Design and Modification of a Chiller Device for Quality Preservation of Coconut (Cocos nucifera) Inflorescence Sap

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Design and Modification of a Chiller Device for Quality Preservation of Coconut (*Cocos nucifera*) Inflorescence Sap

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Abstract: *Coconut (Cocos nucifera) inflorescence sap is a sweet, highly nutritious juice extracted from a coconut spadix. It contains essential vitamins and minerals, making it a promising alternative for healthy and fresh beverages. Despite its commercial potential, fresh coconut sap production remains limited due to the absence of efficient techniques to prevent natural fermentation during tapping. Studies have shown that maintaining a chilling temperature slows fermentation during collection and storage. This study introduced a modified chiller device, conceptualized through engineering principles, to stabilize the internal temperature for preserving coconut sap. The device maintained a temperature of 2–4 °C for 12 hours, slowing the fermentation process. Sap collected using the chiller method exhibited higher pH, total soluble solids (TSS), and browning index than the traditional method. Additionally, it showed lower yeast and mold counts, indicating reduced fermentation and better preservation under chilled conditions.*

Keywords: Coconut inflorescence sap; Fermentation; Tapping process; Chiller device; Traditional method

1. INTRODUCTION

Coconut Inflorescence Sap (CIS), also known as "toddy" or "Neera," is one of the most promising products that has been utilized for over a century due to its high nutritional value. CIS can be processed into various products, including coconut sugar, vinegar, alcoholic and non-alcoholic beverages, and bioethanol. Rich in nutrients and bioactive compounds, it also serves as a base for value-added products in the food, health, and cosmetic industries. Coconut sap is rich in nutrients, including vitamins, minerals, and amino acids [2, 3]. It is also a natural source of various antioxidants, and has a low glycemic index, making it suitable for individuals with diabetes or those aiming to manage their blood sugar levels [4], and was reported to function as a good digestive agent [5]. Critical analysis of CIS's chemical and physical properties is essential for studying its potential uses and health benefits. Studying the other characteristics, such as reaction kinetics [6, 7] and physicochemical behavior [8] during processing, it is a key parameter to determine the possible design and quality control, and to understand its shelf life under different temperature conditions to develop suitable and desirable value-added products. The significance of CIS is further underscored by the importance of coconuts in the Philippines, where coconuts are a significant crop. The country produces around 6 million metric tons of coconut husks annually, yielding approximately 732,750 metric tons of coco fiber, highlighting the economic value of coconut by-products and the vast potential for sustainable utilization of this vital resource [7, 1].

The market potential of coconut sap presents economic opportunities, particularly for rural communities in coconut-producing countries like the Philippines, Indonesia, and Thailand. Tapping makes farmers earn a steady income through daily harvesting, which is less demanding than other traditional agricultural practices. This source of income is crucial for many families who rely on it for their livelihoods. The growing consumer awareness of the health benefits linked to natural sweeteners has significantly driven the increasing demand for coconut sap products [3]. Its versatility enhances its market competitiveness, driven by growing consumer demand for natural, healthy, and sustainably sourced foods. Fadhlina [9] stated that the global market for coconut sugar alone is projected to grow significantly in the coming years, driven by increasing consumer preferences for natural and healthier sweeteners. This growing demand supports local economies while encouraging sustainable agricultural practices, positioning coconut sap as a valuable commodity in the evolving landscape of natural food products.

Despite the promising potential of CIS in the industry due to its naturally nutritious content, product diversification remains limited. The nutrient contents of CIS necessary for processing various value-added products are significantly altered by fermentation, reducing their quality and usability. Fermentation affects the quality of coconut sap and causes a significant loss of nutritional content. One major factor influencing this challenge is the unhygienic and uncontrolled traditional tapping process. Incoming coconut sap sourced from farmers appears to have setbacks in its quality, affecting the production of coconut sap beverages [10]. Tapping is a traditional method to extract CIS from an unopened coconut spadix. According to Indoadmin [11], this process involves selectively bleeding the inflorescence to yield a sweet, translucent juice with an oyster white hue, boasting remarkable nutritional content. The tapping process stops the production of coconut, but it will not damage or halt the continuous growth of the tree [12]. The methods of collecting and preserving coconut sap are crucial to maintaining its chemical content, which is necessary for processing so as to formulate desirable products. For instance, improper packing or storage of collected CIS may result in rapid fermentation, which will cause a decrease or complete degradation of its sugar content. The surrounding environmental conditions may also exhibit microbial growth, affecting the sap's freshness. Therefore, hygienic practices are necessary to

