Process Design of an Integrated Virgin Coconut Oil (VCO) Processing Technology

Jolina Danielle D. R. Bautista, Cristelle Diane S. Diaz, Lans Z. Sayson, Joshua Ladd A. Siat, Miyami B. Tamaki, Lindsay Odyssey L. Timbre, and Lola Domnina B. Pestaño*

Department of Chemical Engineering, University of Santo Tomas, España Boulevard, Manila, Philippines
*Correspondence: lbpestano@ust.edu.ph (L.D.B.P)

***Abstract*—Virgin Coconut Oil (VCO) is a product obtained from fresh coconut that has been very famous in the market due to its several uses. The research aims to: design a process for the production VCO that utilizes both fresh-dry and fresh-wet methods; determine the weights of recovered coconut waste materials, VCO recovery of the three production lines, and investigate the possible utilization of these wastes to produce value-added commodities; and develop a conceptual design of the production of VCO that applies to a small-medium scale coconut community or farm in the Philippines. Preparation of raw materials includes splitting and grating of coconut meat and milk extraction. A conceptual design for the integrated method applicable to a small-medium scale coconut community in the Philippines was developed employing three assembly lines: (1) the low-pressure oil extraction via centrifugation method; (2) the fresh-dry process through low-pressure oil extraction method; and (3) the fresh-wet process through modified kitchen method that produces the clearest oil with VCO recovery of 18.43%, 25% and 16.5% for VCO production lines 1, 2 and 3 respectively. The VCO produced is expected to qualify in the Asian and Pacific Coconut Community (APCC) VCO Standards. The weight of all recovered materials and wastes were accounted for.**

***Keywords*—copra, centrifugation method, low-pressure oil extraction, modified kitchen method, *sinusinu*, small-medium scale, virgin coconut oil**

I. Introduction

VCO (Virgin Coconut Oil) is an oil that can be extracted mechanically or naturally from mature and fresh coconut kernels, with or without the use of heat, without chemical refining, bleaching, or deodorizing, and without changing the oil's composition [1]. VCO is currently produced mostly by small-medium scale businesses in the Philippines, with few caterings to the export market. It may be produced without any special equipment, and the raw material is coconut meat [2]. According to ACOP Inc., its affiliates can generate 50,000 L of VCO using a cold press [3]. A shorter period is required to achieve an increased production while also ensuring the quality of VCO, which depends on different factors relating to the condition of the raw material, processing method, packaging, and storage condition [4]. Bawalan and Chapman [5] classified these two methods into two types: wet and dry process. Production of VCO under wet and dry processing methods are applicable at a small-medium scale setting with capacities of 5,000–10,000 nuts/day [6]. VCO is the most valued coconut-based product globally [7]; thus, the production of VCO adds more profit than producing copra alone. This process design of the combined techniques for VCO processing will benefit coconut farmers as well as their families. This will provide additional income to improve the cost of living as they venture into an improved VCO processing. Furthermore, researchers recommend VCO as a potential antiviral agent against coronavirus disease 2019 (COVID-19) [8]. Also, it is said to have a variety of health benefits and shows potential cardio protective effects due to its medium-chain fatty acids content, which is known for high antioxidant properties [9, 10]. This research aims to design an integrated VCO processing technology that utilizes low-pressure oil extraction that employs centrifugation and the combined low-pressure oil extraction method and modified kitchen method to produce VCO, recover all recovered materials and wastes in the VCO processing, determine the percent VCO recovery by weight in the three production lines, and develop a conceptual design of the production of VCO applicable to a small-medium scale coconut community or farm in the Philippines.

II. Materials and Methods

A. Collection and Preparation of Raw Materials

After the procurement of fresh and matured de-husked coconuts, the preparation of raw materials will be done that includes: (1) collection of coconut water; (2) splitting; and (3) grating of coconut meat.

B. The Integrated VCO Processing Technology

1) VCO Production Line 1: Low-pressure Oil Extraction Employing Centrifugation Method

VCO production line 1 includes: (1) drying of grated coconut meat; (2) low-pressure extraction; (3) centrifugation; and (4) decantation of the final VCO.

