Materials and methods

2.1. Materials and preliminary studies

To collect coconut sap, plastic cylinder containers were hung on the proboscis of coconut trees (*Cocos nucifera* L.) for 12 h. The collection took place in the evenings of September and November, from a coconut tree farm located in Mueang District, Samut Song Kram Province, Thailand. Payom wood chips (*Shorea roxburghii* G. Don) were obtained from a local market in the same province, while food-grade sodium metabisulfite ($Na_2S_2O_5$) was purchased from a chemical store in Bangkok, Thailand. Clean plastic cylinders were used in the study and were pre-washed and air-dried before use. These cylinders were obtained from the same coconut tree farm where the sap was collected.

The study conducted preliminary experiments to assess the changes in pH, total soluble solids (TSS in ^{o}Brix unit), and total microbial count in coconut sap after harvest for different intervals (0–8 h) under specific conditions. These conditions included a 12-h collection period, a pre-treatment method of cleaning the plastic cylinders with canal water, a preservative used of 5 mL of 1.189 g/L of $Na_2S_2O_5$, and a post-harvesting temperature of 25–30 °C (Ambient Temperature), which are commonly used by processing companies for pre- and post-harvesting methods of coconut sap. The TSS and pH were measured at the coconut tree farm, while the total microbial count was determined in a microbiology laboratory at Central Lab in Thailand. The coconut sap was collected using pre-sterilized glass bottles at the predetermined harvesting intervals and immediately placed in a foam box with ice before being transported to the laboratory for analysis.

2.2. Pre- and post-harvesting factors of coconut sap quality

Two pre-harvesting factors, including the type of cleaning water used for the plastic cylinders and the type of preservative added, and one post-harvesting factor of the transportation temperature were studied for the effect on pH and TSS of the coconut sap after harvesting for 4 h and 8 h. Each factor had 3 levels, which are detailed in Table 1. To maintain temperatures below ambient, ice or a mixture of ice and water were used in the ice boxes (for ≤10 °C and 11–20 °C, respectively). Two types of preservatives were used including sodium metabisulfite solution with the same amount used in the preliminary studies and 3 g of Payom wood chips were

Table 1
Studied pre- and post-harvesting factors and levels of coconut sap quality.

Factors	Level		
	(1)	(2)	(3)
1. Transportation temperature (T)	≤10 °*C*	11-20 °*C*	ambient (>21 °*C*)
2. Cleaning water (C)	Boiled Water	Tap Water	Canal Water
3. Type of preservatives (P)	None	Payom	$Na_2S_2O_5$

added to the plastic cylinders.

2.3. Evaluation of coconut sap quality

At each evaluation time and treatment, the coconut sap was collected randomly using plastic cups to measure its quality. The TSS content was evaluated using a refractometer (N1 Atago, Japan) calibrated with deionized distilled water before measurement. The pH values were measured using a pH meter (ST 20 Ohaus, China) calibrated with buffer solutions of pH 4 and pH 7. The total microbial counts of the coconut sap were evaluated by counting colony-forming units (CFUs) on plate count agar (PCA; Oxoid Ltd, Hampshire, UK) according to the U.S. Food and Drug Administration (2001) method. To obtain separated colonies when plating, a 10-fold serial dilution of the microbial population of the coconut sap was prepared using Butterfield's phosphate buffered water (HiMedia, PA, USA). Ten milliliters of the coconut sap from one harvesting interval were added to 90 mL of the diluent in a stomacher bag and mixed thoroughly with a stomacher to create a 10^{-1} dilution (w/v). From the resulting homogenate, 1 mL was sampled and serially diluted to obtain dilutions of 10^{-2} to 10^{-7}. One milliliter of each respective dilution was plated onto *petri dishes* prior to pouring the plate count agar (PCA) at around 45 °C. The inoculated plates were then incubated at 35 °C in an inverted position for 48 ± 2 h. After incubation, the number of colonies per plate was counted using a colony counter, with plates containing colonies of 25–250 being used for the calculation of the total microbial count as CFU/mL.

2.4. Experimental design and statistical analysis

Regression analyses and correlation were performed in Microsoft Excel® software between pH, TSS, total microbial counts, and post-harvesting times to determine the best-fitted model. The overall model performance was evaluated using R^2 and *RMSE* values. In this study, two different experimental designs were used to investigate the effects of the factors on the quality of the coconut sap after harvesting. The first design was the Taguchi L_9 orthogonal design, and the second was the 2^3 factorial design.

2.4.1. Taguchi orthogonal experimental design

Based on the Taguchi L_9 (3^3) orthogonal design, three factors were examined at three different levels, resulting in a total of 27 trials. From these trials, nine treatments were obtained to investigate the influence of each factor on the quality of coconut sap, as shown in Table 2 (Roy, 2010). The pH and TSS responses were evaluated for two transportation intervals (4 and 8 h) with two replications, based on the factors and levels mentioned in Table 2. The signal-to-noise (S/N) ratio for each experimental run and transportation time was calculated using Eq. (1), with the objective function of "larger is better" response characteristic [22–25].

$$S/N = -10\log\left[1/n\left(\sum_{i=1}^{n}\frac{1}{y_i}^2\right)\right]. \tag{1}$$

Where y_i = observed pH or TSS at a repetition of i, n = number of repetitions.

To determine the influence of each factor, the overall mean value of the S/N ratio across the three experimental runs of the same factor was calculated for each factor and level. The influence value of a factor was defined as the absolute difference between the average of the S/N ratio at the maximum and minimum levels of the factor. The % influence of each factor was then calculated using Eq. (2) [26]:

$$\%\ \text{influence} = (\text{influence of a factor/sum of all influence})\ \text{x}\ 100 \tag{2}$$

The statistical software Minitab version 16 was utilized to analyze variance (ANOVA) and *t*-test to obtain the corresponding statistical significance for each factor and transportation time at a 95% confidence interval. The mean difference between 9 different experimental numbers according to the Taguchi method was carried out by Duncan's new multiple range test at a 95% confidence interval.

Table 2
The orthogonal array of Taguchi method with L_9 experiment determining pre- and post-harvesting factors of coconut sap quality.

Exp.	Factor level			Factor level		
	Transportation temp. (T)	Cleaning water (C)	Preservative (P)	Transportation temp. (T)	Cleaning water (C)	Preservative (P)
1	1	1	1	≤10 °C	Boiled Water	None
2	1	2	2	≤10 °C	Tap Water	Payom
3	1	3	3	≤10 °C	Canal Water	$Na_2S_2O_5$
4	2	1	2	11-20 °C	Boiled Water	Payom
5	2	2	3	11-20 °C	Tap Water	$Na_2S_2O_5$
6	2	3	1	11-20 °C	Canal Water	None
7	3	1	3	>21 °C	Boiled Water	$Na_2S_2O_5$
8	3	2	1	>21 °C	Tap Water	None
9	3	3	2	>21 °C	Canal Water	Payom

2.4.2. Factorial experimental design

To assess the interaction effect among the factors, a 2^3 factorial experimental design was conducted. The controlled factors and levels were transportation temperatures, cleaning water, and preservative types with two levels each. The levels included a temperature of $\leq 10\ ^{\circ}C$ and ambient (21–30 $^{\circ}C$), tap water and canal water for cleaning water, and Payom woodchip and sodium metabisulfite solution for preservative types, as shown in Table 3. The responses of pH and TSS values with two replications for transportation interval times of 0–10 h after harvest, according to the factors and levels in Table 3, were evaluated. The interaction effects among the factors for transportation times of 4 and 8 h were analyzed using Minitab version 16 at a confidence interval of 95% for ANOVA and mean differences using Duncan's new multiple range test.

