Process Design of Virgin Coconut Oil (VCO) Production Using Low-Pressure Oil Extraction

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Abstract. Virgin coconut oil (VCO) has become one of the most prominent high-value coconut product in coconut producing countries because of its versatility. This research attempts to design a fresh-dry process based on the Low-Pressure Oil Extraction Method for the production of VCO to reduce the settling time of the oil after extraction, that usually takes 1-2 weeks. Different parameters, such as drying temperature, centrifuge speed, and centrifugation time were varied and analysed. Three mathematical models were examined to describe the drying behaviour of the grated coconut meat at 65, 70, and 75°C using a tray dryer. A VCO production fresh-dry process based on the Low-Pressure Oil Extraction Method was developed through the employment of a centrifuge. The modified method lessens the settling time while still producing standard quality VCO. As predicted by the Laplace Transform Model, the shortest time for the comminuted coconut meat to reach a moisture content of 11% at which oil from nuts can be extracted using low pressure is at 29.07 minutes using a tray dryer. The best setting of VCO production using the modified method is at a drying temperature of 70˚C and at 2700 RPM and 60 minutes of centrifugation as it produced the clearest oil with a yield of 92.84 % v/v and a recovery of 18.43%. The produced VCO was tested for free fatty acid (FFA), moisture and volatile matter, colour, peroxide value, and iodine value, and the results are 0.03%, 0.11%, 0R/0.3Y, 0, and 5.77, respectively, which all passed the Philippine National Standards for VCO.

1 Introduction

The purest type of coconut oil, virgin coconut oil (VCO), was introduced to the world market at the end of the 20th century. It is considered one of the products of great value derived from the fresh coconut [1]. VCO, the clear, high value oil resulting from the fresh and mature kernel of coconut (*Cocos nucifera L.*), is obtained through mechanical and natural means, with or without the use of heat, without undergoing chemical refining, bleaching or deodorizing, which does not lead to alteration or transformation of the natural characteristics of oil [2]. It is now gaining a worldwide popularity because of its wide range of applications in medicine, food, cosmetics and the like [3].

VCO processing technologies can be generally categorized into fresh-dry process and fresh-wet process. The term fresh-wet is for the VCO process in which the VCO is obtained from the coconut milk by a variety of means after it has been extracted from freshly comminuted coconut kernel. The term fresh-dry on the other hand, is for the VCO process where VCO is obtained directly from the fresh coconut kernel which requires drying of the kernel in comminuted form before the extraction of oil [1].

Under the fresh-dry technologies is the low pressure oil extraction method. This method is common among micro- and village-scale industries and works on the principle that oil from seeds or nuts can be extracted using low pressure at about 460 psi provided that the moisture content of the material is within the range of 10–13% [3].

This process, however, requires at least two weeks of settling time to separate the fine particles of dried kernel from the extracted oil. A centrifuge, which is commonly used for emulsion breaking of coconut milk in fresh-wet VCO processing technologies [4] may be utilized to greatly lessen the settling time while still producing VCO which passes the quality standards set by the Philippine National Standards (PNS) for VCO, as well as the Asian and Pacific Coconut Community (APCC). Other factors,

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such as drying temperature, centrifugation speed, and centrifugation time may also affect the quality of the VCO produced [5].

The general objective of this study is to lessen the settling time of the low pressure oil extraction method of VCO fresh-dry production through the employment of a centrifuge as replacement to the traditional settling. Different parameters such as drying temperature, centrifugation speed, and centrifugation time were varied and analyzed in order to obtain the optimum setting for the process design.

Specifically, the objectives of the study are:

(1) To design a VCO production fresh-dry process based on the low-pressure oil extraction method that greatly lessens the settling time through the employment of a centrifuge while still producing standard quality VCO; and

(2) to determine the optimum drying temperature and drying time to achieve 11% MC of the comminuted coconut meat, centrifugation speed, and centrifugation time, and the optimum setting that will yield the fastest process and the highest quality of product.

2 Methods

2.1 Raw material collection and preparation

Fresh de-husked coconuts of 10 to 12 months of age were obtained from Oriental Mindoro, Philippines. The coconuts used in this research were of similar sizes, brown in color and did not have haustorium. The nuts were labelled Nut 1 to Nut 10. The fresh mature coconuts were split and comminuted through a manual/motor grater.

