

**OPTIMIZING COLD PRESSED VIRGIN COCONUT OIL EXTRACTION:  
YIELD IMPROVEMENT AND FUNCTIONAL POTENTIAL OF  
COCONUT MEAL VALORIZATION**

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**Abstract**

Virgin Coconut Oil (VCO) is an unrefined oil extracted from fresh coconut kernel without chemical additives, typically using a cold-press method that also yields Virgin Coconut Meal (VCM) as a by-product. This study aimed to optimize the yield and quality of both VCO and VCM. Coconut (*Cocos nucifera* L.) types of Tall, Hybrid, and Dwarf varieties were screened to identify the one with the highest VCO yield and the lowest meal yield. The cold press technique combined with the response surface methodology (RSM) was employed for optimization. The Mapanget Tall coconut (MTT) showed the highest VCO yield (23.81%), the lowest meal yield (27.43%), and water evaporation (47.38%). Optimization yielded a VCO yield of 28.83% under ideal processing conditions, meal yield of 26.51%, and water evaporation of 46.42%. The major fatty acid in the VCO was the lauric acid (48.50%), meeting International Coconut Community standards. VCM composition included 9.15% moisture, 33.40% carbohydrates, 20.95% fat, 14.51% protein, 17.14% crude fiber, and 4.84% ash. These results highlight the potential of valorization of VCM as a functional food ingredient, particularly for its use in coconut-based skim milk beverages and other nutraceutical formulations.

**Keywords:** Cold press, Mapanget Tall, Virgin coconut oil, Coconut meal, Response surface methodology

**Introduction**

Virgin Coconut Oil (VCO) is highly valued for its health benefits, primarily due to its medium-chain triglycerides (C6-C12), including 48-53% lauric acid, along with

essential vitamins, and phenolic compounds (Negi *et al.*, 2024). Extracted without the application of heat, bleaching, or deodorization, the mechanical cold-pressing process preserves its antioxidant properties, yielding a fresh, colorless oil with a natural coconut aroma (Mudiyanselage and Wickramasinghe, 2023; Krishna *et al.*, 2010).

Global coconut oil production is projected to remain stable at approximately 3.22 million metric tons (MMT) in 2025, slightly lower than the 3.28 MMT forecast for 2024. The Philippines, the leading producer, is expected to reduce its output from 1.33 MMT in 2024 to 1.25 MMT in 2025. Meanwhile, Indonesia and India are projected to experience slight changes, producing 0.87 MMT and 0.50 MMT, respectively (ICC, 2025). Enhancing processing techniques may improve coconut oil yield. The increasing global demand for coconut oil has also led to a significant rise in the production of copra cake or coconut meal – a by-product of coconut oil extraction – reaching 1.92 MMT in 2024, according to the latest data from the United States Department of Agriculture (USDA, 2025).

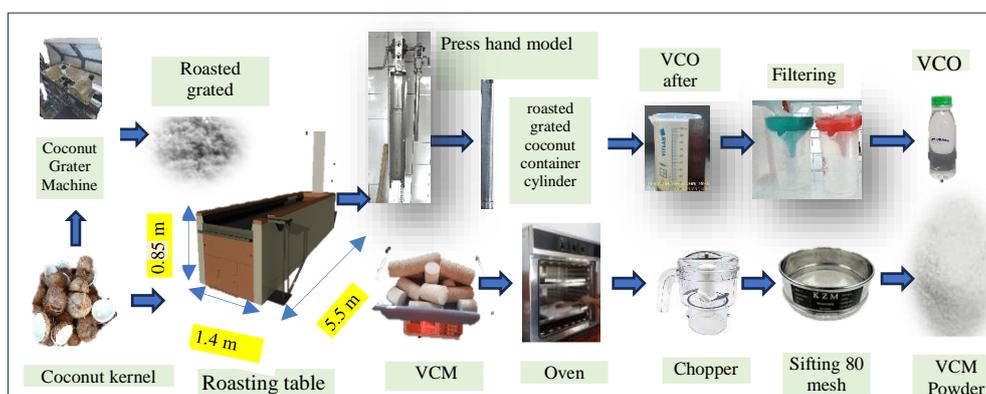
VCO can be extracted through either wet or dry processing methods. The dry method, utilizing the Direct Micro Expelling (DME) technique, involves the rapid drying of coconut flesh before mechanical pressing (Mansor *et al.*, 2012). However, yields from the DME method remain relatively low, producing only 16.41-18.87% VCO from 10 coconuts (Pradhana *et al.*, 2019; Trivana *et al.*, 2023).

