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Technical Evaluation of Coconut Sugar Production Methods and Quality of Selected Processors in the Philippines

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ABSTRACT

The study evaluated the coconut sugar production methods and quality of products of selected processors in the Philippines. It involved classifying respondents who practiced traditional and mechanical production methods and identifying the processing plant's production process capacity. It also assessed the physical quality of coconut sugar produced by the processors. Results showed that most of the processes involved in coconut sugar production are still manually done using the traditional method. It was found that the average evaporation, crystallization, and drying capacity for processors employing traditional methods were 8.16 L of coconut sap per hour, 3.96 L of coconut syrup per hour, and 3.67 kg of wet coconut sugar per hour, respectively. Meanwhile, the average evaporation, crystallization, and drying capacity of the equipment of respondents employing mechanical methods were 19.09 L of coconut sap per hour, 2 L of coconut syrup per hour, and 37.37 kg of wet coconut sugar per hour, respectively. The mechanical method of evaporation and drying in coconut sugar production shows a higher production capacity than the traditional method. On the other hand, the color of coconut sugar samples of the processors-respondents was yellow to brown with average HSB values of 26.25°, 38.44%, and 62.61% respectively, and moisture content ranged from 0.82% to 3.01% which both conform with the specifications of the Philippine National Standards PNS/BAFS 76:2016. For the majority of coconut sugar processors with product samples available for analysis, the measured particle size, fineness modulus, bulk density, and angle of repose on the average were 557.81µm, 4.20, 578.04kg/m3, and 28.39°, respectively. Additionally, the angle of friction for stainless steel with mirror finish, stainless steel 304, GI1, GI2, plywood (against the grain), and plywood (along the grain) surface had mean values of 44.29°, 41.31°, 42.93°, 42.30°, 45.05°, and 46.21°, respectively.

Keywords: *coconut sugar, mechanization, production process*

INTRODUCTION

Coconut sugar is a natural sweetener made from the sap of the coconut tree inflorescence. Based on several studies, coconut sugar has a low glycemic index (GI) and high nutritional value, namely vitamins, antioxidants, and minerals (Trinidad et al., 2015; Asghar et al., 2020a). Accordingly, it has become popularly known as an alternative sweetener to cane sugar and palm sugar especially for those with health problems, such as diabetes, obesity, and dental caries, and for those who are vegan and health conscious (Teves, 2018; Samriddhi and Roshan, 2022).

The increase in demand for coconut sugar became an avenue for the Philippines to be a globally competitive producer and exporter of the product. The Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (PCAARRD) 2005 Industry Strategic Plan for Coconut recommended prioritizing research and development for new processing products, technology transfer, and commercialization (PCAARRD, 2021a). In 2006, the Bureau of Agricultural Research (BAR) in partnership with the Philippine Coconut Authority (PCA) started a project to boost the coconut sugar industry and to promote and support village-level production (Lesaca, P. R. & dela Cruz, R., n.d.). The coconut sugar industry has significantly changed the livelihood of many stakeholders in some coconut production areas. People dependent on coconut trees in Aroman, Carmen, South Cotabato were introduced to coconut sap sugar processing and reported an increase in their income (Manohar, et. al, 2010). Many farmers were able to utilize their coconut trees not only for their fruits, but also for their sap. Data from the PCA showed that coconut sugar export from 2017-2019 was 344 metric tons on average which generated earnings of USD 1.1M per year (PCA, 2021). Currently, the Philippines is considered one of the top coconut sugar producers in the world, along with Indonesia and Thailand.

Processors who produced coconut sugar using the traditional method of production utilized wok and furnace. On the other hand, those that have incorporated machines in the production process utilize the mechanical method. There were processors-respondents who utilized mechanical equipment for coconut sugar production, but most of the coconut sugar processors in the Philippines still employed the traditional method of coconut sugar processing, which involves manual filtering, boiling, stirring, pulverizing, sifting, drying, and packaging coconut sugar. Traditional equipment such as a wok or "*kawa*" and a biomass-heated furnace or stove or "*pugon*" are still being used. The traditional method is a long and tedious process and has issues with temperature control, smoke and microbial contamination. More importantly, the quality of the processed coconut sugar heavily depends on the skill level of the processor (Susanti et al., 2021).