2.2 The equipment used

The equipment used in the experimentation were the tray dryer, fabricated manual press and the digital centrifuge DSC-301SD. The tray dryer was readily available in the Unit Operations Laboratory (Lab 4A) of the Chemical Engineering Department in the Roque Ruaño building of University of Santo Tomas, while the digital centrifuge used was from the UST College of Education, located at the Food Technology Laboratory Annex, 2nd floor of the UST Albertus Magnus building. The 4-ton hydraulic jack manual press was fabricated and bought from an external supplier.

2.2.1 Manual press

The hydraulic manual press used in the experiment was pre-fabricated. The manual press' frames and body were made from aluminum while the parts that come in direct contact with the grated coconut meat, such as the tray and the roof, were made of stainless steel. A bottle-type hydraulic jack with a maximum allowable load of 4 tons, manufactured by Hoyoma, Japan Power Tools, was the source of the hydraulic system of the manual press. Figure 1 shows the dimensions and the different views of the fabricated hydraulic jack manual press.

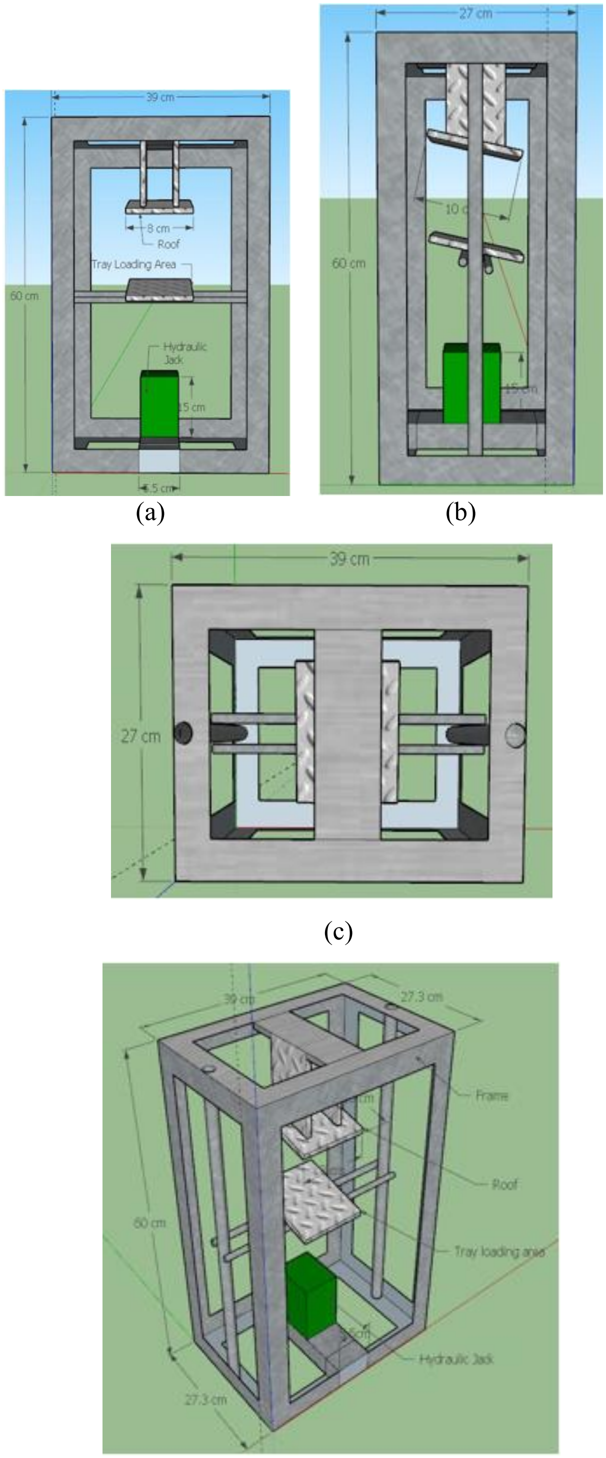

Fig. 1. Fabricated hydraulic manual press: (a) Front view, (b) Right-side view, (c) Top view, (d) Isometric view.