Traditionally, many studies have employed classical experimental designs, wherein one parameter is varied while others are held constant (Jankovic *et al.*, 2021). Recently, advanced optimization techniques, such as the Box-Behnken Design (BBD) integrated with the Response Surface Methodology (RSM), have been adopted to minimize experimental trials, reduce costs, and save time while achieving optimal outcomes (Kabutey *et al.*, 2024; Jalili *et al.*, 2018) and this is a research gap. In this context, the present study aims to identify optimal processing conditions using RSM on BBD for response surface regression and validation. Notably, the by-product Virgin Coconut Meal (VCM) is often discarded, despite its high fiber and protein (Yulvianti *et al.*, 2015). Nevertheless, Pradhana *et al.* (2021) highlighted its potential in producing flour and brownies.

This study introduces a novel cold-press optimization approach that not only maximizes virgin coconut oil yield but also minimizes by-product output, utilizing screening across 10 Indonesian superior local coconut varieties and multivariate optimization via Response Surface Methodology (RSM). Furthermore, it highlights the underutilized functional potential of valorization of VCM as a high-fiber, protein-rich ingredient, promoting a circular bioeconomy model in coconut processing and promoting responsible consumption patterns aligned with the United Nations Sustainable Development Goals (SDGs), especially target 2 "Zero Hunger" and 12 "Responsible Production and Consumption".

## Materials and methods

The materials comprised coconuts from 10 selected varieties: Bali Tall (BIT), Palu Tall (PUT), Mapanget Tall (MTT), Tenga Tall (TAT), Hybrid (KHINA1), Salak Green Dwarf (SGD), Kopyor Brown Dwarf (KBD), Nias Yellow Dwarf (NYD), Raja Brown Dwarf (RBD), and Bali Yellow Dwarf (BYD). The coconuts were harvested at full maturity, between 11 and 12 months, as indicated by their dry brown husk. The samples were obtained from the Mapanget and Kima Atas experimental gardens in North Sulawesi, Indonesia (BRMP Palma). VCO was extracted using the cold-pressed method, which utilizes the white portion of the coconut kernel. The processing steps are illustrated in Figure 1. All chemicals, namely sodium hydroxide-NaOH, sulfuric acid-H<sub>2</sub>SO<sub>4</sub>, boric acid-H<sub>3</sub>BO<sub>3</sub>, hydrochloric acid-HCl, brom cresol green-methyl red, hexane, phenolphthalein and methanol were provided by Sigma Aldrich Steinheim (Darmstadt, Germany).



**Figure 1.** The procedure for transforming coconut kernels into VCO and VCM as by-products

### Water evaporation while drying

Water evaporation (WE) during the drying process of grated coconut was calculated based on the AOAC Method 925.10 (2005) and using gravimetry (loss on drying) according to Equation 1.

$$WE (\%) = \frac{(\text{Weight of initial grated coconut} - \text{dry grated coconut})(g)}{\text{Weight of initial grated coconut} (g)} \times 100\% \quad (1)$$

### Meal yield

After pressing the dry-grated coconut to produce VCO and its by-product (meal), the meal yield was calculated following (Effendy *et al.*, 2023) using Equation 2.

$$\text{Meal Yield} (\%) = \frac{\text{Weight of meal obtained} (g)}{\text{Weight of grated coconut} (g)} \times 100\% \quad (2)$$

### VCO yield

The yield of the VCO was determined as the proportion of the VCO weight to the weight of grated coconut, expressed as a percentage, following Roni *et al.* (2022), and using Equation 3.

$$\text{VCO Yield (\%)} = \frac{\text{Weight of VCO obtained (g)}}{\text{Weight of grated coconut (g)}} \times 100\% \quad (3)$$

### **Free fatty acid of VCO**

The free fatty acid (FFA) content of the VCO was measured in accordance with AOAC methods (AOAC method 940.28, 2005; Horwitz, 2006), and calculated as described in Equation 4.

$$\% \text{FFA} = \frac{(B-S) \text{ ml of NaOH} \times N \times 56}{1.99 \times \text{weight of sample (g)}} \quad (4)$$

where B is the volume (mL) of NaOH used in the blank titration, S is the volume used in the sample titration, and N is the normality of NaOH. The endpoint was determined when a stable pink color persisted.