2.5. Validation of experiment

Following the identification of factors influencing coconut sap quality, the study progressed to a practical validation phase conducted in authentic farm and factory settings. The confirmation test specifically delved into the examination of factors affecting coconut sap quality, commencing with the washing of cylinders utilizing canal water and the introduction of sodium metabisulfite. Executed during September and November, the experiment involved the collection of approximately 300–500 mL of sugar harvested from coconut trees. A cylinder washed with canal water was used, and the harvested coconut sap was poured into a 20-litre plastic cylinder without closing the lid, representing the worst-case scenario. Coconut sap was gathered under two distinct temperature conditions—low temperatures ($\leq 10\ ^{\circ}C$) and ambient temperatures (25–35 $^{\circ}C$). Subsequently, a comprehensive assessment was undertaken, encompassing the examination of physical attributes, gas bubble characteristics (including bubble height measured in millimeters), and olfactory observations above the surface of the coconut sap within plastic cylinders. These evaluations were conducted post-harvest at varying transportation times ranging from 0 to 8 h. This approach allowed for a systematic and coherent analysis of the impact of the identified factors on coconut sap quality in real-world scenarios.

3. Results

3.1. Relationships between total microbial loads, pH, total soluble solid (TSS), and post-harvest intervals

To determine the optimal level of factors for collecting coconut sap, the preliminary experiments were conducted to investigate relationships among the total microbial count, pH, and total soluble solid in the coconut sap after harvesting for different intervals starting from 0 to 8 h (Fig. 1 (a - b)). It is clear that pH and TSS values of the coconut sap decreased with longer post-harvesting intervals at ambient temperature in the linear relation. On the contrary, the total microbial content increased as a function of post-harvest intervals in the exponential model. When pH or TSS was related to the total microbial count, both of them exhibited a power model (Fig. 1 (c)). Changes in TSS and pH values are in good relation with the total microbial count with a high value of R^2 and low value of *RMSE* ($R^2 = 0.958$, $RMSE = 0.034$ and $R^2 = 0.9307$, $RMSE = 0.085$, respectively). The pH and TSS values of the coconut sap decreased rapidly before the growth of microorganisms reached 1 log CFU/mL and gradually decreased after that was higher than 1 log CFU/mL. In addition, analysis of total microbial count requires time-consuming and high analysis costs as well as may be subjected to easily systematic error from contamination during collecting samples in the field, use of pH and TSS measurement in further investigation and data collection for statistical analysis would be done instead of measurement of total microbial count.

3.2. Taguchi method for screening factors affecting the coconut sap quality after harvesting

The Taguchi method was employed to analyze the optimal conditions during the harvesting stage and after harvesting coconut sap. The analysis involved calculating the average results and the average of each factor from the experiment (Fig. 2 (a) – (f)). Based on the product, there were three types of responses: the best response value is the largest (B), the best response value is the smallest (S), and the best response value is closer to the target value (N). For this experiment, the best response value was determined to be the largest since coconut sap with a high pH value. The results of Figs. 1 and 2 emphasized that the storage and transportation temperature significantly influenced the pH value.

Table 3
Factors and levels of factors determined in factorial experiments.

Treatment Number	Name	Treatment		
		Post-Harvest temperature	Cleaning water	Type of preservatives
1	LCS	$\leq 10\ ^{\circ}C$	Canal Water	$Na_2S_2O_5$
2	LCP	$\leq 10\ ^{\circ}C$	Canal Water	Payom
3	LTS	$\leq 10\ ^{\circ}C$	Tap Water	$Na_2S_2O_5$
4	LTP	$\leq 10\ ^{\circ}C$	Tap Water	Payom
5	HCS	Ambient	Canal Water	$Na_2S_2O_5$
6	HCP	Ambient	Canal Water	Payom
7	HTS	Ambient	Tap Water	$Na_2S_2O_5$
8	HTP	Ambient	Tap Water	Payom

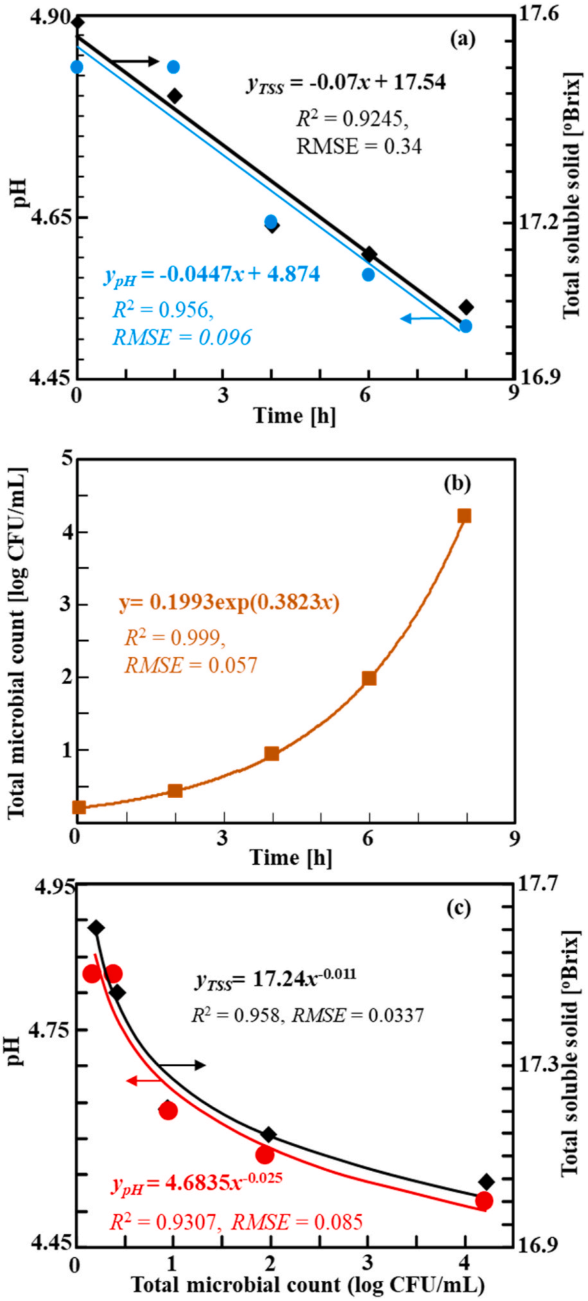

Fig. 1. Dependence of (a) pH (♦,—) and total soluble solid (●,—),(b) total microbial count on post-harvest interval time and (c) dependence of pH ♦,—) and total soluble solid (●,—) on total microbial count.

The next step in Table 4 involved using the S/N ratio to determine the influence of factors affecting the pH (Fig. 2 (a)–(c) and TSS (Fig. 2 (d)-(f)) values by calculating the average of factors at each level. These factors were responsible for 57.62 % of the pH value variation during the 4-h post-harvest period. The type of preservative and cylinder washing had a secondary influence, respectively. Furthermore, the influence of temperature factors in storage and transportation increased by 10.01 percent, while the influence of preservative factors decreased by 10.24 percent. Similarly, it was found that the TSS value of coconut sap falls within the range of approximately 15–18 ° Brix. When the TSS value obtained in each set of experiments is calculated for the S/N Ratio, it is evident that the temperature of storage and transportation is the most influential factor on sweetness after harvest in the 4th hour at 46.43 percent, followed by the type of preservative with the highest influence on pH at 57.69 percent, followed by the type of preservative (7.69 percent), the washing factor that affects the TSS value (7.69 percent), and the cleaning of cylinders (34.62 percent), respectively.