2) VCO Production Line 2: Low-pressure oil Extraction Method

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The VCO production line 2 includes: (1) drying of sapal; (2) manual pressing; (3) settling; (4) decantation of the final VCO; and (5) collection of spent sapal.

3) VCO Production Line 3: Modified kitchen method

The VCO production line 3 includes: (1) settling; (2) slow heating; (3) filtering; (4) collection of residue (*sinusinu*); and (5) oil drying.

C. Quality Testing

The resulting VCO from the three production lines will be submitted to the Philippine Coconut Authority (PCA) for the testing of specific parameters such as iodine value, Free Fatty Acids (FFA), peroxide value, saponification value, moisture and volatile matter, and color.

D. Development of Data for Conceptual Design for a Small-Medium Scale Coconut Production

A conceptual design for the integrated VCO processing technology was developed and illustrated. The recovery of important coconut parts and wastes was validated.

E. Material Balances

A material balance of all the process units was executed to account for the mass of various streams entering and leaving each process. 10,000 nuts per day were used as the basis for a small-medium scale setting in a coconut farm in the Philippines. All percentage compositions are per weight. The percent oil recovery in the three production lines were determined.

III. Result and Discussion

A. Conceptual Design for a Small-Medium Scale VCO Production

The VCO processing plant will process 10,000 matured de-husked nuts per day that produces VCO through the integration of the VCO processing methods, the fresh-dry and the fresh-wet methods.

1) Collection and preparation of raw materials

Fresh and matured de-husked coconuts of 10 to 12 months of age will be utilized. Place the nuts in large rice sacks and bring them to an area for splitting and grating.

2) Collection of coconut water

Make a hole in one of the "eyes" of the nut. Using a hammer and a clean nail, puncture a hole to create an orifice and let the coconut water drain. Collect the coconut water using clean plastic containers and store it in a refrigerator [11].

3) Splitting

Hold the nut with one hand and apply force using a large kitchen knife until the nut is completely split into half [11].

4) Grating coconut meat

Grate the coconut meat from the husk using a manual coconut grating tool or using an electric scraping to comminute the meat into fine particles. Collect the grated coconut meat in clean large plastic pails and put the coconut shells in large plastic bags.

5) Coconut milk extraction

Mix the grated coconut with water, which creates a milky heterogeneous mixture. Several sources claim that the ideal ratio of water to grated coconut is 1:1 to create the desired consistency of coconut milk [12].

a) Extraction of coconut milk by hand

Place the grated coconut mixture in cheesecloth bags. Squeeze the cheesecloth bags containing the grated coconut mixture to extract the coconut milk. Collect the extracted coconut milk and coconut meat residue (sapal) separately in clean large transparent plastic containers.

b) Extraction of coconut milk by manual hydraulic jack

Place the cheesecloth bag containing the grated coconut mixture at the center of a manually operated hydraulic jack and extract the coconut milk according to the jack's operating procedure. Collect the coconut milk and grated coconut meat residue separately in clean large transparent plastic containers.

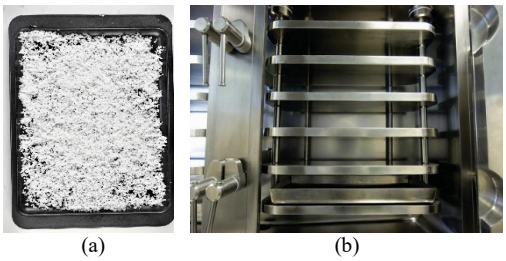
B. The Integrated VCO Processing Technology

40% by weight of the grated coconut meat will be used for the fresh dry process: VCO Production Line 1, and the remaining grated coconut meat will be used for the fresh wet process: VCO Production Lines 2 and 3 from which after the coconut milk extraction, the collected sapal will be subjected to low-pressure oil extraction method in VCO Production Line 2, while the collected coconut milk will undergo modified kitchen method in VCO Production Line 3.