### **Color of VCO**

Color parameters of the VCO were measured using a colorimeter (Konica Minolta, CR-300, AMTAST, Japan) and recorded in terms of L\*, a\*, and b\* values, representing lightness, red/green, and yellow/blue components, respectively (Patil et al., 2016; Pei et al., 2014). Chroma (C\*) and hue angle (h°) were calculated using Equations 5 and 6.

$$C^* = \sqrt{(a^*)^2 + (b^*)^2} \quad (5)$$

$$h^\circ = \arctan \frac{b^*}{a^*} \quad (6)$$

### **Fatty acid composition of VCO**

The fatty acid composition of the VCO was Analyzed using Gas Chromatography-Mass Spectrometry (GCMS, Shimadzu QP2010, Japan), and the components were identified using the Wileys Library database (Makalalag et al., 2020).

### **Proximate analysis of VCM and powder**

Moisture content of the VCM, VCM powder, and the VCO was determined by the oven-drying method (AOAC Method 925.10, 2005). Ash content was measured using a furnace (AOAC Method 923.03, 2005), protein content was analyzed using the Kjeldahl method (AOAC method 940.28, 2005), fiber content was assessed following digestion and filtration (AOAC Method 991.43, 2005), and fat content was determined via Soxhlet extraction method (AOAC Method 922.06, 2005).

### **Experimental Design**

Response Surface Methodology (RSM) was applied to optimize the VCO extraction parameters (Edem, 2016). The Design Expert software (Version 13.0, Stat-Ease Inc., Minneapolis, USA) was used to optimize VCO and VCM yields. A Box-Behnken Design (BBD) was employed to evaluate the cold-press extraction process. The goal was to maximize VCO yield and minimize meal yield.

The extraction parameters – roasting time, initial temperature and final temperature – were selected as operating factors, each adjusted to five levels (Table 1). The water evaporated during drying, VCO yield, and meal yield of the different coded variables on the central composite design (CCD) with the design of the response surface order

II using three independent variables, namely roasting time (X1), initial temperature (X2) and final temperature (X3). CCD in the 2k experiment with  $k = 3$  factors and at a value of  $\alpha = (23)^{1/4} = 1.682$ , the center point (nc) uses a maximum number of 6, so that the total run is  $14 + nc = 14 + 6 = 20$ . Each parameter was varied at five levels, including eight factorial points, six axial (star) points at  $\pm 1.682$  from the center, and six replicates of the central point (Shakeri *et al.*, 2021; Danbaba *et al.*, 2015).

**Table 1.** Experimental levels of the Central Composite Design (CCD)

Extraction Parameters	Levels				
	$-\alpha$	$-1$	$0$	$1$	$+\alpha$
X <sub>1</sub> :Roasting time (min)	53.18	60	70	80	86.81
X <sub>2</sub> :Initial temperature (°C)	36.59	40	45	50	53.40
X <sub>3</sub> :Final temperature (°C)	51.59	55	60	65	68.40

The actual and coded values of the parameters were calculated using Equation 7:

$$x = \frac{X_i - X_0}{\Delta X} \quad (7)$$

The regression equation to estimate the model's responses is shown in Equation 8:

$$Y = \beta_0 + \sum_{i=1}^3 \beta_i X_i + \sum_{i=1}^3 \beta_{ii} X_i^2 + \sum_{i=1}^2 \sum_{j=i+1}^3 \beta_{ij} X_i X_j + \varepsilon \quad (8)$$

where: Y = Response (water evaporated during drying, VCO yield, and VCM yield).  $\beta_0$  = Intercept;  $\beta_i$ ,  $\beta_{ii}$ ,  $\beta_{ij}$  = Coefficients of linear, quadratic, and interaction terms,  $\varepsilon$  = Random error (Trinh *et al.*, 2024).

### Statistical analysis

The differences between predicted responses and experimental results were evaluated using one-way ANOVA. A significance level of  $p \leq 0.05$  was used to determine statistical significance. All analyses were performed using SPSS software version 16.0 (Lu and Tan, 2009).