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2.2.2 Digital Centrifuge

The digital centrifuge used was Digital Centrifuge Model DSC 301SD developed by Digi system Laboratory Instrument Inc. It has a maximum RPM of 4000 and can contain 4 units of 50 mL corning tubes per run. A specifications sheet of the necessary information is given in Table 1.

Table 1. Specifications sheet of Digital Centrifuge Model DSC-301SD

Speed	300-4000 RPM
Motor	DC Motor
Rotor	SB-071550
Rotor Type	45°Angle
Capacity	16 x (5-7 mL) 12 x (10-15 mL) 4x (50 mL)
Weight	N.W. 19 Kg G.W. 21 Kg
Overall Dimensions	500mm x 390 x 290
Power Supply	AC110V 50/60Hz

2.3 Mass balance

For each nut, the shell, water, and grated coconut meat were weighed using a precision balance with accuracy of 0.01g. Per cent composition of the materials for each nut was determined. Mass balance was performed to account for the losses. The average values for the ten nuts were calculated.

2.4 The Drying Experiment

The grated coconut meat was spread evenly and thinly on a tray with a surface area of 182.88 square centimeters and a thickness of not more than 1 cm. The grated coconut meat was heated at temperatures, 65-75°C at 5°C intervals every 5 min until constant weight is obtained. Before beginning the experiments, the tray dryer system was preheated in order to achieve a desirable steady state condition of temperature.

Weighing of the dried grated coconut meat was done using a precision balance with an accuracy of 0.01 g. Drying experiments for each temperature were conducted in triplicate.

2.4.1 Mathematical Modelling

The parameters that will be used in the modeling are the moisture ratio (MR) and the drying rate (R). The MR during drying was calculated using Equation 1:

$$MR = \frac{M - M_e}{M_i - M_e} \quad (1)$$

where M, Mi and Me are the MC, in g, at any time t, the initial MC and the equilibrium MC, respectively. The R was calculated from the experimental data using Equation 2:

$$R = -\frac{W_S}{A}\frac{d\overline{X'}}{dt} \quad (2)$$

where Ws is the weight in g, of the dry solid, A is the surface drying area in m^2, X' is the bulk MC and t is time. Equation 2 can be rearranged and integrated. The integral form Equation 3 was used to obtain the drying time.

$$\int_0^t dt = -\frac{W_S}{A}\int_{\overline{X'}_1}^{\overline{X'}_2}\frac{d\overline{X'}}{R} \quad (3)$$

The drying data (MR vs. t) at 65, 70 and 75°C were fitted into the three mathematical models: Page Model, Laplace Transform Model and Non-linear Decomposition Model. Drying is a complex process and as a means to simplify the analysis of the drying kinetics of grated coconut meat, empirical expressions are used [6]. Mathematical modeling using thin-layer drying equations are used to evaluate drying time of products based from experimental data. Models are often used to study the variables involved in the process, predict drying kinetics of the product and optimize the operating parameters and circumstances [7]. The values of the correlation coefficient, R^2, for the Page and Non-linear Decomposition Model, the time constant, tau, τ for the Laplace Transform Model and the total error for the three models were computed. The selection of the best model to describe the drying behavior of the grated coconut meat will be based on the least total error and the goodness of fit of a model.

The Page Model was successfully used to describe the drying characteristics of some agricultural products [8, 9, 10]. The Page Model [11, 12] that was used in this study was derived by linearizing the R equation shown in Equation 4.

$$MR = ae^{-kt^n} \quad (4)$$

Eq. (5) is the linearized form of Eq. (4).

$$MR = ln\, a - kt^n \quad (5)$$

The Laplace Transform Model and Non-Linear Decomposition Model are used for prediction of the behavior of a system as reduction of moisture proceeds until it reaches equilibrium [13]. The Laplace Transform Model was derived from a material balance of the system in the experiment. The general material balance states that the input minus the output of the system is equal to rate of accumulation as shown in Equation 6.

$$M_i - M_o = \tau \frac{dM}{dt} \quad (6)$$

Equation 6 is then formulated to its Laplace Transform Model [14], integrated and simplified forming Equation 7 used in modeling the drying rate characteristics of the grated coconut meat.