Generally, the coconut sugar production process includes filtration and evaporation, crystallization and pulverization, sieving and drying, and lastly, packaging (PCAARRD, 2010). Some producers repeat some of the processes such as pulverization and sieving depending on their desired outcome. The coconut sap is collected from a mature and unopened inflorescence and immediately processed within five hours of cutting the inflorescence to prevent the coconut sap from fermenting. The coconut sap is then filtered to remove impurities that may have been collected during harvesting. This is usually done using a cheesecloth or any cloth with a fine mesh. Excess moisture from the filtered coconut sap is then removed via evaporation or boiling until the sap thickens to a syrup-like consistency with removed scum. The traditional way of evaporating coconut sap uses a "kawa" or wok over a wood-fired stove (PCAARRD, 2010). Several studies have tested the use of more modern technology, such as the pan evaporator (Rini et al., 2022; Hanifah et al, 2022), rotary evaporator and the microwave (Asghar et al., 2020b) to improve this part of the process. After which, the coconut syrup is continuously stirred and gradually cooled until it starts to thicken and harden. This is the crystallization process where the coconut syrup becomes wet coconut sugar. Processors either stir the syrup manually with a ladle or with an electric mixer (The Food Club, 2022). In addition to this, producers manually pulverize the forming granules during the crystallization process using the ladle or the bottom of small stainless-steel bowls to ensure that no large and coarse granules form (Agribusiness How It Works, 2014). In the Philippines, there is a standard design and specification for the crystallizer; PAES 236:2008. However, it is specifically used for ginger tea and jam production. No studies have been conducted using the said design of crystallizer to process coconut sugar. Nevertheless, in a study conducted by Rini et al. (2022), the crystallization process was done using a rotary crystallizer with two static stirrers to control the stirring of the coconut syrup while Hanifah et al. (2022) used a vertical-type double jacket stirred crystallizer. Sieving of the wet coconut is necessary to separate the large clumps from the fine granules. After the sieving process, the wet granulated coconut sugar can be dried by either air drying, steam drying, oven drying, or by using a mechanical heated dryer. A cabinet dryer was utilized in a study by Rini et al. (2022), and Hanifah et al. (2022) while Nomura Research Institute, Ohkawara Kakohki Co., Ltd., and the DTI Misamis Oriental developed a spray dryer that instantly processes coconut syrup to dried coconut sugar (Oblina-Rucat, J. M., 2014).

Coconut sugar production is comparable to the muscovado production process in the sense that both employ the evaporation, crystallization, and drying process. The muscovado sugar is produced by boiling sugar cane juice and letting it air dry to produce an alternative sugar with the characteristic aroma and flavor from its high molasses content (PNS/BAFS 145:2015). Additionally, the production of muscovado includes the process of sugar cane juice clarification using lime and heat. Despite the rising global demand for alternative sweeteners, muscovado sugar processing is still done traditionally without modern technology in the manufacturing equipment (Teves, K. 2016; Duran, J. et al, 2022; BAS Food, 2023). The conduct of this study would provide beneficial insights into the production process of both coconut sugar and muscovado.

There is no enough literature to describe coconut sugar processing in the Philippine setting. Moreover, there is a need to evaluate the mechanization of coconut sugar production to appropriately address the growing global demand for coconut sugar. There are important parameters that need to be considered in mechanization of the coconut sugar process since these determine the product quality and machine design elements. The said parameters include temperature, sugar content, density, moisture content, fineness modulus, particle size, and color (Rini et al., 2022; Hanifah et al., 2022; Asghar et al., 2020b). Moreover, in relation to the quality of coconut sugar, the Philippine National Standard PNS/BAFS 76:2016 states that the maximum moisture content of dry granulated sugar must not exceed 3.5%. In Indonesia, a major competitor in the coconut sugar industry, the moisture content of coconut sugar must not exceed 3%, based on the Indonesian National Standard 01.3743:1995 (Rini et al., 2022). The said parameters are used to evaluate the quality of coconut sugar produced by selected processors from the Philippines. Since there is no available measure to quantify an agricultural process of the same nature as coconut sugar production, the study used process capacity as an indicator of mechanization status. Production capacity for each process was measured based on data provided by the processors, enabling classification of each method as either traditional or mechanical.

The Center for Agri-Fisheries and Biosystems Mechanization (BIOMECH) conducted this study as a preliminary part of their project to improve production efficiency and capacity, and enhance product quality of coconut sugar processing through the introduction of a mechanization technology package or machinery requirement for coconut sugar processing. Specifically, this study evaluated the current production capacity of the equipment utilized in coconut sugar processing among selected processors in the Philippines and assessed the physical and engineering properties, and the quality of coconut sugar produced by the processors, specifically its color and moisture content in compliance to PNS/BAFS 76:2016.