## Results and discussion

### Scanning the yield of VCO and VCM (by-product)

The highest VCO yield was obtained from the Mapanget Tall variety (MTT), producing  $901.67 \pm 7.64$  mL of oil from 3.5 kg of grated fresh coconut (equivalent to 10 Tall coconuts). This corresponds to a yield of approximately 23.81% (w/w), which was significantly higher than those of the other varieties tested ( $p < 0.05$ ). For comparison, traditional copra processing typically yields around 610 g of oil per kilogram of copra, or approximately 1,220 g coconut. These findings indicate that although the cold-pressed VCO extraction method used here achieved relatively high yields, there remains potential for further optimization (Punzalan and Rosentrater, 2024).

The lower VCO extraction yields observed in Dwarf coconut varieties may be attributed to their higher phospholipid content, which possesses amphiphilic

properties – containing both hydrophilic and hydrophobic components – thus facilitating the formation of water-oil emulsions. Moreover, Dwarf coconuts are rich in galactomannan, a polysaccharide that serves as a natural stabilizer and enhances cell wall structure, which can cause the oil to remain trapped within the fiber matrix and complicate the extraction process (Deepa *et al.*, 2015). As shown in Table 2, the water loss due to drying in MTT reached 47.38%, which is consistent with findings by Mussatto *et al.* (2011), who reported a moisture content of 49.40% in fresh grated coconut. This further indicates that process optimization is possible.

**Table 2.** Screening of VCO extraction and by-product VCM yield from various coconut varieties

Coconut variety	Water evaporated during roasting (%)	Meal yield (%)	VCO after Filtration (mL)	VCO Yield (%)	Coconuts per liter
BIT	46.90 ± 0.08 c	28.95 ± 0.33 b	875 ± 5 b	23.11 ± 0.13 b	11.43 ± 0.07 e
PUT	48.14 ± 0.14 a	28.57 ± 0.57 b	870 ± 20 b	22.97 ± 0.53 b	11.50 ± 0.26 e
MTT	47.38 ± 0.16 b	27.43 ± 0.49 c	901.67 ± 7.64 a	23.81 ± 0.20 a	11.11 ± 0.12 f
TAT	46.95 ± 0.16 c	28.90 ± 0.30 b	871.67 ± 2.89 b	23.02 ± 0.08 a	11.47 ± 0.04 e
KHINA1	46.95 ± 0.08 c	28.52 ± 0.22 b	870 ± 20 b	22.97 ± 0.53 b	13.80 ± 0.32 d
SGD	47.57 ± 0.49 b	28.19 ± 0.33 b	885 ± 5.00 b	23.37 ± 0.13 b	22.60 ± 0.13 c
KBD	48.67 ± 0.08 a	28.86 ± 0.49 b	823.33 ± 5.77 c	21.74 ± 0.15 d	24.29 ± 0.17 a
NYD	48.62 ± 0.08 a	29.14 ± 0.25 a	825 ± 21.79 c	21.79 ± 0.58 c	24.25 ± 0.65 a
RBD	47.00 ± 0.25 b	28.52 ± 0.50 b	883.33 ± 5.77 b	23.33 ± 0.15 b	22.64 ± 0.15 c
GKB	48.19 ± 0.54 a	28.38 ± 0.33 b	865 ± 5.00 b	22.84 ± 0.13 b	23.12 ± 0.13 b

**Notes:** Coconut varieties: Bali Tall (BIT), Palu Tall (PUT), Mapanget Tall (MTT), Tenga Tall (TAT), Hybrid (KHINA1), Salak Green Dwarf (SGD), Kopyor Brown Dwarf (KBD), Nias Yellow Dwarf (NYD), Raja Brown Dwarf (RBD), Bali Yellow Dwarf (GKB). Values within the same column followed by different letters indicate significant differences based on Duncan's multiple range test at  $p < 0.05$ . KHINA-1 is a hybrid between Nias Yellow Dwarf (NYD) and Tenga Tall (Alouw and Wulandari, 2020). The initial weight of grated coconut was 3,500 g, equivalent to 10 Tall coconuts. The density of coconut oil is 924.27 kg/m<sup>3</sup>, or 0.92427 g/mL (Ng *et al.*, 2021).

The by-product of the pressing process, known as VCM, yielded 27.43% or approximately 960 g from 10 coconuts. On average, five coconuts are required to produce 1 kg of copra, which in turn produces approximately 370 g of meal. Therefore, 10 coconuts used for copra would yield about 740 g of meal (Punzalan and Rosentrater, 2024).