counter the threat of bacteria, yeast, and mold [13]. Haryanti [14] stated that several natural and synthetic preservatives can be used to preserve the sap effectively. Although widely practiced among local farmers, the traditional method of collecting CIS poses several challenges to counter natural fermentation, significantly reducing its nutritional value. Coconut sap collected from this method, such as using a bamboo tube and an earthen pot, is highly exposed to the open environment, making it susceptible to microbial infestation and other environmental factors, specifically temperature, resulting in rapid fermentation. Without temperature control during harvesting, microbial fermentation occurs, leading to an acidic, off-white sap with a distinct fermented odor [15]. The growth of microbes, including bacteria, yeast, and mold, presents a significant risk to the quality of coconut sap during harvesting and transport. This problem compromises CIS's ability to enhance its nutritional and economic value, limiting its potential for broader applications and market growth. This highlights the importance of lowering temperatures and maintaining hygiene [13].

Collecting and preserving coconut sap is crucial to maintaining its chemical content. This not only helps to protect its quality but also maximizes its industrial potential. Many studies have evaluated the physicochemical characteristics of CIS collected using different methods and devices. However, no existing studies have been conducted to assess and evaluate the fermentation rate of CIS collected using a chiller device incorporating aluminum-filmed polyethylene foam and aluminum containment systems for their thermal efficiency. Thus, this study aims to evaluate the performance of the developed coconut sap-chiller device and assess its efficiency as an internal temperature stabilizer. The selection of materials and the design concept are strategically tailored to create a device that can maintain the desired thermal conditions and contribute to energy efficiency, durability, and overall performance. The benefit of this device not only centers on reducing the fermentation rate during harvesting but also on minimizing the need for farmers to frequently climb the coconut tree to collect fresh and nutritious toddy.

2. MATERIALS AND METHODS

2.1 Design Conceptualization

The selection of materials for chiller devices preserving coconut sap must balance thermal efficiency, durability, cost, and weight to ensure optimal performance and longevity. [10]. The modifications involved implementing a double-walled system with an outer wall made of Polyethylene Glycol Terephthalate (PEGT) plastic covered with polyethylene foam and an inner wall of aluminum sheet containing the fresh sap. This design features convex outer surfaces perpendicular to the direction of solar radiation. Convex surfaces are generally better at resisting heat transfer than flat and concave surfaces, partly due to the Coanda effect [16]. Meanwhile, the concave surface on the inner wall (within the collection container) paved the way for rapid heat dissipation from the sap to the cooler surroundings. [17], enhancing thermal insulation and improving temperature stability.

The chiller can hold the expected amount of coconut sap collected during tapping. [18]. The average yield of the sap is typically around 2 liters per day [19] was considered in the design. The design capacity was ensured for ease of use without compromising the amount of sap that can be stored. The inner chamber has a diameter of 8 cm and a height of 40 cm from the aluminum filter. This was designed to hold 2 liters of sap, with a cylindrical shape for easy cleaning and handling. The outer chamber provided ample space for crushed ice and housing for the inner chamber. The outer chamber is cylindrical with an inner diameter of 16.2 cm and a 2 cm thickness (Figure 1). The extension from the inlet on the outer surface of the chiller, where the spadix is inserted directly into the container, was designed to ensure that different diameters ranging from 14 - 16 cm for the Philippine variety, as described by Nayar [20] will be catered.

Figure 1. Modified Coconut Sap Chiller

2.2 Collection of Sap by Traditional Method (TM)

Fully developed and tapped saplings were selected for tapping to ensure a sufficient sap yield for the required sample. The chosen spadices were carefully cut, and the cut ends were tied securely to prevent the opening of the inflorescence and facilitate optimal sap flow. Traditional sap collection vessels, specifically plastic containers, were used. The conventional containers were positioned beneath the cut spadix to collect the sap.