METHODOLOGY

Data Collection

The data collection process involved the selection of respondents through purposive sampling. The respondents were specifically identified to be coconut sugar processors from top-producing coconut regions in the Philippines. The selected processors were from Luzon and Mindanao (**Table 1**).

Table 1. Location of selected coconut sugar

LOCATION		NO. OF RESPONDENTS (N)
Luzon	Quezon	5
	Bicol	5
Mindanao	Zamboanga	1
	Davao	3
	SOCCSKSARGEN	9

The survey instrument was structured and was designed to gather detailed information about the processors' coconut sugar production, including the specific sources of raw materials and methods employed. Respondents were asked to provide information on each stage of the production process. Additionally, the survey collected data on the technology used in production as well as the production capacity of the processing plant. Furthermore, coconut sugar samples were procured from the respondents for determination of its physical and engineering properties. Five (5) respondents-processors did not have available coconut sugar products for sale during the survey, and thus, no samples were collected from them.

Assessment of Mechanization Status

The mechanization of coconut sugar production was assessed by considering the equipment or tools used by the processors in their production process. The equipment was further categorized if it is used for either manual/ traditional or mechanized methods of coconut sugar production. The capacity of each equipment/tool in each step of the production process, specifically for the evaporation, crystallization, and drying process, was evaluated based on the gathered data from the processors-respondents. The process capacity was calculated using Equation 1.

$$Process\ Capacity = \frac{Input\ Material}{Time} \qquad \textit{Equation 1}$$

where:
Input material is the weight of the sample at the start of evaporation, crystallization or drying process
Time is the duration needed to complete the evaporation, crystallization or drying process

Evaluation of Product Properties and Quality

The coconut sugar samples obtained from the respondents were evaluated for their physical properties, namely, color, particle size and fineness modulus, bulk density, moisture content, angle of repose, and angle of friction.

The description of color for the coconut sugar samples was determined in terms of L*, a*, and b* values using a Color Reader (Konica Minolta CR-10). After which, the L*, a*, and b* values were converted to HSB values. Hue (H) is denoted by the angle on a color wheel with values from 0º (red), 240º (blue), to 360º. Saturation (S) is the intensity of hue present in the final color as a percentage from 0 to 100%. Lastly, brightness (B) is the brightness of the color as a percentage from 0 to 100%.

The W.S Tyler Ro-tap sieve shaker with sieve sizes 16, 20, 30, 40, 50, 70, and 100 was used to determine the average particle size, fineness modulus, and standard deviation of each sample. The fineness modulus describes the coarseness and fineness of a granule. The closer the value is to 1 the finer it is. The particle size describes the average size of the granule in micrometers. The standard deviation describes the dispersion or variation of the particle sizes of the coconut sugar. The closer the value is to 1, the closer the particle sizes are to the mean particle size. The following equations were used to solve for the average particle size, fineness modulus, and standard deviation.

$$Fineness\ modulus = \sum \left(\frac{W_i n}{\sum W_i}\right) \qquad \textit{Equation 2}$$

$$d_{gw} = log^{-1}\left[\frac{\sum \left(W_i\ log(d_u d_o)^{0.5}\right)}{\sum W_i}\right] \qquad \textit{Equation 3}$$

$$s_{gw} = log^{-1}\left[\frac{\sum \left(W_i\ (log(d_u d_o)^{0.5} - log\ d_{gw})^2\right)}{\sum W_i}\right]^{0.5} \qquad \textit{Equation 4}$$

where:

W_i is the weight of the sample in the i^{th} sieve

n is the multiplier assigned to the n^{th} sieve, counted from bottom to top, minus 1

d_u is the diameter opening through which particles will pass (sieve proceeding i^{th})

d_o is the diameter opening through which particles will not pass (i^{th} sieve)

d_{gw} is the geometric mean diameter

s_{gw} is the standard deviation

A bulk density apparatus with a measurement cup set was used to measure the bulk density of each sample. The 1-liter cup was filled to the brim using the attached funnel and was weighed in grams using the balancing scale of the density measurement cup set. The density was determined using Equation 5 and recorded in kg/m^3.

$$\rho = \frac{m}{V} \qquad \textit{Equation 5}$$

where:

ρ is the density of the sample

m is the mass of the sample

V is the volume of the sample

The Sartorius moisture analyzer model MA37 was used to determine the moisture content of each sample. A 15-g of the sample was placed in the pan and the moisture analyzer was set to automatic gentle heating of a maximum of 105°C to prevent the coconut sugar from caramelizing.