#### ***Fitting the model***

The analysis results of the response surface model are presented in Table 3. The evaluation of model fitness was based on four criteria: (1) the significance of the response model ( $p < 0.05$ ), (2) a non-significant lack of fit ( $p > 0.05$ ), (3) reasonable agreement between adjusted  $R^2$  and Predicted  $R^2$  (difference  $< 0.2$ ), and (4) an adequate precision value greater than 4. The model outputs for water evaporated during drying, meal yield, and VCO yield each demonstrated  $p$ -values  $< 0.0001$ , indicating that the models were statistically significant and fulfilled the first criterion.

The lack-of-fit values were 0.1916, 1.78, and 0.1615, respectively, which were not statistically significant ( $p > 0.05$ ), satisfying the second criterion. The differences between adjusted  $R^2$  and predicted  $R^2$  were 0.049, 0.136, and 0.0839, all within the acceptable range of less than 0.2, thereby meeting the third criterion. The adequate precision values were 24.77, 18.77, and 20.92, all of which exceeded the minimum threshold of 4, thus satisfying the fourth requirement. Based on these evaluations, the developed models are valid and can be reliably used in the subsequent optimization stage. All four model adequacy criteria were met, including the Adequate Precision values, which were all substantially greater than the minimum threshold of 4 – indicating a strong signal-to-noise ratio and confirming model robustness. The optimization process was carried out by setting the factor/component selection to "in range". The VCO yield was set as the response to be maximized, while meal yield was set as the response to be minimized.

**Table 3.** Regression coefficients of estimated water evaporated during drying, VCO yield, and meal yield

Factors	Water evaporated during drying	VCO Yield	Meal Yield
Intercept	46.28	28.19	26.41
Linear			
X <sub>1</sub> – Roasting time	-0.0026	-0.3234	0.0984
X <sub>2</sub> – Initial temperature	-0.0792	0.5205*	-0.0676
X <sub>3</sub> – Final temperature	0.1083	-0.3634	0.2980
Interactions			
X <sub>1</sub> X <sub>2</sub>	0.0929	-0.0264	0.0429
X <sub>1</sub> X <sub>3</sub>	0.2071*	-0.8186**	0.3500*
X <sub>2</sub> X <sub>3</sub>	-0.2214*	0.3037	-0.0643*
Quadratic			
X <sub>1</sub> <sup>2</sup>	0.8268***	-1.57***	0.4846***
X <sub>2</sub> <sup>2</sup>	0.7561***	-1.26***	0.5804***
X <sub>3</sub> <sup>2</sup>	0.6652***	-1.12***	0.32179***
<b>Lack of fit</b>	0.1916	1.78	0.1615
<b>R<sup>2</sup></b>	0.9885	0.9721	0.9794
<b>Adjusted R<sup>2</sup></b>	0.9782	0.9470	0.9608
<b>Predicted R<sup>2</sup></b>	0.9292	0.8111	0.8769
<b>Adeq Precision</b>	24.7717	18.7745	20.9231
<b>F-value</b>	3.29	4.01	2.55
<b>Model p-value</b>	<0.0001***	<0.0001***	<0.0001***
<b>C.V%</b>	0.3389	1.85	0.5481

Regression coefficient, the bold parameters indicate higher validity, reproducibility, and fitness of the model \* $p < 0.01$ ; \*\* $p < 0.001$ ; \*\*\* $p < 0.0001$ .

The second-order polynomial equations derived from the regression coefficients (Table 3) are as follows (Equations 9-11).