Furthermore, the ANOVA analysis in Table 4 demonstrated that storage and transportation temperature was significantly

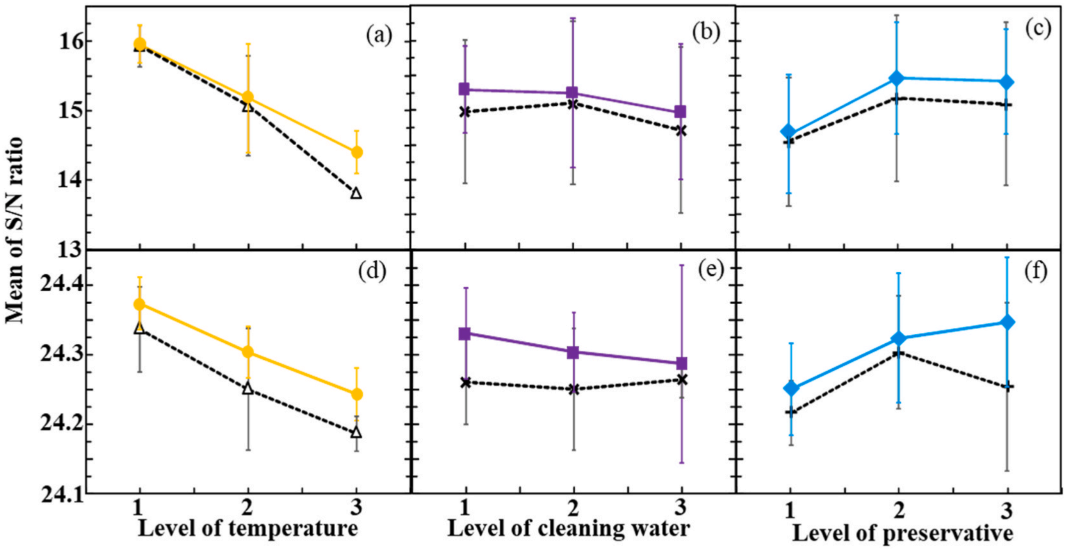

Fig. 2. Main effects plot for S/N ratio of (a, b, and c) pH and (d, e, and f) total soluble solid values of coconut sap with transportation time 4 h (circle, square, and diamond symbols) and 8 h (triangle, cross, and plus symbols) at different levels of temperature, cleaning water, and preservative, respectively.

Table 4
P-Value and % Influence of pH and TSS for Taguchi experiment at 4 and 8 h after harvest.

Method-Output	Taguchi - pH				Taguchi - TSS			
Time	4 h		8 h		4 h		8 h	
Factors	P-Value	% Influence	P-Value	% Influence	P-Value	% Influence	P-Value	% Influence
Temperature	0.038*	57.62%	0.040*	67.63%	0.373	46.43%	0.261	57.69%
Cleaning Method	0.436	12.27%	0.543	12.50%	0.833	17.86%	0.965	7.69%
Preservative Type	0.103	30.11%	0.289	19.87%	0.513	35.71%	0.512	34.62%

influenced the pH values of coconut sap at the 4th but not at the 8th hour ($p < 0.05$). Cylinder cleaning and preservative types, however, did not have a significant impact on pH ($p < 0.05$).Comparing the pH values at these time points, a slight decrease in TSS value was observed with longer waiting times after harvest. However, in each series of experiments, all three factors were found to have an insignificant influence on the quality of coconut sap, including the TSS value ($p > 0.05$).

3.3. 2^3 factorial design for determining factors affecting the coconut sap quality after harvesting

Coconut sap stored at ambient temperature (HCS, HCP, HTS, and HTP) obviously demonstrated a decline in pH over time in comparison with at low temperature (LCS, LCP, LTS, and LTP), especially after 4 h of waiting time as shown in Fig. 3. An increase in temperature during storage and transportation led to a decrease in pH, indicating a decline in coconut sap quality. The TSS value of coconut sap remained similar between the 0 and 10-h trials, with a slight decrease of approximately 0.5° Brix. After harvesting at 4, 8, and 10 h, it was not significantly influenced by the studied factors of storage and transportation temperature, cylinder washing, and preservative type ($p > 0.05$).

The coconut sap stored at low temperatures had better physical qualities, including color, smell, and gas bubbles as shown in Fig. 4 and Table 5. Coconut sap stored at ambient temperature showed an visible increase in gas bubbles and turbid color apperance, as well as a sour smell due to the fermentation process after the 4th hour, while coconut sap stored at low temperatures maintained its quality with no fermentation process. The TSS value of the coconut sap stored at low temperatures was a little lower than that stored at ambient temperature and remained similar in both storage conditions. Physical quality analysis revealed signs of fermentation in coconut sap as early as the 8th hour. At ambient temperature (21–30^{o}C), gas bubbles and a sour smell were observed as shown in Table 5, At ambient temperature, turbidity and lightning of the brown color were observed at 8 and 10 h, respectively. However, storing the sap at low temperatures prevented changes in color and turbidity.

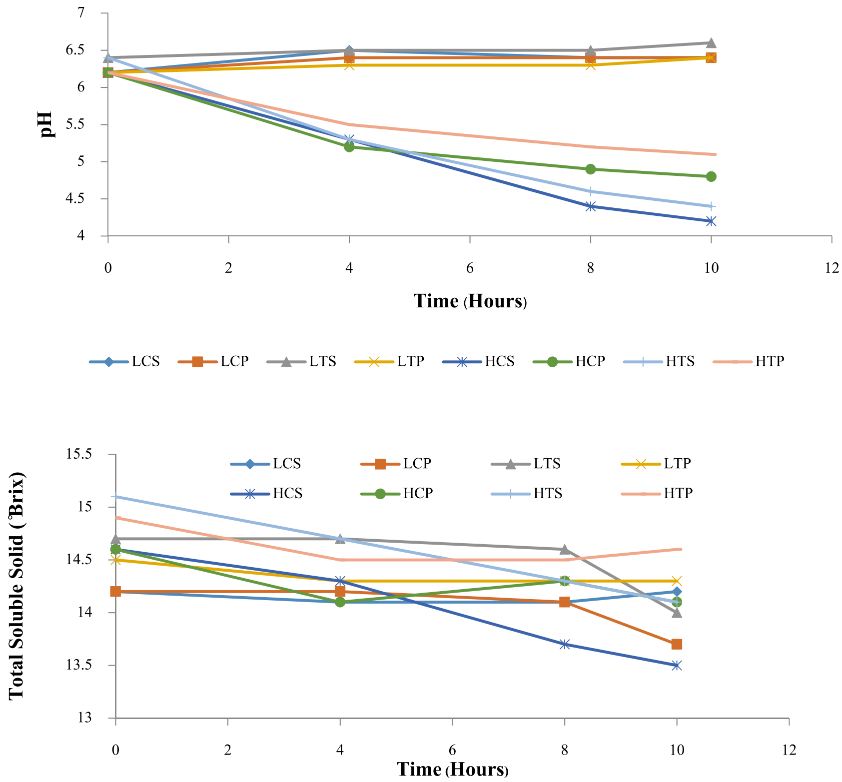

Fig. 3. Effect of waiting time after harvest on pH and TSS of coconut sap (LCS, LCP, LTS, LTP, HCS, HCP, HTS, and HTP) according to 2^3 factorial experiments.