2.3 Collection of Sap by Modified Coconut Sap Chiller Method (MCSCM)

The selected spadix was washed with distilled water and wiped dry before being rubbed with 70% isopropyl alcohol along its entire length and open edge. The spadix was then wiped dry and washed with distilled water to eliminate the smell of alcohol. The spadix was then wiped dry before being wrapped with plastic from the base to the cut edge. Afterward, the device component sterilization vessel is inserted into the spadix to isolate and create a sterile environment while ensuring that the edge of the spadix reaches the inner wall, where sap drops directly into the filtration system once the device is inserted. The ties incorporated in the design secure the device's connection to the spadix to avoid losing contact. The fabric handle attached to the device's sides was tied in the coconut tree canopies, supporting the device's weight.

2.4 Physicochemical Properties

2.4.1 pH

The pH value of the samples was measured using a digital pH meter. pH 4.0, 6.86, and 9.18 buffers calibrated the digital pen pH meter. Upon measurement, the Digital pH meter was submerged in each 100 mL replication for direct reading. To ensure no cross-contamination in each test, the Digital pH meter is washed with distilled water and wiped dry after each test before proceeding with the following sample.

2.4.2 Total Soluble Solids (TSS)

TSS was measured using a Portable handheld refractometer. The Portable Handled Refractometer was calibrated with distilled water, setting the device at 0 °Brix as stated in the device manual before each set of measurements to ensure accuracy. In the sample test, a few drops from each sample were carefully placed on the refractometer's main prism while ensuring that the sample was 54 spread across the entire surface without bubbles or dry spots for an accurate reading. After each measurement, the prism was thoroughly cleaned with distilled water and dried to prevent cross-contamination between samples [21].

2.4.3 Color

The color of the coconut sap was measured using a Digital Colorimeter. The sap samples were placed in transparent, colorless containers to avoid interference. The colorimeter provides color data based on the CIE system, including L* (lightness), a* (redness or greenness), b* (yellowness or blueness), H* (hue angle), and C* (chroma) [22]. The Browning Index (BI) was then determined using Equation 1 [23].

$$BI = \frac{100(x-0.31)}{0.17} \quad \text{(Eq.1)}$$

$$x = \frac{a* + 1.75L*}{5.645l* + a* - 3.012b*} \quad \text{(Eq.2)}$$

The color evaluation of the sap samples was conducted using the CIELAB color space and C* H*, which provides a standardized and objective method for describing color attributes. Using the CIELAB color space, the study clearly described and compared the visual appearance of the sap samples from each treatment, especially regarding lightness and browning index.

2.4.4 Microbial Analysis (Yeasts & Molds)

The Dry Rehydratable Film Method using Compact Dry™ YMR was used. Incubation was carried out at 25 ± 1°C for 72 ± 3 hours, following the Compact Dry™ YMR Instruction Manual. Colony growth was observed to determine the yeast and mold populations, similar to the study of Pandieselvam. [6]. Results were quantified and reported as colony-forming units per milliliter (cfu/mL) of sap samples collected using the modified chiller and the traditional method.

2.5 Data Analysis

Descriptive analysis and T-test analysis were employed to assess the performance of the coconut sap chiller device, executed using the Statistical Tool for Agricultural Research (STAR). Bar graphs and summary statistics were used to track changes in pH, Total Soluble Solids (TSS), color, and Microbial Analysis for both collection methods (chiller and traditional). The dependent variables are pH, TSS, color, and microbial count (yeast and Molds), while the independent variables are the collection methods (chiller and traditional). This analysis highlights the modified coconut sap chiller's impact on the fermentation of CIS based on the data trends and reveals any potential interactions between factors influencing CIS quality.

3. RESULTS AND DISCUSSION

3.1 Thermal Performance of the Device

The majority of yeast and mold species are mesophilic, which means they thrive best in temperatures ranging from 15°C to 30°C [24]. This implies that temperature below 4°C retards the growth of yeast, molds and many foodborne pathogens. [25]. While temperature variations significantly affect the quality of coconut sap as temperatures rise leads to intensified microbial activity, resulting to a faster rate of fermentation and an increased risk of spoilage, the modified chiller device serves as a promising tool in stabilizing the coconut sap temperature, retaining 2 – 4 °C in particular surrounding temperature and humidity (Table 1) for 12 hours duration, which is comparable to the study of Patil [26] and Hebbar [2].