1) The fresh dry process

a) VCO production line 1: Low-Pressure oil extraction employing centrifugation method

Drying coconut meat: The grated coconut meat will be spread evenly and thinly on each tray before placing it in the electric tray dryer as shown in Fig. 1. The grated coconut meat will be heated at a temperature of 70°C for 29.70 minutes [13] to obtain 11% moisture content to attain an optimum oil recovery [1]. The dried grated coconut meat will be cooled before transferring them into large clean plastic containers.



(a) (b)

Figure 1. (a) Grated coconut on a tray [14]; and (b) an electric tray dryer [15].

Low-Pressure extraction: Place the dried grated coconut meat inside a cheesecloth bag [16]. This will undergo oil extraction at a low pressure of 460 psi by means of a hydraulic manual press. The extracted crude coconut oil will be transferred into large clean plastic containers, and the dried grated coconut meat residue will be collected in large garbage bags.

Centrifugation: The extracted crude coconut oil will be placed gently into a basket centrifuge shown in Fig. 2. A centrifugation speed of 2,700 rpm will be set with a

centrifugation time of 60 minutes [13]. Once the centrifugation time has been completed, transfer the crude coconut oil into large clean transparent pails for decantation.

Figure 2. Basket centrifuge [17].

Decantation: The two layers that consist of VCO and the dried coconut meat sediments or foots obtained from the centrifugation process will be separated through decanting. Pour the upper layer (VCO) into large clean plastic containers while the bottom layer (foots) will be placed in garbage bags [5].

b) VCO production line 2: Low-Pressure oil extraction

Drying: Follow the drying procedure in 2.1.1.1 to dry the collected sapal as shown in Fig. 1 at a temperature of 70oC for 29.7 minutes reaching 11% moisture content, to attain an optimum oil recovery [13, 18]. Place the dried sapal in clean cheesecloth bags.

Manual pressing: Follow the extraction procedure using a hydraulic jack in 1.5.2 to extract the crude coconut oil from the dried sapal. Collect the spent dried sapal in clean plastic bags. Set aside the crude coconut oil for settling.

Settling: Let the extracted crude coconut oil stand for seven days to settle the fine particles. Allot another seven days to complete the settling process [18]. Decant the final VCO to clean plastic containers and collect the fine particles in plastic bags for disposal. Cover and label the containers.

2) The fresh wet process

a) VCO production line 3: Modified kitchen method

Settling: Let the collected coconut milk extract contain two phases: the coconut cream layer and the coconut skim milk layer as shown in Fig. 3 settle for exactly 2 hours in a chilled refrigerator about 0°C to 4°C [18]. Scoop the coconut cream from the top. Put the cream in clean medium plastic containers and store the skim milk in the refrigerator.

Figure 3. Separated coconut cream and skim milk [18].

Slow heating: Heat the coconut cream in a casserole pan. For the first hour, set the stove between medium to high until the temperature reaches 90°C. For the succeeding hours, heating will be done at a temperature not higher than 80°C until the coconut cream starts to form the coagulated protein (sinusinu) [18] (See Fig. 4). At this point, lower the temperature setting at 60°C. Continuously stir the mixture to prevent the oil from turning yellowish in color.

Figure 4. Separation of oil from the coagulated protein (*sinusinu*) [18].

Filtering: Filter the oil-sinusinu mixture to eliminate the adhering fine particles, leaving a colorless oil. Put a muslin cloth into a strainer and pour the oil-sinusinu mixture over the cloth. Collect the filtered coconut oil in clean transparent plastic containers [18]. Collect the sinusinu residue in plastic bags.

Oil drying: Oil drying will be done using a double boiler process [18]. Submerge a stainless-steel mixing bowl inside a pot with half full of water. Put the filtered coconut oil in the mixing bowl. Reduce the setting of the stove to low once the water starts to boil. The coconut oil should not be heated directly in the pot to prevent the temperature from exceeding 65°C since this will make the coconut oil yellowish in color [18]. Collect the final colorless VCO from the mixing bowl in clean plastic containers with a cover. Label the containers as VCO.