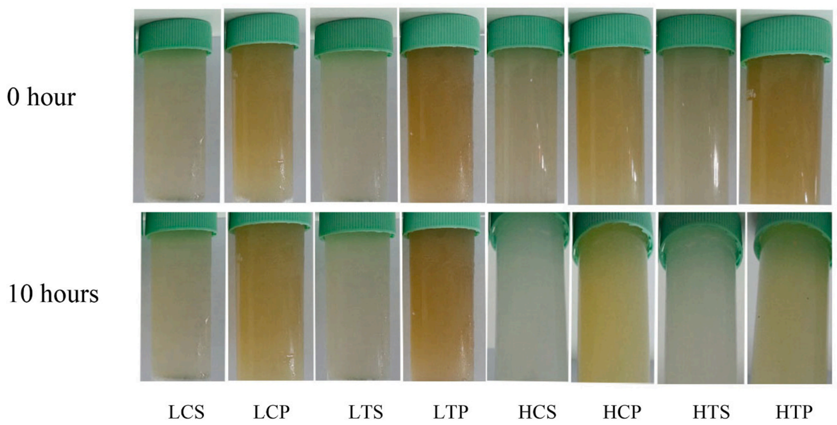

Fig. 4. Changes in color of coconut sap after harvesting for 0 and 10 h. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

3.4. Validation of experiment

The results indicated that changes in coconut sap quality occurred after 4 h of harvesting. Therefore, hours 5, 6, and 7 were replicated to simulate conditions similar to those of most farmers. The experimental findings demonstrated that coconut sap stored at low temperatures exhibited superior physical qualities, such as color, smell, and absence of gas bubbles (gas height ≤6 mm), compared to coconut sap stored at ambient temperature (Fig. 5 (a)-(n) and Table 5). Coconut sap stored at ambient temperature started forming

Table 5
Average results of physical qualities of coconut sap.

Time (Hours)	Physical Property	Treatment							
		1	2	3	4	5	6	7	8
	Abbr.	LCS	LCP	LTS	LTP	HCS	HCP	HTS	HTP
0	Gas height (mm.)	0	0	0	0	0	0	0	0
	Sour smell	–	–	–	–	–	–	–	–
4	Gas height (mm.)	0	0	0	0	0	0	0	0
	Sour smell	–	–	–	–	–	–	–	–
8	Gas height (mm.)	0	0	0	0	10	5	7	2
	Sour smell	–	–	–	–	+	+	+	+
10	Gas height (mm.)	0	0	0	0	13	7	10	5
	Sour smell	–	–	–	–	+	+	+	+

gas bubbles from the 2 nd h (Fig. 5 (i)–(n)), which continually increased in gas volume with longer post-harvest intervals. Additionally, noticeable changes in color, cloudiness, and sour smell due to the fermentation process were observed from the 4th hour onward in ambient temperature storage, whereas coconut sap stored at low temperatures showed no gas bubble, sour smell, or significant changes in color until the 7th hour, as indicated in Table 6 and Fig. 5 (a)–(g). The TSS value remained consistent, and the pH and total soluble solids (TSS) of coconut sap stored at low temperatures demonstrated its ability to maintain quality, with no signs of fermentation during storage.

4. Discussion

In this study, the relationships between total bacteria loads, pH, TSS, and post-harvest intervals were investigated in the preliminary test. By using convenient tools including hand-held pH meter and refractometer, a good correlation between pH, TSS, and total microbial count was obtained. The pH and TSS values are commonly used for the characterization of the coconut sap quality as they could imply fermentation level resulting from microorganism growth. During increasing population, microorganisms utilized sugars as carbon and energy sources and consequently generate organic acids, which led to a decrease in pH and TSS. The major TSS content in the coconut sap is non-reducing and reducing sugar [27,28]. The results are under the other reports, which showed a decrease in pH and non-reducing sugar content as a function of incubation hours and a slight increase in the reduced sugar content [12, 29]. Since the major microorganisms in the coconut sap are yeast, lactic acid bacteria, and acetic acid bacteria, an increase in the total microbial count over incubation times implies the growth of those microorganisms, which are mesophilic and the optimum temperature for growth is around 25–39 °C [27,29].

In the current study, the best response value or pH value of the coconut sap was determined to be the largest, which indicates that the microorganisms in coconut sap have not yet undergone fermentation, and the sugar has been not degraded [30,31]. These findings align with the preliminary results obtained in the study. The storage and transportation time and temperature affect change in pH values of the coconut sap, which is consistent with the findings of Sarma et al. (2022) [32]. The determination of the relationship between factors reveals that the temperature factor in storage and transportation significantly influences the pH value of coconut sap after harvesting at the 4th and 8th hours ($p < 0.05$). The waiting time after harvest increases and the pH value decreases indicate a decline in the quality of coconut sap. This effect is particularly evident when the sap is stored in areas with temperatures ranging from 21 to 30 °C, emphasizing the significance of temperature in storage and transportation on coconut sap quality. Similarly, the optimal conditions for maintaining the quality of coconut sap after harvesting at the 4th and 8th hours, with a focus on TSS value, are consistent. Although the recommendation of storage temperature for coconut sap to slow down fermentation is not higher than 5°C [33], in the current study it is recommended to store and transport the coconut sap at a temperature of 10 °C for farmers to practically use of ice boxes from the field to processing places, which usually take around 30 min. In addition, instead of using chemicals, placing some wood chips at the bottom of the barrel to collect coconut sap as a natural preservative is preferred.

Regarding the factors affecting the quality of coconut sap after harvesting at the 4th hour, the temperature of storage and transportation significantly affects the pH ($p < 0.05$). On the other hand, cylinder cleaning and preservative types do not have a significant influence on pH. An increase in temperature during storage and transportation leads to a lower pH value, indicating a decrease in the quality of coconut sap. Similar findings is observed for coconut sap harvested at the 8th hour, with storage and transportation temperature significantly affecting the pH value ($p < 0.05$). A significant interaction effect between temperature and preservative type is observed ($p < 0.05$). Sodium metabisulfite, as a preservative, slightly improved the quality of coconut sap compared to Payom. However, when coconut sap is stored and transported at ambient temperature, using Payom as a preservative results in better quality compared to sodium metabisulfite. Moreover, the study highlights the effectiveness of natural preservatives such as green betel, mangosteen rind, jackfruit wood, and clover leaf in enhancing the quality profile of coconut sugar compared to the use of chemical powder alone [34]. In summary, the research findings indicate that maintaining coconut sap quality requires certain optimal conditions. These include washing the plastic cylinder with tap water and using Payom wood as a preservative within the first 4 h after harvest, storing and transporting the sap at a temperature of 10 °C, and utilizing natural preservatives rather than chemicals. By adhering to these guidelines, the quality and sweetness of coconut sap can be preserved, resulting in a high-quality end product.

Based on the analysis of the S/N ratio and the relationship between various factors, the optimal conditions for harvesting coconut