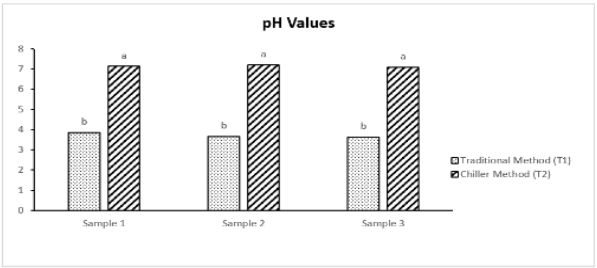
Table 1. Mean values of sap temperature at 31.63 °C and 78.63 % surrounding temperature and relative humidity, respectively.

Treatment	Sap Temperature (after 12 hours)
Traditional	24.8 °C
Chiller	3 °C

3.2 Fermentation Parameters

Fermentation measurement plays a crucial role in assessing the quality and stability of coconut sap, particularly due to its susceptibility to rapid microbial activity and chemical changes post-harvest. Key parameters used to evaluate fermentation include the pH value, which indicates the acidity level and provides insights into the extent of microbial activity; a lower pH typically signifies higher fermentation. TSS, often measured in degrees Brix, reflects the concentration of sugars and other dissolved solids, which can decrease as fermentation progresses and microorganisms metabolize sugars. Color changes are also significant, as fresh coconut sap is typically darker yellow or mustard brown. At the same time, fermentation can cause an increase in light intensity, turning the sap cloudy white, signaling quality deterioration. Lastly, microbial analysis identifies and quantifies the presence of yeasts, bacteria, and other microbes responsible for fermentation, helping to determine the microbial load and safety of the sap. These measurements provide a comprehensive picture of the sap's freshness and quality.

3.2.1 pH Value



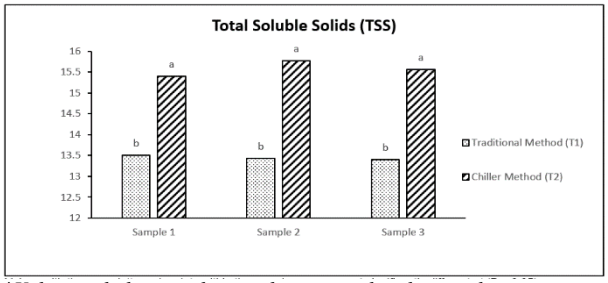
Values with the same letter subscripts within the sample group are not significantly different at (P < 0.05)

Figure 2. pH Value of Sap Samples

Data on Figure 2 showed that the Modified Chiller Method resulted in significantly higher pH, with a recorded mean value of 7.14, compared to the lower pH values observed in the Traditional Method, with a mean value of 3.71 across all three samples. A significant difference ($p < 0.05$) in the pH value was observed between the two treatments across all three samples. The pH value serves as a good indicator of the freshness of

coconut sap, as supported by the findings of Hebbar [15]. According to Ashgar [27], the pH shifts from slightly alkaline to acidic due to the formation of organic acids during fermentation. A lower pH value typically indicates that the coconut sap has undergone fermentation. As reported by Henley [28], fresh and unfermented CIS has a pH value of around 7.3 and drops to as low as 3.3 as fermentation progresses. This pH lowering is influenced by the increased acid production and microbial activity [29, 30], suggesting that the sap collected using the traditional method was more acidic than the sap collected using the chiller device. The lower pH value is observed in the sap collected through the Traditional Method compared to that collected using the Coconut Chiller Method, aligning with the findings of Hebbar [15]. Lower pH value in the CIS is influenced by lactic acid and acetic acid bacteria that thrive at 6.2 – 5.9 and < 4 pH values, respectively [6]. As microbes such as yeast, molds, lactic acid, and acetic acid thrive best at temperatures ranging from 20 to 35 °C, within which microbial activity increases [31], lower temperatures < 4 °C significantly slow down microbial activity that influences pH [10].