The angle of repose was determined using the funnel of the density measurement cup set, a piece of plywood, and a set of rulers. The sample was poured from the funnel onto the plywood. When the sample settled, the angle of repose was computed using the following equation.

$$\Theta = tan^{-1}\left(\frac{h}{D/2}\right) \qquad \textit{Equation 6}$$

where:

Θ is the angle of repose

h is the height of the sample

D is the diameter of the sample

The angle of friction of the coconut sugar samples was determined on different surfaces attached to an adjustable reclining board using a Vernier protractor. The surfaces used in the test were stainless steel with mirror finish, stainless steel 304, Galvanized Iron (GI) sheets, and plywood.

Data Analysis

The assessment of the mechanization status (whether traditional or mechanized) of the respondents' coconut sugar production process, was based on the equipment or tools used and corresponding equipment capacity in a particular process. The assessment also delineated the percentage of processors utilizing traditional/manual methods and mechanized methods. The process capacity for each stage of the production process was averaged and compared between processors who utilized manual versus mechanized methods of production.

The measured characteristics of coconut sugar were analyzed and presented through its mean value, range and coefficient of variance. The data gathered for color and moisture content were evaluated in relation to the minimum requirements for coconut sugar based on the PNS/BAFS 76:2016.

Limitations of the Study

The odor and taste requirements of the coconut sugar samples as specified in the PNS were not determined since these are subjective characteristics and require the analysis of a professional food sensory tester.

The costs of production relative to coconut sugar processing were not considered in the study due to the insufficiency of data collected from the processors who had difficulty estimating costs during the data collection.

RESULTS AND DISCUSSIONS

The Coconut Sugar Processors

The survey established the source of raw materials of the processors for coconut sugar production. Not all processors had their own coconut tree farm. **Table 2** shows that, among the 23 processors, 11 of them own their coconut trees and one processor from Davao procured additional coconut syrup from other processors due to insufficient coconut sap from their farm. A total of 8 processors procured coconut sap and/or coconut syrup from other sources, and 5 processors rented coconut trees for its coconut sap.

The coconut tree varieties utilized by coconut sugar processors in the Philippines are Laguna tall, Tacunan dwarf, Kinabalan dwarf, Catigan dwarf, Aromatic dwarf, Mawa hybrid, and Reciprocal hybrid variety. Varieties recommended by the PCA for coconut sugar production include PCA 15-2, PCA 15-1, PCA 15-3, and PB 121 for hybrid varieties and CATD and MRD for dwarf varieties; no tall varieties were stated (PCAARRD, 2021b). **Table 3** presents the varieties of coconut trees that were used by the processors.

Table 4 lists the frequency of harvest practiced by the processors-respondents. **Table 5** shows that the processors harvest 0.5 up to 4.5L of coconut sap per tree per day with an average of 1.5L of coconut sap per tree per day. According to the processors from Quezon, the yield increased and decreased depending on the climate season. The yield was higher during the dry season from February to August, and lower during the rainy season from September to January. The same trend was also observed by one processor from Bicol. The seasons also affected the frequency of their harvest, wherein 4 of the 5 processors from Quezon harvested every 4 hours, 5 times a day during the dry season and only every 5 to 8 hours, 4 times a day during the rainy season. This change was due to the decrease in temperature during the rainy season which inhibits fermentation of the coconut sap. Nevertheless, one processor from Quezon only harvested twice a day at 6pm and 10pm. The sap harvested after 10pm was used for producing their other products, namely coconut wine or "lambanog" and vinegar, due to the sap's lower pH level after the first two collections. The processors from Zamboanga and Davao, on the other hand, harvested every 4-5 hours throughout the year. Meanwhile, processors from Bicol and SOCCSKSARGEN's harvesting of coconut sap varied from every 4 hours to 3 or 4 times a day. Overall, the processors harvested coconut sap about

Table 2. Source of sap, 2023.

SOURCE	NO. OF RESPONDENTS (N=23)	%
Own farm	10	43.48
Rent trees	5	21.74
Other processors	7	30.43
Own farm + other processors	1	4.35

Table 3. Variety of coconut trees, 2023.

SOURCE	NO. OF RESPONDENTS (N=20)	%
Hybrid	3	15.00
Dwarf	7	35.00
Laguna Tall	2	10.00
Laguna Tall + hybrid	1	5.00
Laguna Tall + dwarf	5	25.00
Hybrid + dwarf	2	10.00

Table 4. Number of harvests per day, 2023.

FREQUENCY OF HARVEST	NO. OF RESPONDENTS (N=22)	%
2 times/ day	1	4.55
3-4 times/ day	11	50.00
5 times/ day	3	13.64
By order	7	31.82

Table 5. Volume of harvests per tree per day 2023.