C. Process Flow Diagram for the Production of VCO

A flowchart of the integrated VCO processing technology was designed to understand each step of the three (3) VCO production lines (See Fig. 5): (1) the fresh-dry process by the low-pressure oil extraction method that employs centrifugation that utilizes the grated coconut meat; (2) the fresh-dry process by the low-pressure oil extraction method that utilizes the sapal; and (3) the fresh-wet process by the modified kitchen method that will consume the extracted coconut milk. The major product of the three assembly lines is the VCO.

D. Calculation of Oil Recovery

The density of VCO at room temperature is 0.903 g/mL [19]. Eq. (1) was used to calculate the oil recovery at the best setting.

$$\text{oil recovery} = \frac{\text{wt. of VCO recovered}}{\text{wt. of coconut meat used}} \times 100 \quad (1)$$

A nut with an average weight of 1374.01 g gave the following composition: 22.72% shell, 37.85% water, 37.65% meat, and 1.78% that corresponds to losses in handling [13]. For 10,000 fresh mature de-husked coconuts per day that will be collected, the total weight of the nuts is 13,740.1 kg and contains 5200.7 kg water, 3122.1 kg coconut shell, 5172.7 kg grated coconut meat, and 244.6 kg losses.

1) VCO production line 1

40% of the grated coconut meat weighing 2069.08 kg will undergo a low-pressure oil extraction method to remove 1096.98 kg of dried coconut meat residue while the 271.62 kg crude coconut oil is subjected to centrifugation. The obtained crude coconut oil from the centrifuge will be decanted to separate the 19.43 kg foots from the 252.19 kg VCO with 18.43% oil recovery [13].

2) VCO production line 2

The remaining 60% of the grated coconut meat will be extracted. The *sapal* weighing 2069.08 kg is subjected to drying: evaporating 573.19 kg of water and producing 1244.24 kg dried *sapal*. The obtained dried *sapal* is sent to manual pressing, producing 950.66 kg crude coconut oil and 293.59 kg spent dried *sapal* [6]. The obtained crude coconut oil is subjected to settling, collecting 174.75 kg fine particles and the final product, 775.91 kg VCO or 25% oil recovery.