3.2.2 Total Soluble Solids (TSS) Value



**Values with the same letter subscripts within the sample group are not significantly different at (P < 0.05)*

Figure 3. Total Soluble Solids (TSS) Value of Sap Samples

TSS are measured in degrees Brix (°Bx), representing the percentage of dissolved solids, primarily sugars [32]. Figure 3 shows that the Modified Chiller Method had significantly higher TSS values than the Traditional Method. The t-test results showed a p-value of 0.0000, providing strong evidence of a significant difference in the average TSS between the two methods, with the chiller device having a higher mean value of 15.58 than the traditional method with a mean value of 13.44. Coconut sap, during the course of atmospheric fermentation, experiences a reduction in TSS, which is caused by the transformation of sugars into alcohol through the activity of bacteria such as yeast and mold [6, 33]. The significantly higher TSS observed in the sap collected using the Modified Chiller Method, as presented in Figure 27, is supported by Hebbar [34], who found that lowered temperature helps minimize the fermentation process. While the lower TSS in the sap collected through the Traditional Method is likely due to rapid fermentation resulting from exposure to ambient temperature, aligning with the findings of Hebbar [15]. This suggests that the sap's quality difference can be attributed to reduced metabolic degradation or improved preservation of sugars under the modified chilling conditions. However, it is essential to note that various coconut cultivars exhibit differing initial TSS levels, influenced by environmental conditions such as soil type and climate. [35, 36].

3.2.3 Color and Appearance

Fresh and unfermented coconut sap typically appears to be brownish, while fermented CIS tends to appear cloudy white [37]. This is due to the breakdown of sugars during fermentation [10]. Figure 4 provides a visual comparison of the color of coconut sap collected using the traditional method and the chiller device. The traditional sap (Figure 4a) is whitish, while the sap in the chiller (Figure 4b) is golden brown.

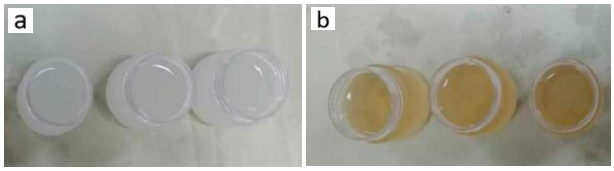


Figure 4. Coconut sap under the traditional method (a) and the chiller device (b)

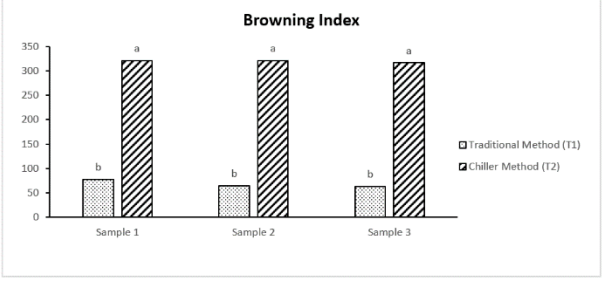
Table 2. Color parameters for coconut sap in the two methods

TREATMENT	*L*±SD*	*a*±SD*	*b*±SD*	*C±SD*	*H±SD*	*BI±SD*
Traditional	23.67 ± 0.48^{a}	-0.11 ± 0.11^{b}	12.10 ± 0.20^{b}	12.10 ± 0.20^{b}	90.45 ± 0.52^{a}	68.30 ± 7.62^{b}
Chiller	14.72 ± 0.49^{b}	1.12 ± 0.49^{a}	17.49 ± 0.59^{a}	17.54 ± 0.57^{a}	85.96 ± 1.24^{b}	319.09 ± 2.45^{a}

**Each value in the table represents the mean of three samples. Means with different superscripts are significantly different (p < 0.05) along each column.*

The color measurements in the CIELAB color space reveal significant differences between the traditionally collected sap, resulting in a significantly lighter appearance, with a higher L* value (23.70), compared to that collected using the chiller device with a darker sample (14.72). Regarding chromaticity, the traditional sample exhibited lower chroma (C = 12.10), indicating a less saturated color than the chiller device sample, which showed greater chroma (C = 17.54), suggesting a more vivid and intense coloration. The a* values also differed, with the traditional treatment presenting a nearly neutral or slightly greenish tone (–0.11), while the chiller-treated sample leaned toward red (1.12). Additionally, the b* value, representing the yellow-blue axis, was significantly higher in the chiller sample (17.49) than in the traditional one (12.10), indicating a stronger yellow component. This was further reflected in the hue angle (H), where the conventional treatment had a value of 90.45°, corresponding closely to yellow. In comparison, the chiller sample had a slightly lower hue angle (85.96°), indicating a shift toward a redder yellow. Overall, the chiller treatment produced a darker, more intensely colored sample with a warmer yellow tone, while the traditional treatment resulted in a lighter, less saturated, and cloudy white in color, aligning with the study of Saraiva [37]. This color difference is further confirmed through its browning index illustrated in Figure 4.