AVERAGE VOLUME OF SAP HARVESTED/TREE/DAY (L/tree/day)	NO. OF RESPONDENTS (N=14)	%
0.50 – 1.49	8	57.14
1.50 – 2.49	5	35.71
2.50 – 3.49	0	0.00
3.50 – 4.50	1	7.14

4 times a day on the average. These considerations are necessary for planning and quantifying the volume of coconut sugar production of the processing plant.

Mechanization in the Production Process

The equipment and method of processing done by coconut sugar processors ranged from filtration machines, mixers with burners, pulverizers, mechanical sieves, and heated mechanical dryers for mechanical method of production while strainers, woks, and ladles were used for the traditional or manual method of coconut sugar processing.

All processors, whether handling coconut sap or coconut syrup, did the filtration process manually using a strainer except for one processor from Davao who used a microfiltration machine. The evaporation process from **Table 6** showed that twenty out of 21 processors who conducted the evaporation process used the manual method (**Figure 1a**), using simple technology, namely a *kawa*, ladle, strainer, and pugon. Two of the said 20 processors used both manual and mechanical methods depending on the amount of coconut sap they harvested. The Zamboanga processor uses a steam kettle mixer when they harvest coconut sap exceeding 300L. On the other hand, one processor from Davao used a mechanical mixer with an LPG burner at their coconut syrup production plant in General Santos.

The specifics of how the processors handle their coconut sap during the evaporation process until it is ready for crystallization are presented in **Table 7**. The evaporation capacity describes the volume of coconut sap each processor processes per hour. It is observed that the evaporation capacity of the processors is dissimilar from each other due to the varying final degree brix of the resulting coconut syrup, heat energy applied, and length of time to boil the coconut sap. Nevertheless, the evaporation capacity outlined how much coconut sap was processed per batch and per equipment used by the processors. Processors utilizing the traditional method had an evaporation capacity that ranged from 1.75-17.50 L of coconut sap per hour, while those that utilized the mechanical method (**Figure 1b**) had an evaporation capacity of 10.67-30.00 L of coconut sap per hour.

Figure 1. Manual (right) vs. mechanical (left) evaporation process.

Table 6. Coconut sugar processing methods by operation (manual vs. mechanical), 2023.

PROCESS	N	MANUAL % OF RESPONDENTS	MECHANICAL % OF RESPONDENTS	BOTH % OF RESPONDENTS
Filtration	23	96.00	4.00	–
Evaporation	21	85.71	4.76	9.52
Crystallization	20	95.00	5.00	–
Sieving	18	66.67	22.22	11.11
Drying	19	31.58	68.42	–

As for the first part of the crystallization process, 19 out of 20 of the processors use the manual method of continuously stirring the coconut sugar using a ladle until it thickened (**Figure 2a**); only one processor from Davao among all the processors surveyed used a mechanical mixer with an LPG burner (**Table 6** and **Figure 2b**). For the second part of the crystallization process, all of the processors used the manual method of stirring and pulverizing the forming granulated wet sugar using a ladle. The processors continuously mixed and spread the thick syrup to the side of the kawa to simultaneously cool and pulverize the forming crystal structures to finer granules. Additionally, processors from SOCCSKSARGEN used modified ladle, wherein the handle was shortened, cut off, bent, and attached to the opposite end of the ladle bowl, to pulverize the wet coconut sugar. One processor from Davao and SOCCSKSARGEN also had a pulverizer. The Davao processor only used the pulverizer after the drying process and only when clients ordered very fine coconut sugar. While the processor from SOCCSKSARGEN used pulverizer, after dry sieving, mainly for pulverizing the crumbs that remained on the sieve.

Table 8 presents the specifics on how the processors handled their coconut syrup during the crystallization process until it turned into wet granulated sugar. Only one from Zamboanga and Davao, and all the processors from SOCCSKSARGEN, except for one who only processed up to coconut syrup, recorded the amount of wet granulated sugar they produced from coconut syrup. The rest of the processors recorded the resulting amount of coconut sugar after it was dried. Similar to the evaporation capacity, the crystallization capacity differed per processor due to factors such as the initial degree brix of the coconut syrup, the amount of heat energy applied, and the length of time the syrup is heated before cooling.

Figure 2. Manual (right) vs. mechanical (left) crystallization process.

Table 7. Evaporation process per batch per equipment of coconut sap to syrup, 2023.