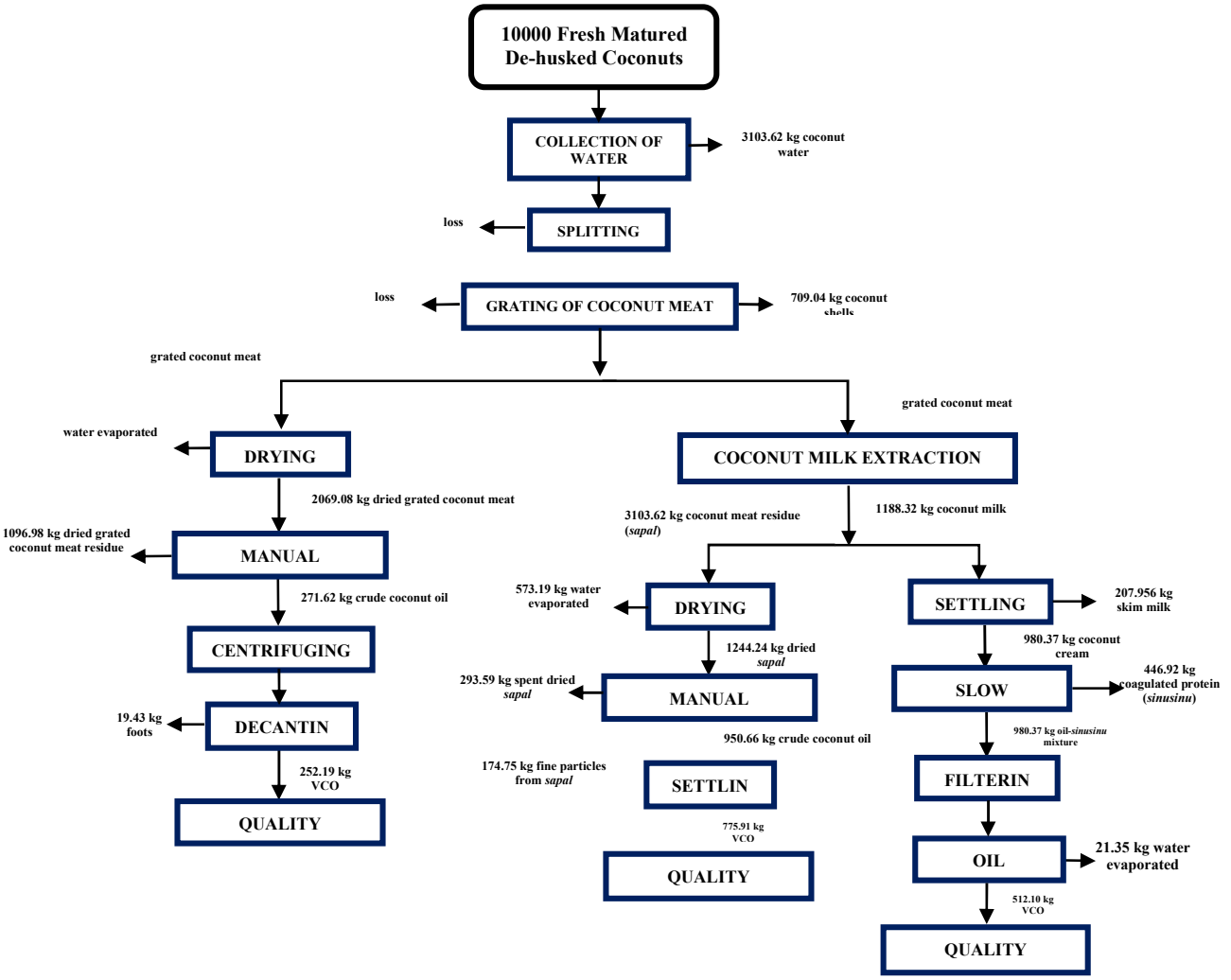


Figure 5. Process flow diagram of the integrated VCO processing technology.

3) VCO production line 3

On the other hand, from 1188.32 kg coconut milk, 207.956 kg coconut skim milk and 980.37 kg coconut cream are produced. The obtained coconut cream is sent to a slow heating process resulting in a 980.37 kg oil-*sinusinu* mixture. The product mixture is filtered producing 446.92 kg *sinusinu* and 533.45 kg coconut oil [6, 12]. The obtained coconut oil evaporated 21.35 kg of residual moisture and produced the final product, 512.10 kg VCO or 16.5% oil recovery [18].

E. Quality Testing

The Asian Pacific Coconut Community (APCC) and Codex Alimentarius have standardized quality control criteria for physical, chemical, and microbiological characteristics of VCO, as seen in Table I [20]. A VCO that meets APCC's interim standard indicates that the oil is produced by natural means and there are no alterations in its properties. Conforming to the Codex Standard for Coconut Oil implies that "virgin oils" are suitable for human consumption and purification can be done by water-washing, settling, filtering, and centrifugation to remove undesired components and extend shelf life [21]. Table I showed the quality testing results from various journals for physicochemical properties. The data were investigated and compared from the required values based on APCC Standard for VCO.

For the study of Achinewhu *et al.* [22] and Ferrer *et al.* [13], the Peroxide Value (PV) of the oil samples are lower than the APCC standard due to the freshness of the

mature coconut copra used. Also, this indicates that the samples are highly stable against oxidative rancidity [22]. The Saponification Value (SV) of the sample is within the standard of APCC for VCO. High SV indicates the suitability of vegetable oil for industrial application [22]. Moisture Impurities and Volatile matter (MIV) of the samples are below APCC standard which indicates good quality and longer shelf life by preventing oxidation and rancidity [22]. The Iodine Value (IV) of the samples is within the standard of APCC. Low IV of coconut oil indicates that the oil is rich in saturated fatty acids [20] and is unlikely for VCO to become rancid from lipid oxidation [23]. The Free Fatty Acid (FFA) of the samples is lower than the APCC standard which indicates good storage stability [22]. The physicochemical properties of VCO extracted from fresh-dry low-pressure oil extraction method and employs centrifugation were analyzed in a study by Afiq *et al.* [23]. The drying time for *sapal* prior to oil extraction affects the %FFA of VCO. A longer drying time leads to an increase in % FFA, causing more time for the process of rancidity to occur [23].