3.2.4 Browning Index Value



**Values with the same letter subscripts within the sample group are not significantly different at (P < 0.05)*

Figure 5. Browning Index of sap samples

The Browning Index is a key parameter used to evaluate the degree of browning in coconut sap [38], where a higher value indicates a more intense brown coloration [39]. The data presented in Figure 5 provides a comparative analysis of the browning index across three samples collected under traditional (T1) and chiller methods (T2). Across all three samples, a significant difference ($p < 0.05$) in the Browning Index was observed between the two treatments. Treatment 2 exhibited a higher browning index with a mean value of 329.09 compared to Treatment 1, which showed significantly lower mean values of 68.30. This significant increase in the browning index under Treatment 2 suggests that the coconut sap collected using the chiller device is less fermented [26]. This is primarily due to the low temperature, which slows down fermentation [40]. According to Pandiselvam [6], under this condition, the sap retains high levels of phenols, antioxidants, amino acids, and flavonoids, contributing to both its nutritional quality and its appealing brown color. Conversely, the lower browning index in treatment 1 indicates higher fermentation, similar to the study of Hebbar [15] and Hebbar [2]. The t-test result indicates a significant difference in the Browning Index between the two treatments ($p < 0.0000$). This statistical finding strongly supports that the treatments have a distinct impact on the browning of the coconut sap. The color changes of sap collected under the traditional method, from brownish to whitish, are a result of the enhancement of the degree of oxidation of phenolic compounds that happens under natural fermentation [41]. Antioxidants like flavonoids and ascorbic acid somewhat reduce the oxidation rate. However, when there are more free radicals than antioxidants, the golden brown color of sap changes to milky white [42]. Syamala Devi [43] unfermented coconut sap generally contains higher levels of antioxidants than fermented sap because as fermentation progresses, there is a reduction in total phenolic content and ascorbic acid, both of which are key contributors to antioxidant activity.

3.2.5 Microbial Analysis

Table 3. Yeast and Molds Count (CFU/mL) of coconut sap samples

Treatment	Sample No.	Yeast and Molds (estimated mean, CFU/mL)
Traditional	3	8,733.33
Chiller	3	4,666.67

The higher value under the traditional method suggests that atmospheric condition or natural fermentation allows microorganisms, particularly yeast and molds, to grow more rapidly. In contrast, the samples collected under the chiller method had the lowest yeast and mold counts, indicating that the sap collected using the chiller device slows down the growth of yeast and molds during the 12-hour collection process. The results in Table 3 support the findings of Hebbar [15], which noted that the cooling method produces sap with fewer yeast and mold count, while the traditional method results in higher microbial populations. According to Hai [44], when the sap begins to ferment, it augments yeast concentration, which in turn exhibits the conversion of sugar (mainly sucrose, glucose, and fructose) into alcohol through alcoholic fermentation [6]. As fermentation advances, molds and yeasts tend to proliferate, particularly in acidic and alcoholic environments where bacterial populations begin to diminish [28]. This fast fermentation leads to spoilage and changes the fresh sap into toddy or sap partially fermented, which is not ideal when the goal is to keep the sap fresh for processing.

4. CONCLUSIONS

The physicochemical characteristics, such as pH, Total Soluble Solids (TSS), Browning Index, and yeast and mold count of the coconut inflorescence sap collected both under traditional and chiller methods were thoroughly examined in this study. The Statistical Tool for Agricultural Research (STAR) was utilized for data analysis, employing descriptive statistics and a t-test to determine significant differences between the two methods. Results revealed that sap collected using the chiller device exhibited significantly better quality regarding higher pH, Browning Index, Total soluble solids, and reduced yeast and mold count. These findings underscore the chiller device's potential in preserving the quality of coconut sap during the tapping process. The advantage of using a chiller device over the traditional method was statistically supported through the t-test results showing a significant difference ($p < 0.05$) among all dependent variables in this study. These parameters are critical indicators of freshness and quality, and their improvement in the chiller method underscores its potential as a better approach to sap collection. Consequently, the results validate that the chiller design concept effectively preserves the quality of the sap by maintaining a stable chilling temperature of 2 – 4 °C for up to 12 hours.

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