AVE. EVAPORATION CAPACITY (L/H)	N=13	% OF RESPONDENTS	METHOD UTILIZED
1.75 – 6.79	5	38.46	manual
6.80 – 11.84	1	7.69	manual
11.85 – 16.89	4	30.77	manual
11.85 – 16.89	1	7.69	mechanical
16.90 – 21.94	1	7.69	manual
21.95 – 27.00	1	7.69	mechanical

Table 8. Crystallization process per batch per equipment of coconut syrup to wet sugar, 2023.

AVE. CRYSTAL-LIZATION CAPACITY (L/h)	N=11	% OF RESPONDENTS	METHOD UTILIZED
1.75 – 3.77	5	45.45	manual
1.75 – 3.77	1	9.09	mechanical
3.78 – 5.81	3	27.27	manual
5.82 – 7.84	0	0.00	manual
7.85 – 9.88	2	18.18	manual

Nevertheless, the crystallization capacity still displayed how much coconut syrup was processed per batch and per equipment used by the processors. Processors utilizing the traditional method had a crystallization capacity that ranged from 1.49-11.76 L of coconut syrup per hour, while the one that utilized the mechanical method had a crystallization capacity of 2 L of coconut syrup per hour.

During the sieving process, all of the processors used a fine mesh for sieving wet or dry coconut sugar, although the mesh sizes were generally not measured. Three processors from Quezon did not directly perform this process, it was instead done at the coco hub. As shown in **Table 6**, fourteen out of the 18 processors manually sieved their coconut sugar. Two of them also used a mechanized sieve. However, one processor stated that their mechanized sieve capacity was low while the other stated that using their mechanized sieve for wet sieving caused its sieve to clump ever so often which resulted in the need to replace the sieve more often, so they opted to use a manual sifter instead. Finally, a total of 6 processors used mechanized sieves.

As shown in **Table 6**, the drying process was manually done (**Figure 3a)** by 6 out of 19 processors. Three processors from Bicol utilized sun drying, one processor dried coconut sugar on a kawa over a pugon (traditional oven) with low heat, while two processors dried their coconut sugar on a kawa placed over the top of another kawa with boiling water. The mechanical method **(Figure 3b)** of drying was done by 13 processors using the conventional cabinet-type heated mechanical dryer; four processors utilized heating coils, eight utilized biomass, and one processor utilized LPG for the drying process.

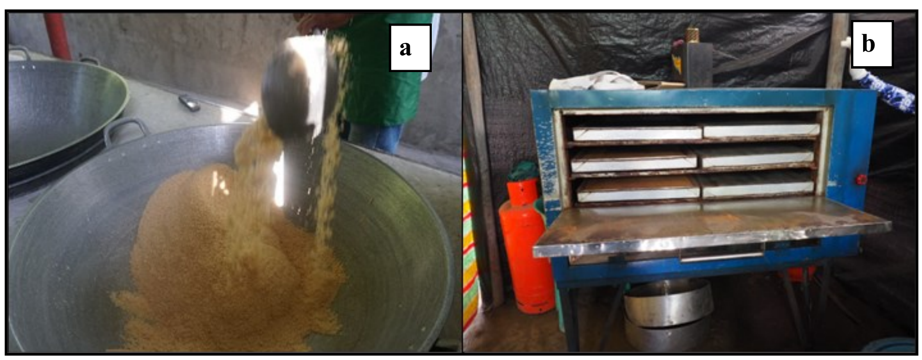

Figure 3. Manual (right) vs. mechanical (left) drying process.

The drying capacity describing the amount of wet coconut sugar processed by the processors per hour is presented in **Table 9**. Processors utilizing the traditional method had a drying capacity that ranged from 2.67-6.00 kg of wet coconut sugar per hour, while those that utilized the mechanical method had a drying capacity of 10.00-80.00 kg of wet coconut sugar per hour.

Based on the experiences and records of the processors, an average of 8.08L of coconut sap or 1.73L of syrup was required to produce 1 kilogram of coconut sugar. Hence, on the average, 12.38% of the coconut sap in liters or 57.80% of coconut syrup in liters was made into coconut sugar in kilograms.

The process capacities when utilizing manual and mechanical methods of production are summarized in **Table 11**. The evaporation and drying process capacity for utilizing the mechanical method was higher as compared to the evaporation and drying capacity when the traditional method was utilized. This suggests that mechanization in the evaporation and drying process of coconut sugar production

Table 9. Drying process per batch per equipment of wet coconut sugar to dry sugar, 2023.