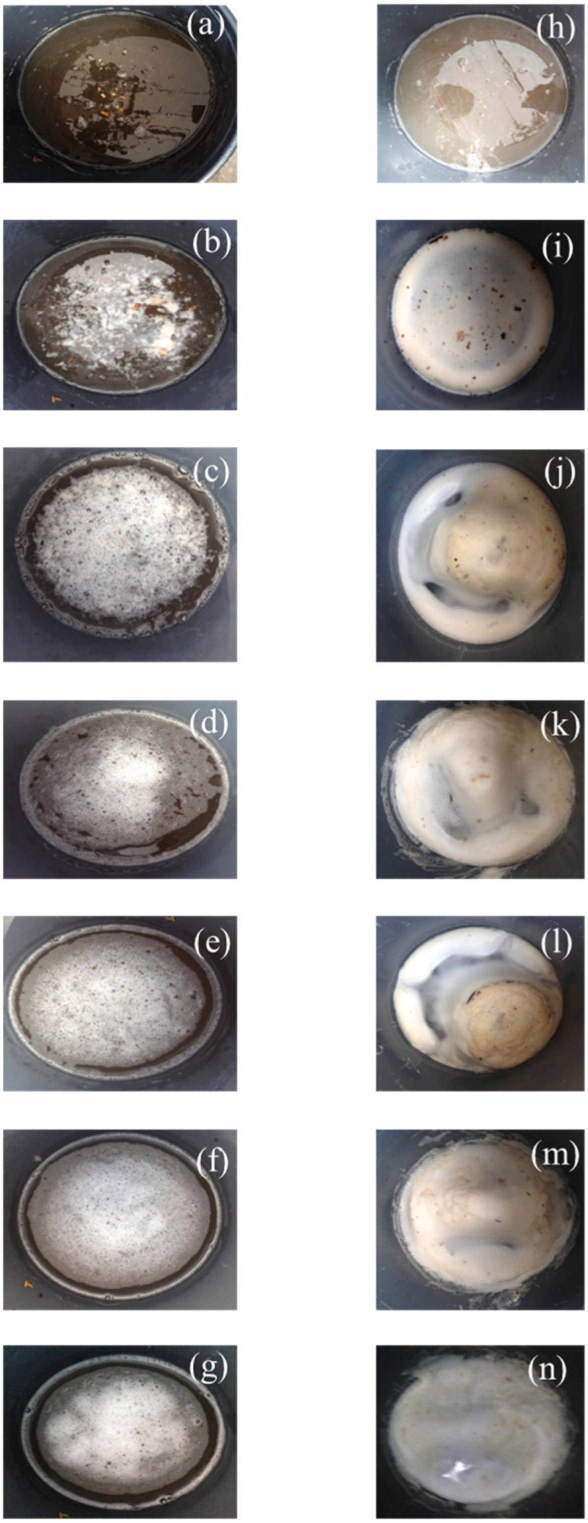

Fig. 5. Appearance of coconut sap stored at low (a–g) and ambient (h–n) temperatures for 0 h (a, h), 2 h (b, i), 4 h (c, j), 5 h (d, k), 6 h (e, l), 7 h (f, m), and 8 h (g, n).

Table 6
Physical changes in coconut sap at low and ambient temperatures.

Temp. (°C)	Properties	Time (hours)						
		0	2	4	5	6	7	8
≤10	Sour smell	–	–	–	–	–	–	–
	Gas height (mm.)	0	1	4.5	5	5	5	5.5
25–30	Sour smell	–	–	+	+	+	+	+
	Gas height (mm)	0	17.5	22.5	22.5	22.5	30.5	30.5

sap after 4 h are washing the plastic cylinder with hot water and using a preservative, and storing and transporting coconut sap at a temperature of ≤10 °C. For harvesting after 8 h, the plastic cylinder should be washed with tap water, and coconut sap should be stored and transported at a temperature of ≤10 °C. The use of Payom wood chips as a preservative in cylinders is recommended for both cases. These optimal conditions are based on maintaining a pH value of around 6–7, which indicates that coconut sap has not undergone significant degradation due to microbial activity. The optimal conditions for maximizing the TSS value of coconut sap is determined at the harvesting stage and after harvest. According to the relationship between the S/N ratio and the level of each factor, after harvesting in the 4th hour, washing the plastic bucket used to support coconut sap with tap water and using the Payom wood chip as a preservative are the appropriate conditions. Additionally, after harvesting in the 8th hour, any type of water could be used for washing, and the optimal preservative is the wood chip. The optimal conditions for quality management are similar for both the 4th and 8th hours in terms of storage and transportation temperature. Moreover, instead of using chemicals as preservatives, containers should be placed at the bottom of the tank for storing coconut sap. To prevent degradation and microbial contamination, it is advisable to store the sap at low temperatures, preferably in a cold or chilled environment. It is recommended to store and transport the coconut sap at a temperature of ≤10 °C to maintain is quality, and sligly fermentation process occurs during storage.

The physical quality of the coconut sap including gas bubble, color apperarance, and sour smell indicates the involvement of yeast and bacteria [35,36], which produce carbon dioxide bubbles and sour odor. Additionally, appearance in color changes was observed over time. Coconut sap preserved with chemicals exhibited an oyster-white color similar to natural sap, while Payom wood chips as a preservative resulted in a brown color due to polyphenol compounds and enzymatic browning reaction. Turbidity is caused by microorganisms such as yeast and lactic acid bacteria, which produce dextran during fermentation [37], resulting in a milky white appearance.

Considering the budget and time constraints, the implementation of the Taguchi method is essential as it reduces the number of treatments significantly from 81 to 9. After utilizing the Taguchi method to understand the effects of different factors, the factorial design was applied following the reduction in levels. These two methodologies are then compared to determine if their results align, facilitating a thorough analysis of the observed outcomes and providing valuable insights for subsequent steps. This comparative approach strengthens the robustness of the study's findings as shown in Tables 7 and 8. The temperature factors in storage and transportation had a significant impact on pH ($p < 0.05$). However, none of the three factors—storage and transport temperature, cylinder washing, and preservative type—significantly influenced the TSS value ($p > 0.05$). The pH value of coconut sap showed a decrease, while the TSS value exhibited only a slight change. These findings is in line with the results reported by Xia et al. (2011) [38], who found that acidity increased rapidly during the initial 0–24 h of fermentation, while the total sugar content changed minimally. The microorganisms present in coconut sap utilize sugar as a carbon source during fermentation, resulting in a slight alteration in sweetness. As refractomer is a low sensitivity method for measuring sugar content, there were no significant differences observed in the TSS value measured using this technique.

Based on these outcomes, it is recommended to store and transport coconut sap at a temperature of approximately ≤10 °C. The other factors produce similar results, but since they do not have a significant impact on the pH and TSS of coconut sap ($p > 0.05$), the choice of method can depend on other considerations, such as convenience for farmers. The results obtained from both Taguchi and Factorial methods demonstrate consistency, indicating that both experiments hold similar credibility.

Table 9 presents a comparative analysis of trial cost and duration between the Taguchi and factorial methods employed in the experimental study. The findings demonstrate that the Taguchi method exhibited a reduced trial requirement, resulting in a total cost of 3600 baht and a duration of 108 min. In contrast, the factorial method necessitated a higher number of trials, consequently incurring a greater trial cost of 32,400 baht and a lengthier duration of 972 min. This substantial disparity in trial-related parameters can be

Table 7
P-Value Comparison between Taguchi and Factorial Design for different hours.

P-Value	Taguchi - pH		Factorial - pH	
Factors/Time	4 h	8 h	4 h	8 h
Temperature (T)	0.038*	0.040*	0.000*	0.000*
Cleaning Method (C)	0.436	0.543	0.579	0.356
Preservative Type (P)	0.103	0.289	0.724	0.136
T*C			0.606	0.387
T*P			0.660	0.039*
C*P			0.919	0.836
T*C*P			0.639	0.663

Table 8
Comparison of the best factor for each design.

Time	Factor	Response			
		pH		TSS	
		Taguchi	Factorial	Taguchi	Factorial
4	Temperature (T)	$\leq 10\ ^\circ C$	$\leq 10\ ^\circ C$	$\leq 10\ ^\circ C$	$\leq 10\ ^\circ C$
	Cleaning water (C)	Boiled water	Tap Water	Tap Water	Tap Water
	Preservative type (P)	Payom	$Na_2S_2O_5$	$Na_2S_2O_5$	$Na_2S_2O_5$
8	Temperature (T)	$\leq 10\ ^\circ C$	$\leq 10\ ^\circ C$	$\leq 10\ ^\circ C$	$\leq 10\ ^\circ C$
	Cleaning water (C)	Tap Water	Tap Water	Canal Water	Tap Water
	Preservative type (P)	Payom	Payom	Payom	Payom

Table 9
Comparison of performance in different experiments.

Detail	Experimental Design	
	Taguchi	Factorial
Number of Repetitions	9	81
Total treatments	36	324
Total Experimental Cost (Baht)[a]	3600	32,400
Experiment Time (Minutes)	108	972

[a] The total experimental costs are based on chemical quality analysis, including pH and TSS values.

attributed to the inherent dissimilarities in the trial design specifications of each method, as elucidated in the works of the researchers [39,40]. The observed divergence primarily emanates from the Taguchi method's efficiency in achieving robust results with a diminished number of experimental trials.