TABLE I. QUALITY TESTING RESULTS FOR THE TWO VCO PROCESSING TECHNOLOGIES

Parameter	**Asian and Pacific Coconut Community (APCC) Standard for VCO** [20]	**Modified Kitchen Method**		**Low-Pressure Oil Extraction**	**Low Pressure Extraction with Centrifugation**
		Achinewhu *et al.* [23]	Sedode [24]	Afiq *et al.* [25]	Ferrer *et al.* [14]
Iodine Value (g/100g)	4.1–11	6.05 ± 0.071	5.88	4.18 ± 0.04	4.11–11
FFA (%)	0.2	0.051 ± 0.005	0.14	0.46 ± 0.01	0.2 max
Peroxide Value (MEq/kg)	3	1.288 ± 0.105	0.74	N/A	3 max
Saponification Value (mg KOH/g)	250–260	259.40 ± 0.566	N/A	258.42 ± 1.41	
Moisture Content (%)	0.1	0.055 ± 0.07	0.02	0.04	0.2 max
Oil Recovery (%)	–	58.00 ± 0.001	18.89		
Color (5 1/4" cell) Red/Yellow	0R/0.3Y	–	–	–	Colorless

F. Collection of Wastes and Disposal

Dispose the coconut shells by selling them to charcoal, plywood, or handicraft manufacturers. Store the collected coconut water in a refrigerator for consumption purposes or convert it to a high-energy drink [25]. Reuse cheesecloth bags and muslin cloth fabrics for another batch of operation. Refrigerate the coconut skim milk for a maximum of two hours for consumption purposes. Use the *sinusinu* as a rice cake topping or a meat-based food extender. Spent dried *sapal* meat can be used as a healthy snack food, a meat extender, and an organic fertilizer.

IV. CONCLUSION

The VCO processing that employs the combination of dry and wet processing methods using three VCO production lines was designed based on the investigation of VCO processing technologies. A conceptual design for the integrated method that is applicable to a small-medium scale coconut community in the Philippines was developed for the low-pressure extraction via centrifugation method that produces the clearest oil with a yield of 92.84 % v/v and a recovery of 18.43%. A VCO recovery of 25% and 16.5% was observed for the low-pressure oil extraction method and modified kitchen method, respectively. The VCO produced is expected to qualify in the Asian and Pacific Coconut Community (APCC) VCO Standards. The weight of all recovered materials and wastes in the VCO processing technology and the utilization of wastes to produce value-added commodities were accounted for.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

LDBP, acting as the research adviser, played a pivotal role by formulating the research theme concerning the process design for virgin coconut oil production in the Philippines. She provided continual guidance and assessed the content of the paper, ensuring the research met rigorous standards. LOLTB, MBT, and CDSD collaborated on designing a novel process amalgamating low pressure oil extraction and modified kitchen methods and refining the final paper. They also liaised with editors and adeptly addressed peer-review feedback. Simultaneously, JDB, LZS, and JLS pioneered an alternative approach using low pressure extraction combined with centrifugation, demonstrating meticulous attention to detail in validating their work. They contributed to the paper's refinement, enhancing its overall quality. All authors had approved the final version.

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REFERENCES

[1] Z. Masyithah, "Parametric study in production of virgin coconut oil by fermentation method," *Oriental Journal of Chemistry*, vol. 33, no. 6, pp. 3069–3076, 2017.

[2] C. M. Cariño, "VCO shows potential for cancer treatment," *The Manila Times*, April 2019.

[3] B. O. Juliano, *Virgin Coconut Oil: State of the Art*, National Academy of Science and Technology (NAST), 2007, ch. 2, p. 12.

[4] A. M. Marina, Y. B. C. Man, and I. Amin, "Virgin coconut oil: Emerging functional food oil," *Trends in Food Science & Technology*, vol. 20, no.10, pp. 481–487, 2009.