AVE. DRYING CAPACITY (kg/h)	N=12	% OF RESPONDENTS	METHOD UTILIZED
3.00 – 22.24	2	16.67	manual
3.00 – 22.24	4	33.33	mechanical
22.25 – 41.49	2	16.67	mechanical
41.50 – 60.74	2	16.67	mechanical
60.75 – 80.00	2	16.67	mechanical

increased the production capacity. However, the average crystallization capacity was lower for the mechanical production method as compared to the traditional method. This implies that available equipment for the crystallization process of coconut sugar production did not increase the production capacity but may suggest that the mechanization offered ease to the intensity of labor needed to complete the process.

Product Characteristics

The range, mean, standard deviation, and coefficient of variance of the measured physical properties from all the procured coconut sugar samples are summarized in **Table 12**.

The coconut sugar H values had an average value of 26.25 and ranged from 22.1 to 33.0 indicating color with hints of brown between red and yellow hues. Additionally, the S and B values of coconut sugar samples were 38.44 and 62.61, respectively. All coconut sugar samples adhered to the color specified by PNS/BAFS 76:2016 wherein coconut sugar should have light yellow or cream to dark brown color. The average HSB values of the coconut sugar from Davao, Quezon, Bicol, and SOCCSKSARGEN processors were determined and presented in **Table 13**.

Different factors affect the color of the coconut sugar including the nature of the coconut sap and tree, the procedure of processing, and the storage conditions such as temperature, relative humidity, and pH (Trinidad, et al., 2015). The color of the coconut sugar may vary depending on the time of determination such as reported by Trinidad, et al., (2015), wherein samples decreased in L* values as observed after months of storage. This change can also be attributed to the increase in water activity of the samples. Thus, the color of the coconut sugar sample is dependent on several factors from the nature of resources up to the storage of the sugar samples. Some processors, specifically one from SOCCSKSARGEN, also produced coconut sugar of varying colors for retail. These sugars were sold based on their color and labeled as Light Premium, Regular Premium, and Dark Premium.

The moisture content of coconut sugar was determined to range from 0.82% to 3.01% with an average of 1.99% MCwb. The highest moisture content was from a processor from Bicol and the lowest moisture content was from SOCCSKSARGEN. According to the Philippine National Standard PNS/BAFS 76:2016 states that the maximum moisture content requirement for dry granulated sugar must not exceed 3.5%, hence the measured moisture content from coconut sugar samples adhered to the national standards.

The particle size and the fineness modulus of the coconut sugar sample ranged from 367.29µm to 996.84µm and 3.08 to 5.97, respectively. The average particle size was determined to be 557.81µm and the average fineness modulus is 4.20. Coconut sugar from Bicol had the highest particle size and fineness modulus indicating it to be the coarsest among the samples, while the sample from

Table 10. Required coconut sap to produce 1kg sugar, 2023.

VOLUME OF SAP, L : 1kg SUGAR	L SAP to 1kg SUGAR % RECOVERY	N=16	% OF RESPONDENTS
6.00	16.67	1	6.25
7.00	14.29	4	25.00
7.50	13.33	2	12.50
8.00	12.50	5	31.25
8.35	11.98	1	6.25
9.24	10.82	1	6.25
10.63	9.41	1	6.25
12.00	8.33	1	6.25

Table 11. Average process capacity of processors employing manual vs. mechanical method, 2023.

METHODS	AVE. EVAPORATION CAPACITY (L/h)	AVE. CRYSTALLIZATION CAPACITY (L/h)	AVE. DRYING CAPACITY (kg/h)
Manual	8.16	3.96	3.67
Mechanical	19.09	2.00	37.37

Table 12. Physical properties of coconut sugar.

STATISTICAL PARAMETERS	COLOR			MOISTURE CONTENT, %	PARTICLE SIZE ANALYSIS	
	H	S	B		FINENESS MODULUS	PARTICLE SIZE, µm
Range	22.1-33.0	29.3-44.9	51.3-81.0	0.80-3.01	3.10-5.97	367.30 - 996.84
Mean	26.25	38.44	62.61	1.99	4.20	557.81
SD	2.67	3.53	7.42	0.64	0.72	154.47
CV%	10.16	9.19	11.85	32.33	17.23	27.69

Table 12. ... continued

STATISTICAL PARAMETERS	BULK DENSITY, kg/m3	ANGLE OF REPOSE, °	ANGLE OF FRICTION, °			
			STAINLESS STEEL WITH MIRROR FINISH	STAINLESS STEEL 304	GI1	GI2
Range	518.00-646.67	25.10-34.30	37.30-49.83	34.00-50.00	35.30-48.17	38.50-47.50
Mean	578.04	28.39	44.29	41.31	42.93	42.30
SD	42.45	2.52	3.94	3.94	3.49	2.44
CV%	7.34	8.87	8.89	9.53	8.13	5.77

Davao had the lowest values indicating it to be the finest. The average standard deviation of the particle size of the samples was 1.63.