There are several key findings in the current study in the realm of the food industry. The quality of raw materials plays a pivotal role in shaping the ultimate quality of finished products. The case of coconut sap underscores the necessity for stakeholders to institute effective cold chain management to preserve its high quality. Post-harvest management involves critical factors, including time, temperature, cleaning water, and the type of preservative, each with various levels. Identifying the optimal factors and their levels requires the application of suitable statistical tools. Our investigation demonstrates that the Taguchi method is effective in discerning the directional impact of factors, albeit yielding pH results different from those obtained through factorial design at the 4-h after harvest. Notably, the optimal levels determined by Taguchi and factorial design align closely, except for the TSS at 8 h concerning the cleaning water factor. This suggests that Taguchi serves as a reliable method for quality determination, especially for practical applications. A second noteworthy finding relates to local traditional knowledge, highlighting the use of Payom wood chip as an antimicrobial substance that is both safe for users and consumers. Payom contains polyphenol substances, tannins, and flavonoids renowned for their antimicrobial characteristics [41,42]. Consequently, incorporating it into a coconut sap container has the potential to diminish total bacteria count in coconut sap as revealed by the other researchers [10,42]. This study seeks to identify pivotal factors influencing the quality of harvested coconut sap through the application of statistical techniques, including preliminary experiments aimed at establishing relationships among key quality measurements such as pH, TSS, and TPC. The research operates under constraints of time, budget, and practical limitations. Consequently, parameters such as yeast and mold content, coliform bacteria presence, and ethanol concentration fall beyond the scope of our study. The practical challenge of maintaining a 5 °C temperature poses difficulties in terms of both feasibility and cost. Therefore, an exploration of 10 °C by using ice boxes was adopted to assess its suitability for achieving acceptable quality standards. Lastly, our findings recognize the challenges faced by farmers and small to medium-sized enterprises in maintaining consistently low temperatures throughout the supply chain, which proves to be both costly and logistically demanding. As a more pragmatic alternative, our study proposes a slightly higher temperature, such as 10 °C, which is more feasible and acceptable for implementation within a short lead time.

Some recommendation to coconut sap farmers regarding the cleaning procedure for coconut sap containers are proposed. It is important to use clean, safe water to clean the cylinder containers used to store coconut sap. Using boiled water or treated tap water is generally the most effective and safe option. Table 10 illustrates the comparison of the benefits and drawbacks associated with utilizing boiled water, tap water, and canal water for cleaning coconut sap containers. It is also important to ensure that the containers are thoroughly rinsed and dried before using them to store the coconut sap. Based on the experimental results, it is recommended that farmers use tap or community water supply to clean the plastic cylinders used to support coconut sap. In cases where the plantations are far from tap water resource, canal water can be used. The use of a Payom woodchip [10] at the bottom of the container instead of chemical preservatives is preferred, as there was no significant difference in statistical analysis ($p > 0.05$). Sodium metabisulfite can be used as a preservative but awareness of amount used should follow the food additive regulation. Farmers face substantial challenges in practically achieving and maintaining a temperature of coconut sap at 5 °C due to the formidable hurdles posed by logistical complexity and associated costs. Our research findings suggest that adopting a pragmatic approach, specifically minimizing the transportation duration post-harvest to within 4 h and opting for a temperature of 10 °C, represents a viable alternative. This temperature proves to be sufficient for meeting acceptable quality standards. This practical strategy is consistent with our overarching goal

Table 10
The comparison of the advantages and disadvantages of using boiled water, tap water, and canal water for cleaning the containers of coconut sap.

Washing Method	Advantages	Disadvantages
Boiled water [15]	• Boiling water is an effective way to kill any bacteria or other contaminants that may be present in the containers. • Boiled water is easy to obtain and does not require any special equipment.	• Boiling water can be time-consuming and may not be practical if a large number of containers need to be cleaned. • Boiling water requires fuel or electricity, which could be a cost and environmental consideration.
Tap water [43]	• Tap water is easily accessible and convenient to use. • In many areas, tap water is treated with chemicals to kill bacteria and other contaminants.	• Depending on the quality of the water supply, tap water may not be as effective at killing bacteria as boiling water. • In some areas, the quality of the tap water may be poor and may contain contaminants that could potentially affect the quality of the coconut sap.
Canal water	• Canal water is more convenient for farmers.	• Canal water is not treated and may contain bacteria, chemicals, and other contaminants that could potentially affect the quality of the coconut sap. • Using canal water to clean containers could potentially introduce contaminants to the coconut sap. • Using canal water may not be hygienic or safe, as it may contain harmful microorganisms or other contaminants.

of judiciously utilizing resources to ensure the realization of meaningful outcomes in our study.

The recommendation for pickup system to a sterilized coconut sap manufacturer, likewise, the producer of coconut sap beverages encounters the challenge of preserving the quality of coconut sap procured from farmers while minimizing costs. To uphold product quality standards, it is recommended that the manufacturing entity establish a systematic approach for receiving coconut sap from farmers within a 4-h timeframe post-harvest and implement stringent temperature control measures, ensuring that transportation temperatures do not exceed 10 °C. Additionally, the company should exercise prudence in sourcing coconut sap exclusively from reputable farmers to preclude any compromise in the quality of the coconut sap. Furthermore, it is advised that the company refrain from relying solely on the Total Soluble Solids (TSS) value as a determinant for the purchase price of coconut sap, recognizing its inadequacy as an exclusive indicator of quality. Instead, the integration of the pH value of coconut sap with the TSS value is proposed, enabling a more comprehensive and accurate assessment of coconut sap quality. Subsequently, these combined values can be judiciously employed to establish the purchase price of the coconut sap, facilitating a more nuanced and precise valuation process.

5. Conclusions

In conclusion, this research aimed to assess the quality and degradation of coconut sap in the post-harvest phase. The preliminary experiment revealed a negative correlation between the pH and TSS values of coconut sap and its total microbial content, indicating that microbial fermentation can lead to a decrease in pH and sweetness. The Taguchi method was used to investigate factors influencing coconut sap quality, including cylinder cleaning water and preservative type. The L_9 Orthogonal Array analysis demonstrated that storage and transportation temperature significantly affected pH, while cylinder washing and preservative type did not significantly impact sweetness. The subsequent 2^3 factorial experiments confirmed these findings and revealed a decrease in pH over time, while the TSS value remained relatively stable. These results were validated through retesting in agricultural and factory settings.

Based on these findings, several recommendations are proposed for stakeholders in the coconut sap supply chain. Farmers should prioritize the use of clean and safe water for cleaning containers and opt for Payom wood as a preservative instead of chemicals. Storage and transportation should be carried out under low-temperature conditions ($\leq 10\ ^\circ C$) using cold chains, especially if transportation exceeds 4 h after harvesting. Producers should aim to receive coconut sap within 4 h after harvesting and maintain low-temperature conditions during transportation to prevent degradation. The use of clean water, thorough rinsing, and drying of containers are crucial practices to ensure the quality of coconut sap. Moreover, plastic cylinders can be effectively cleaned with tap or community water supply, while canal water can be utilized in distant plantations. The use of Payom woodchips or sodium metabisulfite as alternatives to chemical preservatives is recommended.