[5] D. D. Bawalan and K. R. Chapman, *Virgin Coconut Oil: Production Manual for Micro- and Village-Scale*, FAO Regional Office for Asia and the Pacific, 2006.
[6] D. U. Angeles, *Philippine Coconut Authority*, 2012.
[7] R. D. S. Lima and J. M. Block, "Coconut oil: What do we really know about it so far?" *Food Quality and Safety*, vol. 3, no. 2, pp. 61–72, 2019.
[8] F. M. Dayrit, I. K. Dimzon, M. F. Valde, *et al.*, "Quality characteristics of virgin coconut oil: Comparisons with refined coconut oil," *Pure and Applied Chemistry*, vol. 83, no. 9, pp. 1789–1799, 2011.
[9] S. Kappally, A. Shirwaikar, and A. Shirwaikar, "Coconut oil – A review of potential applications," *Hygeia Journal for Drugs and Medicines*, vol. 7, no. 2, 2015.
[10] A. Babu, S. Veluswamy, R. Arena, M. Guazzi, and C. Lavie, "Virgin coconut oil and its potential cardioprotective effects," *Postgraduate Medicine*, vol. 126, no. 7, pp. 76–83, 2014.
[11] S. Kazan. (2020). How to open a coconut (4 easy methods). *Alphafoodie*. [Online]. Available: https://www.alphafoodie.com/how-to-open-a-coconut/
[12] F. Fatimah, S. Gugule, and T. Tallei, "Characteristics of coconut milk powder made by variation of coconut-water ratio, concentration of tween and guar gum," *Journal of Applied Sciences Research*, vol. 13, no. 6, pp. 1–10, 2017.
[13] P. J. Ferrer, V. F. Quilinguen J. Rosario, and L. D. Pestaño, "Process design of Virgin Coconut Oil (VCO) production using low-pressure oil extraction," in *Proc. The 24th Regional Symposium on Chemical Engineering*, 2018, vol. 156.
[14] Samira. (2021). How to make shredded coconut (desiccated coconut). *Alphafoodie*. [Online]. Available: https://www.alphafoodie.com/how-to-make-shredded-coconut-desiccated-coconut/
[15] JBM Prispac Solutions India Pvt. Ltd, Tray Dryer, 2021.
[16] IndiaMART, Bottom Discharge Centrifuge Machine, 2021.
[17] D. D. Bawalan, *Processing Manual for Virgin Coconut Oil, Its Products and By-products for Pacific Island Countries and Territories*, Noumea, New Caledonia: Secretariat of the Pacific Community, 2011.
[18] Amazon, "Cheesecloth bags for straining, reusable cold brew coffee cheese cloths strainer, large nut milk tea juice bag, 100% natural cotton fine mesh filter bags (large, 4 pack)," *Home & Kitchen*, 2021.
[19] Y. Wong and H. Hartina, "Virgin coconut oil production by centrifugation method," *Oriental Journal of Chemistry*, vol. 30, no. 1, pp. 237–245, 2014.
[20] K. Seneviratne and N. Jayathilaka, *Coconut Oil: Chemistry and Nutrition*, Battaramulla, Sri Lanka: Lakva Publishers, 2019.
[21] A. Mulyadi, M. Schreiner, and I. Dewi, "An overview of factors that affected in quality of virgin coconut oil," *AIP Conference Proceedings*, vol. 2120, no. 1, 2019.
[22] S. Achinewhu, C. Ajogun, D. Kabari, and O. M. Akusu, "Effect of extraction methods on the physicochemical properties, Philippines," 2020.
[23] J. Sedode, "Effects of small-scale coconut oil processing methods on the quality and yield of oil in the Jomoro District," University of Ghana, 2015.
[24] A. Afiq, T. Mansor, C. Man, and K. Nurul, "Physicochemical properties of virgin coconut oil extracted from different processing methods," *International Food Research Journal*, vol. 19, no. 3, pp. 837–845, 2012.
[25] L. J. Penamora, "Production of handicrafts, wares and novelty items from coconut wood, fronds and coconut fruit residues," *Coconut Research & Development Journal*, vol. 23, no. 2, p. 8, 2007.