The coconut sugar samples were determined to have a bulk density range from 518.33 kg/m3 to 646.67 kg/m3 with an average of 578.04kg/m3. The bulk density of the coconut sample aids in the design and selection of packaging of the samples as it determines the amount of material that can fit the space.

The angle of repose from the samples was determined to range from 25.15° to 34.30° with an average of 38.39°. The lowest angle of repose was determined from a processor from Quezon while the highest was Bicol. The angle of repose of material correlates with its ability to flow, whereas powder materials with an angle of repose between 25-30° have excellent flow and are called “free-flowing” (Clayton, 2019). Meanwhile, materials with a high angle of repose may need interventions such as tapping or vibration to facilitate flow.

The coconut sugar of the processors was tested on six surfaces namely, stainless steel with mirror finish (SS1), stainless steel 304 (SS2), galvanized iron sheets (GI1 and GI2), plywood against the grain (PW1), and plywood along the grain (PW2). The angle of friction ranges from 34.00° to 53.50°. The average angle of friction for each surface is as follows: SS1 – 44.29°, SS2 – 41.31°, GI1 – 42.93°, GI2 – 42.30°, PW1 – 45.05°, and PW2 – 46.21°. The particle size of the coconut sugar affects the angle of friction wherein the larger particle has a lower angle of friction, and the finer particle has a higher angle of friction. This can be roughly observed in the results, especially for one sample from Bicol wherein it had the highest particle size and lowest angle of friction for five out of six surfaces. However, due to the subjective nature of the procedure, not all samples have consistently followed the same trend in the relationship between particle size and angle of friction.

Table 12. ... continued

STATISTICAL PARAMETERS	ANGLE OF FRICTION, °	
	PLYWOOD (AGAINST THE GRAIN)	PLYWOOD (ALONG THE GRAIN)
Range	36.70-50.50	36.30-53.50
Mean	45.05	46.21
SD	3.46	4.26
CV%	7.68	9.22

CONCLUSION

In summary, only 4% of the coconut sugar processors interviewed mechanically filtered their coconut sap using a microfiltration machine. For the evaporation process, 14% utilized the mechanical method of evaporation using a steam kettle. The crystallization and pulverization processes were primarily done manually. During the first part of the crystallization process, only 5% used a mechanical mixer while the process was completely manual during the second part of crystallization wherein the forming coconut sugar was simultaneously granulated. Lastly, the sieving and drying process was mechanically done for 30% and 68% of the processors. Hence, most coconut sugar processing steps were still manually done and employed the traditional method of processing.

The mechanical method of evaporation and drying in coconut sugar production showed a higher production capacity than the traditional method. The mechanization of the evaporation and drying process increases the processing plant's production capacity capabilities. However, the average crystallization capacity was lower in the mechanical production at 2.00L/h compared to 3.96L/h in the manual method. This suggests that while current mechanization did not increase production capacity in crystallization, it may reduce the labor intensity required for the process.

The color of coconut sugar samples was light yellow to dark brown, whereas the moisture content ranged from 0.80% - 3.01%. These color and moisture content conformed with the requirements specified by PNS/BAFS 76:2016. The particle size, bulk density, angle of repose, and angle of friction for stainless steel with mirror finish, stainless steel 304, GI1, GI2, plywood (against the grain), and plywood (along the grain) had mean value 557.81µm, 578.04kg/m3, 28.39°, 44.29°, 41.31°, 42.93°, 42.30°, 45.05°, and 46.21° respectively. These parameters are useful for consideration in machine design elements geared toward the mechanization of coconut sugar production.

Table 13. Average HSB coconut sugar color from Davao, Quezon, Bicol, and SOCCSKSARGEN processors, 2023.

PROCESSOR	H	S	B
Davao	24.8	41.0	59.6
Quezon	25.5	38.9	60.2
Bicol	29.0	34.1	68.8
SOCCSKSARGEN	25.7	40.1	61.0

RECOMMENDATIONS

For a more comprehensive description of the outcomes of the mechanization of coconut sugar production, the physical properties of coconut sugar may be classified depending on the method from which it was produced, either from manual or mechanical production method. Data from this could be used in identifying how mechanization affects the quality of produced coconut sugar.

Collecting data on the input and output material is recommended to determine the material recovery from each process of coconut sugar production. The evaporation, crystallization, and drying capacity per equipment may be reported as the overall process capacity of the production plant by considering the total number of equipment per process that was available in the plant.

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