The coconut sap beverage manufacturers are advised to consider both pH and TSS values when determining the purchase price of coconut sap. Implementing a system to receive coconut sap from farmers within a 4-h timeframe after harvesting and ensuring strict temperature control during transportation (maximum of 10 °C) are essential measures. Nevertheless, it is imperative to acknowledge that this study exclusively concentrated on the rainy season in Thailand (September to November). Further research is warranted to explore the factors influencing coconut sap quality during other seasons, specifically in the summer, given the escalating annual temperatures in the country. Furthermore, there is an opportunity to delve into the crucial aspects of yeast and mold content, coliform bacteria presence, and ethanol concentration, which were not extensively examined in the current study.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Jintana Wiboonsirikul: Writing – review & editing, Writing – original draft, Data curation. **Pornthipa Ongkunaruk:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Piyarat Poonpan:** Formal analysis, Data curation, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

Dr.Pornthipa Ongkunaruk acknowledges financial support from the food industry value chain development with cold chain system and packaging project from the Logistics Bureau, Department of Primary Industries and Mines, Ministry of Industry, Thailand.

References

[1] K.B. Hebbar, M. Arivalagan, M.R. Manikantan, A.C. Mathew, C. Thamban, G. Thomas, P. Chowdappa, Coconut inflorescence sap and its value addition as sugar - collection techniques, yield, properties and market perspective, Curr. Sci. 109 (2015) 1411–1417, https://doi.org/10.18520/cs/v109/i8/1411-1417.
[2] N. Leelayuwat, B. Saelim, Y. Kanpettha, P.T. Aneknan, Tong-Un, Effects of organic coconut flower syrup on glucose and insulin responses and substrate utilization, Asia Pac. J. Sci. Technol. 23 (2018) 1–6, https://doi.org/10.14456/apst.2018.16.
[3] M. Asghar, Y.A. Yusof, M.N. Mokhtar, M.E. Ya'acob, H.M. Ghazali, L.S. Chang, Y.N. Manaf, Coconut (*Cocos nucifera* L.) sap as a potential source of sugar: antioxidant and nutritional properties, Food Sci. Nutr. 8 (2019) 1777–1787, https://doi.org/10.1002/fsn3.1191.
[4] D.K. Ghosh, A. Bandyopadhyay, S. Das, K.B. Hebbar, B. Biswas, Coconut sap (Neera)-untapped opportunity of spin off gains in West Bengal, India, Int. J. Curr. Microbiol. Appl. Sci. 7 (7) (2018) 1883–1897, https://doi.org/10.20546/ijcmas.2018.709.229.
[5] R. Sudha, V. Niral, K.B. Hebbar, K. Samsudeen, Coconut inflorescence sap, Curr. Sci. 116 (2019) 1809–1817, https://doi.org/10.18520/cs/v116/i11/1809-1817.
[6] M.A. Zafar, K.R. Mills, J. Zheng, A. Regmi, S. Hu, L. Gou, L. Chen, Low-glycemic index diets as an intervention for diabetes: a systematic review and meta-analysis, Am. J. Clin. Nutr. 110 (2019) 891–902, https://doi.org/10.1093/ajcn/nqz149.
[7] H. Purnomo, Volatile components of coconut fresh sap, sap syrup and coconut sugar, ASEAN Food J. 14 (2007) 45–49. Retrieved from, http://ifrj.upm.edu.my/afjv14(1)2007/45-49.pdf/. (Accessed 13 April 2023).
[8] K. Ysidor, K.K. Jean-Louis, K.B. Roger, A.R. Rachel, O.D.M. Joelle, I.A. Emmanuel, B. Marius, Changes in physicochemical parameters during storage of the inflorescence sap derived from four coconut (*Cocos nucifera* L.) varieties in Côte d'Ivoire, Am. J. Exp. Agric. 5 (2015) 352–365, https://doi.org/10.9734/ajea/2015/11035.
[9] Y. Somawiharja, H. Purnomo, D.M. Wonohadidjojo, M. Kartikawati, F.R.T. Suniati, Indigenous technology of tapping, collecting and processing of coconut (*Cocos Nucifera*) sap and its quality in Blitar Regency, East Java, Indonesia, Food Res. 2 (2018) 398–403, https://doi.org/10.26656/fr.2017.2(4).075.
[10] K. Singsoong, W. Benjapong, A. Nitithamyong, R. Tavichatwitayakul, W. Karnpanit, N. Moungsrichan, J. Prakobsil, Preservatives used in coconut sap, Toxicol. Lett. 196 (2010) S341–S342, https://doi.org/10.1016/j.toxlet.2010.03.1079.
[11] N. Saidan, A. Kartayasa, N. Lokman, N. Llah, M. Mohamad Nor, S. Mokhtar, K. Zaman, N. Sidek, M.S.R. Hamil, Effect of chengal wood (*Neobalanocarpus heimii*) on physicochemical and antimicrobial properties of coconut sap (*Cocos nucifera*), IOP Conf. Ser. Earth Environ. Sci. 549 (2020) 012073, https://doi.org/10.1088/1755-1315/549/1/012073.
[12] E.R. Adisetya, A.W. Krisdiarto, Preservative of coconut sap shelf life derived from mangosteen yellow latex, JITIPARI 7 (2022) 59–67, https://doi.org/10.33061/jitipari.v7i1.6757.
[13] D. Raharjo, M.Z. Zaman, D. Praseptiangga, A. Yunus, Physicochemical and microbiological characteristics of various stem bark extracts of *Hopea beccariana* Burck potential as natural preservatives of coconut sap, Open Agric 8 (2023) 20220175, https://doi.org/10.1515/opag-2022-0175.
[14] A. Saraiva, C. Carrascosa, F. Ramos, D. Raheem, M. Lopes, A. Raposo, Coconut sugar: chemical analysis and nutritional profile; health impacts; safety and quality control; food industry applications, Int. J. Environ. Res. Public Health. 20 (4) (2023) 3671, https://doi.org/10.3390/ijerph20043671.
[15] B.B. Borse, L.J.M. Rao, K. Ramalakshmi, B. Raghavan, Chemical composition of volatiles from coconut sap (neera) and effect of processing, Food Chem. 101 (2007) 877–880, https://doi.org/10.1016/j.foodchem.2006.02.026.
[16] R. Kapilan, R. Kailayalingam, S. Mahilrajan, S. Srivijeindran, Determination of efficient fermentation inhibitor of sweet sap of *Cocos nucifera* and optimization of concentration for quality outputs in northern Sri Lanka, Int. J. Sci. Res. Agric. Sci. 2 (2015) 166–174, https://doi.org/10.12983/ijsras-2015-p0166-0174.
[17] G. Taguchi, Taguchi on Robust Technology Development Methods, ASME Press, 1993.
[18] S.K. Karna, R. Sahai, An overview on Taguchi method, Int. J. Eng. Math. Sci. 1 (2012) 1–7. Retrieved from, https://www.academia.edu/download/48039951/An_Overview_on_Taguchi_Method.pdf/. (Accessed 13 April 2023).
[19] R. Samanta, M. Ghosh, Optimization of microwave-assisted extraction technique for flavonoids and phenolics from the leaves of *Oroxylum indicum* (L.) Kurtz using Taguchi L9 orthogonal design, Pharmacogn. Mag. 19 (2023) 97–104, https://doi.org/10.1177/09731296221137407.
[20] S.T. Olorunsogo, D. Adgidzi, Use of factorial design methodology in fruit juice quality retention studies, J. Nat. Sci. Eng. Technol. 9 (2) (2010) 1–15. Retrieved from, https://typeset.io/papers/use-of-factorial-design-methodology-in-fruit-juice-quality-4dxclgkbcj. (Accessed 13 April 2023).
[21] B. Suleiman, S.A. Abdulkareem, E.A. Afolabi, U. Musa, I.N. Mohammed, T.A. Eyikanmi, Optimization of bioethanol production from nigerian sugarcane juice using factorial design, Adv Energy Res 4 (1) (2016) 69–86, https://doi.org/10.12989/eri.2016.4.1.069.
[22] I.C. Ardhani, R.M. Putri, M.A.F. Falah, K.H. Widodo, Determination of production factors of dehydrated strawberries by using Taguchi method approach, IOP Conf. Ser. Earth Environ. Sci. 653 (2021) 012048, https://doi.org/10.1088/1755-1315/653/1/012048.
[23] U.S. Food and Drug Administration, Bacteriological Analytical Manual, eighth ed., 2001. Retrieved from, http://www.fda.gov/Food/FoodScienceResearch/LaboratoryMethods/ucm063346.htm/. (Accessed 22 May 2022);
[22] R.K. Roy, Design of Experiments Using the Taguchi Approach: 16 Steps to Product and Process Improvement, John Wiley & Sons, Inc., 2010;
[23] B. Deepanraj, V. Sivasubramanian, S. Jayaraj, Multi-response optimization of process parameters in biogas production from food waste using Taguchi – grey relational analysis, Energy Convers. Manag. 141 (2017) 429–438, https://doi.org/10.1016/j.enconman.2016.12.013.
[24] E. Ginting, M.M. Tambunan, Selection of optimal factor level from process parameters in palm oil industry, IOP Conf. Ser. Mater. Sci. Eng. 288 (2018) 012056, https://doi.org/10.1088/1757-899x/288/1/012056.
[25] S. Salacheep, P. Kasemsiri, U. Pongsa, M. Okhawilai, P. Chindaprasirt, S. Hiziroglu, Optimization of ultrasound-assisted extraction of anthocyanins and bioactive compounds from butterfly pea petals using Taguchi method and grey relational analysis, J. Food Sci. Technol. 57 (2020) 3720–3730, https://doi.org/10.1007/s13197-020-04404-7.