$$M = M_f - M_f e^{-\frac{t}{\tau}} + M_i e^{-\frac{t}{\tau}} \quad (7)$$

The Non-linear Decomposition Model is based on the differential equation for batch decomposition as given in Equation 8.

$$\frac{1}{C^{n-1}} = \frac{1}{C_o^{\,n-1}} + (n-1)kt \quad (8)$$

The determination of the MR is represented by the concentration [15] and is represented below in Equation 9.

$$MR = \sqrt[n-1]{\frac{MR_o^{\,n-1}}{1+(n-1)ktMR_o^{\,n-1}}} \quad (9)$$

2.4.2 Determination of Drying Time to Attain 11% MC

The drying time needed to attain the needed 11% MC was determined through Lagrange interpolation. This method generates nth-order polynomials that pass through (n + 1) points. These polynomials attempt to produce interpolation values of increased accuracy by assuming a curvature in the relationship of the data. Its general equation is represented by Equation 10. The three versions are Equations 11–13.
The Lagrange interpolation:

$$f_n(x) = \sum_{i=0}^{n} L_i(x) f(x_i) \quad (10)$$

First-Order version:

$$f_1(x) = \frac{x - x_1}{x_0 - x_1} f(x_0) + \frac{x - x_0}{x_1 - x_0} f(x_1) \quad (11)$$

Second-Order version:

$$f_1(x) = \frac{(x-x_1)(x-x_2)}{(x_0-x_1)(x_0-x_2)} f(x_0) + \frac{(x-x_0)(x-x_2)}{(x_1-x_0)(x_1-x_2)} f(x_1) + \frac{(x-x_0)(x-x_1)}{(x_2-x_0)(x_2-x_1)} f(x_2) \quad (12)$$

Third-Order version:

$$f_3(x) = \frac{(x-x_1)(x-x_2)(x-x_3)}{(x_0-x_1)(x_0-x_2)(x_0-x_3)} f(x_0) + \frac{(x-x_0)(x-x_2)(x-x_3)}{(x_1-x_0)(x_1-x_2)(x_1-x_3)} f(x_1) + \frac{(x-x_0)(x-x_1)(x-x_3)}{(x_2-x_0)(x_2-x_1)(x_2-x_3)} f(x_2) + \frac{(x-x_0)(x-x_1)(x-x_2)}{(x_3-x_0)(x_3-x_1)(x_3-x_2)} f(x_3) \quad (13)$$

2.5 Combined low pressure oil extraction and centrifugation method

The dried grated coconut meat was subjected under low pressure oil extraction using a fabricated manual press. A clean cheesecloth was used to hold the dried grated coconut meat together and to filter the undesired solid particles from the extract. The extracted crude coconut oil was collected in corning tubes in preparation for the final method which was the centrifugation method. A digital centrifuge (DSC-301SD) was used to speed up the settling time and to separate the foots or the fine kernel particles entrained in the oil, from the desired liquid.

Specific parameters such as the centrifugation speed and centrifugation time were varied occasionally to determine its effect on the resulting product. For the centrifuge speed - 2000 RPM and 2700 RPM were utilized, due to the limitations of the said equipment used. Centrifugation time was varied for each centrifugation speed using 20, 40, and 60 minutes. The centrifugation method was carried out using fresh samples of extracted crude coconut oil for each time and speed. After centrifugation, decantation was done to obtain the VCO, which was the clear top-most layer of the corning tube after centrifugation. Figure 2 shows the flowchart of the modified and improved low-pressure oil extraction method.

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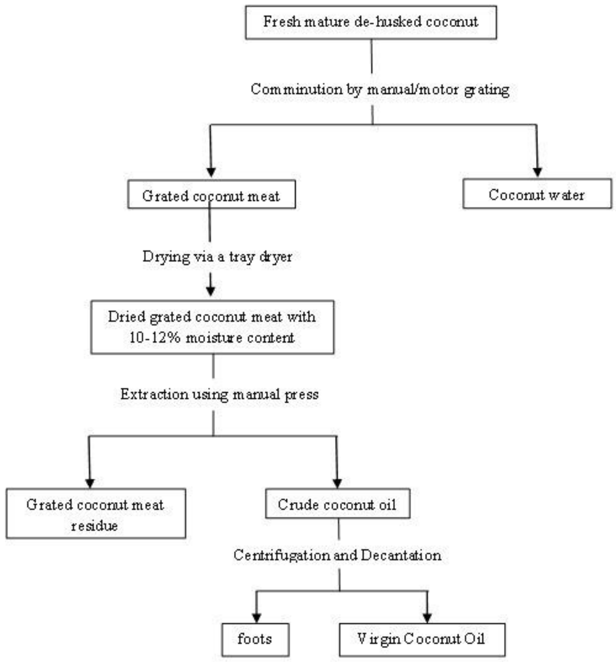