[26] H. Mohamed, M.H. Lee, M. Sarahintu, S. Salleh, B. Sanugi, The use of Taguchi method to determine factors affecting the performance of destination sequence distance vector routing protocol in mobile ad hoc networks, J. Math. Stat. 4 (2008) 194–198, https://doi.org/10.3844/jmssp.2008.194.198.
[27] K. Ramalakshmi, T. Nidheesh, B.S. Chanukya, L.J.M. Rao, Changes in quality profile and flavour components of coconut sap during natural fermentation, Food Nutr.: Curr. Res. 1 (3) (2018) 70–76. Retrieved from, https://www.scitcentral.com/documents/b8f94bb29217e2cc61b0aae721b49dcf.pdf/. (Accessed 13 April 2023).
[28] V.V. Priya, M. Balakrishnan, S. Karthikeyan, P. Rajkumar, M.R. Manikantan, K. Gurusamy, R. Pandiselvam, Evaluation of effect of tapping frequency and lime coating on the biochemical changes and fermentation rate of coconut inflorescence sap, Sugar Tech 25 (2023) 906–915, https://doi.org/10.1007/s12355-023-01254-3.
[29] P. Shetty, A.S. D'Souza, S. Poojari, J. Narayana, P. Rajeeva, Study of fermentation kinetics of palm sap from *Cocos nucifera*, Int. J. Appl. Sci. Biotechnol. 5 (2017) 375–381, https://doi.org/10.3126/ijasbt.v5i3.18297.
[30] M. Gopal, S. Shil, A. Gupta, K.B. Hebbar, M. Arivalagan, Metagenomic investigation uncovers presence of probiotic-type microbiome in Kalparasa® (fresh unfermented coconut inflorescence sap), Front. Microbiol. 12 (2021) 1–18, https://doi.org/10.3389/fmicb.2021.662783.
[31] I. Victor, L. Wikarsa, V. Orsat, Identification of changes in the freshness of palm (*Arenga Pinnata*) sap, Sugar Tech 25 (2022) 250–256, https://doi.org/10.1007/s12355-022-01181-9.
[32] C. Sarma, G. Mummaleti, V. Sivanandham, S.K. Kalakandan, A. Rawson, A. Anandharaj, Anthology of palm sap: the global status, nutritional composition, health benefits & value added products, Trends Food Sci. Technol. 119 (2022) 530–549, https://doi.org/10.1016/j.tifs.2021.12.002.
[33] R. Pandiselvam, M.R. Manikantan, S.M. Binu, K.P. Ramesh, S. Beegum, M. Gopal, K.B. Hebbar, A.C. Mathew, A. Kothakota, R. Kaavya, S. Shil, Reaction kinetics of physico-chemical attributes in coconut inflorescence sap during fermentation, J. Food Sci. Technol. 58 (2021) 3589–3597, https://doi.org/10.1007/s13197-021-05088-3.
[34] T.Y. Karseno, T. Yanto, P. Haryanti, R. Setyawati, Application of Natural Preservation on Coconut Sap and Quality Profile Evaluation of Solidified Coconut Sugar, ICSRD, 2013, p. 141. Retrieved from, https://www.academia.edu/34066538/ICSRD_Proceeding_2013_Sustainable_Rural_Development_Towards_a_Better_World/. (Accessed 14 April 2023).
[35] K.B. Hebbar, M. Arivalagan, K.C. Pavithra, T. Roy, M. Gopal, K.S. Shivashankara, P. Chowdappa, Nutritional profiling of coconut (*Cocos nucifera* L.) inflorescence sap collected using novel coco-sap chiller method and its value added products, J. Food Meas. Charact. 14 (2020) 2703–2712, https://doi.org/10.1007/s11694-020-00516-y.
[36] C.M. Herrera, C. De Vega, A. Canto, M.J. Pozo, Yeasts in floral nectar: a quantitative survey, Ann. Bot. 103 (2009) 1415–1423, https://doi.org/10.1093/aob/mcp026.
[37] O. Lasekan, A. Buettner, M. Christlbauer, Investigation of important odorants of palm wine (*Elaeis guineensis*), Food Chem. 105 (2007) 15–23, https://doi.org/10.1016/j.foodchem.2006.12.052.
[38] Q. Xia, R. Li, S. Zhao, W. Chen, H. Chen, B. Xin, Y. Huang, M. Tang, Chemical composition changes of post-harvest coconut inflorescence sap during natural fermentation, Afr. J. Biotechnol. 10 (2011) 14999–15005, https://doi.org/10.5897/ajb10.2602.
[39] R.R. Rao, C.G. Kumar, R.S. Prakasham, P.J. Hobbs, The Taguchi methodology as a statistical tool for biotechnological applications: a critical appraisal, Biotechnol. J. 3 (2008) 510–523, https://doi.org/10.1002/biot.200700201.
[40] I.N. Shafizah, I. Ramli, H. Omar, M. Yahaya, A.A. Aina, Removal of free fatty acid (FFA) in crude palm oil (CPO) using potassium oxide/dolomite as an adsorbent: optimization by Taguchi method, Food Chem. 373 (2022) 131668, https://doi.org/10.1016/j.foodchem.2021.131668.
[41] A. Musa, N.S. Aminah, A.N. Kristanti, I. fathoni, R.T. Amalla, T.M. Thant, P. Rajasulochana, Y. Takaya, Phytochemical and pharmacological profile of genus *shorea*: a review of the recent literature, Heliyon (2024) e23649, https://doi.org/10.1016/j.heliyon.2023.e23649.
[42] K. Pimrote, K. Teekayu, P. Sudprasert, Antioxidant activity and inhibition effect on *Pseudomonas aeruginosa* of extracts from Pa-Yom (*Shorea roxburghii* G. Don), RMUTSB Acad. J. 8 (1) (2020) 15–27. Retrieved from, https://li01.tci-thaijo.org/index.php/rmutsb-sci/article/view/222407.
[43] G. Kaur, T.K. Goswami, Physical and sensory characteristics of low sugar dairy dessert (rasgulla) developed at different level coconut sap syrup, J. Food Sci. Tech. 58 (2020) 343–348, https://doi.org/10.1007/s13197-020-04547-7.