Fig. 2. Flowchart of low pressure oil extraction method for the production of VCO

2.6 Quality testing

The resulting VCO was tested for specific parameters such as average yield per coconut, color, peroxide number, iodine value, moisture and volatile matter, and presence of free fatty acids (FFA). The extracted oil samples were brought to the Philippine Coconut Authority (PCA) for the testing of said parameters. The tests were done at the Research and Development department, Laboratory Services Division of PCA. VCOs from different parameter alterations of numerous trials were tested and compared. The tests were done at the ambient temperature, 25˚C.

3 Results and Discussion

3.1 Coconut Mass Balance

The composition and corresponding per cent by weight composition of each nut were calculated. From this data, average values were determined. For an average weight of 1374.01 grams, 520.07 grams coconut water, 312.21 grams shell and 517.27 grams grated coconut meat peel were accounted. The mass balance was done to estimate the oil recovery per coconut and to check the consistency of the weights of the coconuts used in this process. Matured coconut has more meat, resulting to higher residue yield.

An average de-husked coconut used in this process, weighing at least 1,300 grams, contained at least 22.72% shell, 37.85% water, and 37.65% meat by weight and accounting for 1.78% losses. The losses can be attributed to the spillage of coconut water and the fragments of grated coconut meat which were not collected during comminution. Figure 3 shows the average composition of the parts of the 10 coconuts.

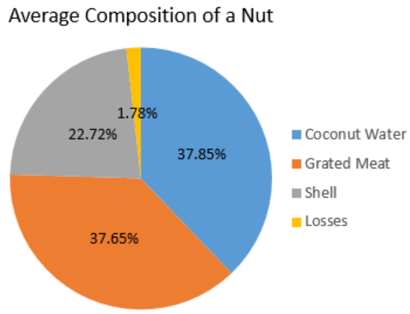

Fig. 3. The average composition (Ave. wt. = 1374 g) of a nut

3.2 Analysis of the Mathematical Models of the Drying of Grated Coconut Meat

The MR data were fitted into the two models. The results, namely, value of the correlation coefficient, R^2, for the Non-Linear Decomposition Model, the time constant, tau, τ for the Laplace Transform Model and the total error for the three models were recorded and are shown in Table 2. The best results based on the least total error were shown by the Laplace Transform Model at the three temperatures studied. The Laplace Transform Model yielded notable accuracy, precisely modeling the data series of grated coconut meat and predicting its future behavior. Using visual inspection, the Laplace Transform Model also gave the best fit as shown in Fig. 4. Hence, the Laplace Transform Model may be assumed to represent the drying behavior of grated coconut meat. Similar findings were reported for the air-drying kinetics of thin slices of coconut meat [14]. Earlier research works reported that the Page Model represent the drying kinetics of coconut meat slices [16, 17]. Figure 4 shows the experimental drying kinetic data as they are fitted with the simulated models at 70°C drying temperature.

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Table 2. Summary of Results

Temp.	Page Model			Non-linear Decomposition Method			Laplace Transform Model	
	n	R^2	Total Error	n	R^2	Total Error	τ	Total Error
65°C	1.4	0.9787	0.0349	0.7	0.9994	0.00328	897	3.50E-07
70°C	1.5	0.9928	0.0109	0.75	0.9464	0.16354	479	6.50E-07
75°C	1.8	0.9864	0.0274	0.7	0.9951	0.01758	267	4.20E-06

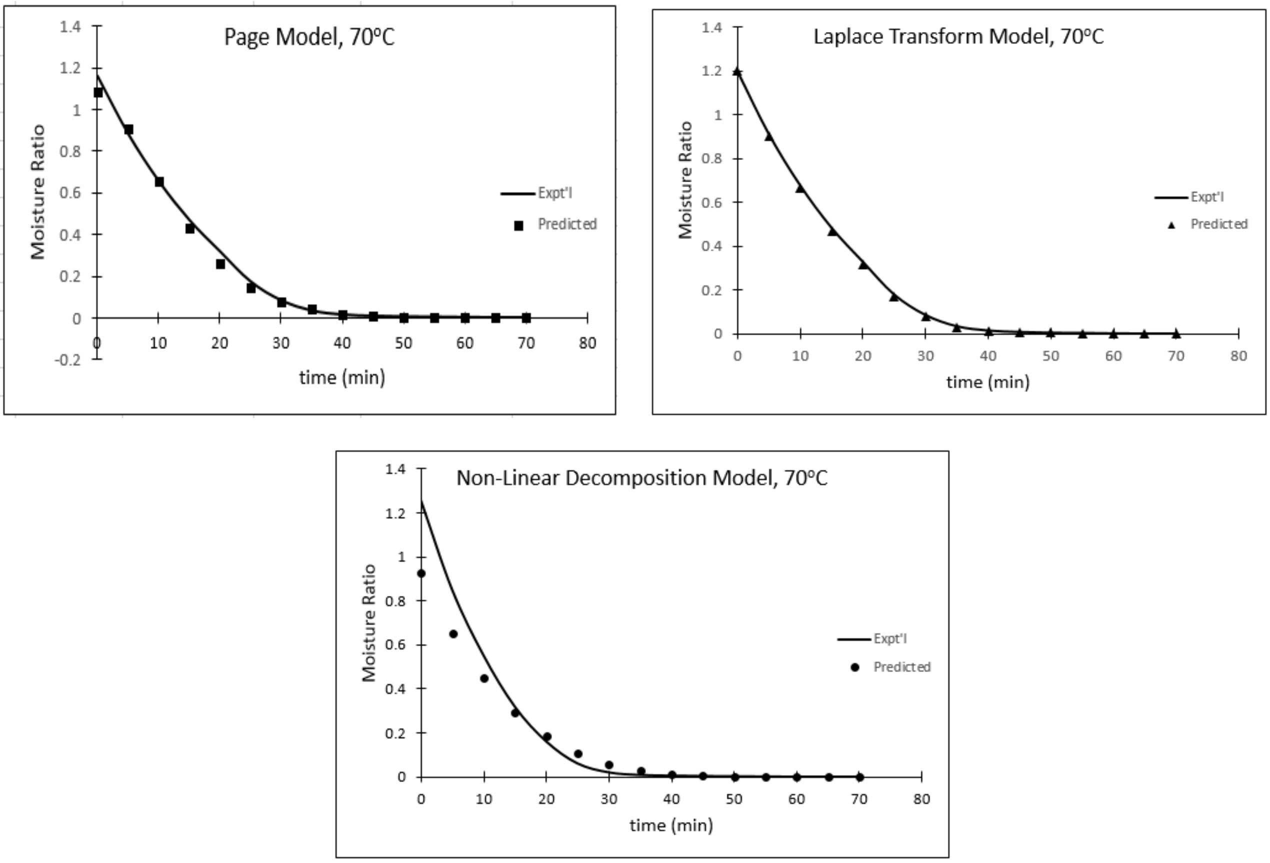

Fig. 4. Comparison of the experimental and predicted values of MR vs. time at 70°C using the three models

Table 3. Calculated drying time at different treatment temperatures as predicted by the Laplace Transform Model

Trial No.	Temperature		
	65°C	70°C	75°C
1	39.26 min	29.70 min	30.51 min
2	54.90 min	34.00 min	27.84 min
3	54.61 min	35.57 min	34.05 min

3.3 Determination of the Drying Time using the Lagrange Method of Interpolation

The drying time for the grated coconut meat to reach the desired MC of 11% at which oil from nuts can be extracted using low pressure [3]. The Laplace Transform Model was used to predict the optimum drying time at which the MC of the grated coconut meat will be 11%. The drying time was computed using Lagrange interpolation. The average drying time to reach 11% MC from the initial range of 54–56% was 49.59, 33.09 and 30.80 min at drying temperatures of 65, 70 and 75°C, respectively. Table 3 shows the calculated heating time as predicted by the Laplace Transform Model. A shorter heating time at 70°C was utilized to attain a 11% MC in the grated coconut meat.

3.3.1 Observation of the grated cocount meat after drying at different temperatures.

The grated coconut meat that was dried at 65˚C was too milky that would require a longer centrifugation time, which may cause undesired heating due to the centrifugal force. On the other hand, when 75˚C was used as a drying temperature, the grated coconut meat was burnt or scorched. Burnt coconut meat causes yellow oil, which does not pass the standards for VCO.

3.4 Statistical analysis of the computed drying Time using the best fit Mathematical Model

The best condition for drying the grated coconut meat was at a drying time of 29.70 minutes at 70˚C, which was computed using the Laplace Transform Model and the Lagrange Method of Interpolation. Table 4 shows the statistical analysis of the drying data gathered at 70˚C, using a 95% confidence level.

The standard deviation and the confidence limits were evaluated using Microsoft Excel. Based on the table, for the drying of grated coconut meat at 70˚C, the results were 95% confident that the drying time needed to achieve 11% moisture content ranges from 29.65 to 36.53 minutes.

Table 4. Statistical analysis of the best drying temperature at 95% confidence level (α=0.05)

Trial	Drying Time, min	Ave.	Std. Dev.	Conf. Int.	LL	UL
1	29.70	33.09	3.04	3.44	29.65	36.53
2	34.00					
3	35.57					

3.5 Analysis of data from the centrifugation process

Centrifugation time and centrifugation speed were both varied to obtain the optimum condition that will provide the greatest amount of oil yield and greatest initial quality of VCO upon organoleptic evaluation. Two variations of centrifuge speed, 2000 and 2700 RPM, were used. Centrifugation time was varied for each centrifugation speed using 20, 40, and 60 minutes. Figure 5 shows the plot for %VCO yield against centrifugation time for both speeds. The process was done under ambient temperature of 25^{o}C.

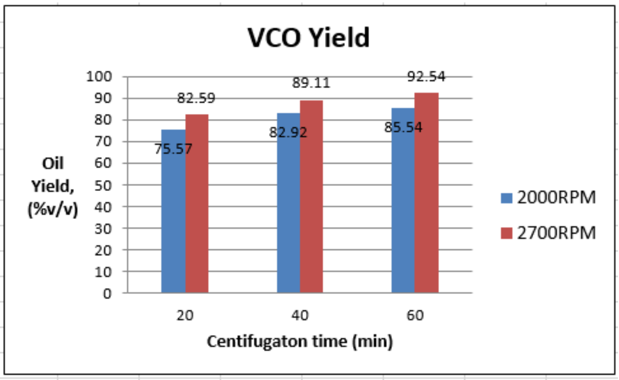

Fig. 5. VCO yield with the effect of centrifugation time for 2000 RPM and 2700 RPM

Based on Figure 5, the highest oil yield occurs at 2700 RPM with 60 minutes of centrifugation time at 92.84 v/v%. Also, upon organoleptic inspection, the clarity of oil increases as centrifugation time and centrifugation speed increases, yielding the clearest oil at 60 minutes of centrifugation for both 2000 and 2700 RPM. This observation is explained by the fact that increasing the centrifuge speed results in increasing the rate of sedimentation and consequently increases the separation of the two phases [4]. Also during centrifugation process, heat is generated by the centrifugal rotation. Density and viscosity, which are temperature dependent properties are altered. When temperature increases, viscosity and density decreases. As a result, the foots and fine particles will settle faster at higher temperatures [18].

3.5.1 Calculation of Oil Recovery

With the density of the virgin coconut oil at room temperature known as 0.903 g/mL, based on literature [5], the oil recovery for the optimum setting was determined using Equation 14.

$$\text{Oil Recovery} = \frac{\text{wt. of VCO recovered}}{\text{wt. of coconut meat used}} \times 100 \quad (14)$$

For each full tray loaded, the average volume of crude coconut oil obtained from 5 trials was 75.20 mL, with 69.82 mL being the VCO obtained, based from the data from the oil yield. The average weight of each full tray from 5 trials was 342.15 g. The oil recovery of the designed process was computed to be 18.43%, while the oil recovery of the traditional low pressure oil extraction is 25 kg / 100 kg meat or 25%.

The amount of VCO that can be obtained from a single coconut can be computed by Equation 15.

$$\text{Amount of VCO per nut} = \left(\frac{\%\,\text{Recovery}}{100}\right)(\text{wt. of meat / nut}) \quad (15)$$

The weight of grated coconut meat was determined by the mass balance in the previous part of the experiment, with a value of 517.27 g. Knowing those values, the weight of oil that can be extracted from a single coconut was computed to be 95.33 g or 105.57 mL.

3.6 Results of Quality Testing

The VCO sample produced at the best condition, 29.70 minutes of drying at 70˚C, and 60 minutes of centrifugation at 2700 RPM, was brought to the Laboratory Services Division of the Philippine Coconut Authority and was tested for the FFA, moisture and volatile matter, color, peroxide value, and iodine value. Table 5 shows the result of the laboratory tests, with the Philippine National Standards for Virgin Coconut Oil alongside.

Table 5. Results of quality testing of the sample VCO (70˚C drying time, 2700 RPM and 60 minutes of centrifugation)

Parameters	Results	Standards
FFA (Lauric)	0.03%	0.20% max.
Moisture and Volatile Matter	0.11%	0.20% max.
Color: (5 1/4" cell) Red/Yellow	0R/0.3Y	Colorless
Peroxide Value (meq/Kg)	0	3 max.
Iodine Value	5.77	4.11-11.0

Based on the quality testing results, all values of each tested parameter passed the Philippine National Standards for VCO. The color test result suggests that there were 0 red color and 0.3 yellow color detected in the produced VCO sample. The detected yellow value was very small and insignificant; thus, the color does not affect the quality of the VCO produced. Favorably, there was no detection of the red color in the sample, otherwise, the produced VCO sample will already be affirmed as a refined, bleached, and deodorized (RBD) oil, not VCO.

There is no standard set by the Philippine Bureau of Product Standards for the iodine values of virgin coconut oil, however, based on the study of Dayrit and his colleagues on the Standards for Essential Composition and Quality Factors of Commercial Virgin Coconut Oil and its Differentiation from RBD Coconut Oil and Copra Oil in 2007*,* the Codex Alimentarius standard for coconut oil range for iodine value is 6.3 to 10.6 [19], while the Asian and Pacific Coconut Community (APCC) standards for VCO range from 4.1 to 11.0, making the iodine value of the produced VCO sample in this study pass the both the Codex standard and the APCC standard.

Both the results for the FFA and peroxide value were within the limits set by the Philippine National Standards for VCO. These two parameters are the most critical chemical properties to be met for an oil to be classified as a VCO. VCO is the purest form of coconut oil containing very low amount of FFA and having a low peroxide value.

Naturally, FFAs are recorded to be low for vegetable oils. A high amount of FFA would give the oil an unpleasant taste, which is undesirable for a VCO that has a fresh and raw coconut taste. In addition, an FFA of above 0.5% will cause itchiness in the throat when consumed [20]. This would mean that a change in the oil's composition has taken place and it is corrosive which can be dangerous to the health.

Peroxide value on the other hand is the measurement of the extent of an oil's rancidity. Rancidity denotes the spoilage of a food which results from oil or fat deterioration. VCO has a low content of unsaturated fatty acids making its tendency to be rancid poor. High peroxide value would mean that the oil is unstable and already contaminated [21].

4 Conclusions and Recommendations

4.1 Conclusions

A VCO production fresh-dry process based on the low-pressure oil extraction method was developed through the employment of a centrifuge. As predicted by the Laplace Transform Model, the shortest time for the comminuted coconut meat to reach a moisture content of 11% is at 29.07 minutes using a tray dryer. The best setting of VCO production using the modified method is at a drying temperature of 70˚C and at 2700 RPM and 60 minutes of centrifugation. The developed method lessens the settling time while still producing standard quality VCO.

The authors would like to express their deepest gratitude to the University of Santo Tomas Food Technology Department, College of Education, for allowing us to use the equipment in their laboratory.

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