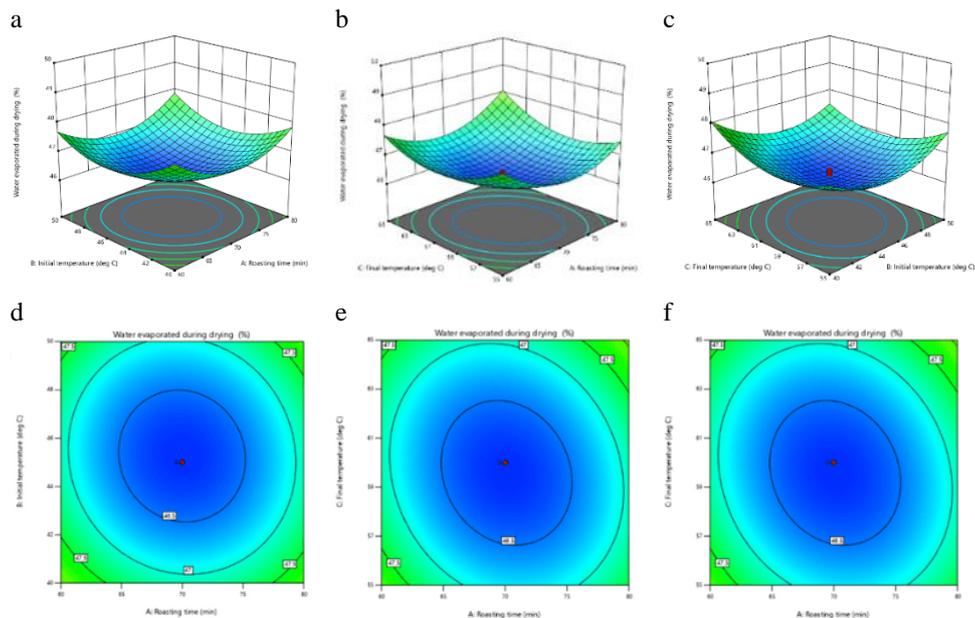
$$Y_{WE} = 46.28 - 0.0026X_1 - 0.0792X_2 + 0.1083X_3 + 0.0929X_1X_2 + 0.2071X_1X_3 - 0.2214X_2X_3 + 0.8268X_1^2 + 0.7561X_2^2 + 0.6652X_3^2 \quad (9)$$

$$Y_{VY} = 28.19 - 0.3234X_1 + 0.5205X_2 - 0.3634X_3 - 0.0264X_1X_2 - 0.8186X_1X_3 + 0.3037X_2X_3 - 1.57X_1^2 - 1.26X_2^2 - 1.12X_3^2 \quad (10)$$

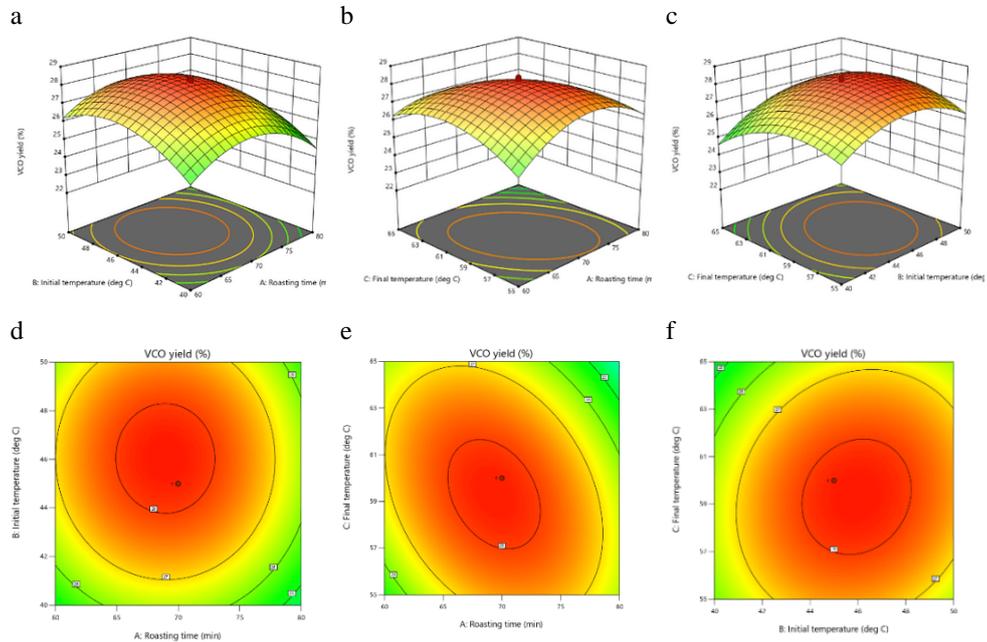
$$Y_{MY} = 26.41 + 0.0984X_1 - 0.0676X_2 + 0.2980X_3 + 0.0429X_1X_2 + 0.3500X_1X_3 - 0.0643X_2X_3 + 0.4846X_1^2 + 0.5804X_2^2 + 0.3179X_3^2 \quad (11)$$

### Effect of extraction condition on responses

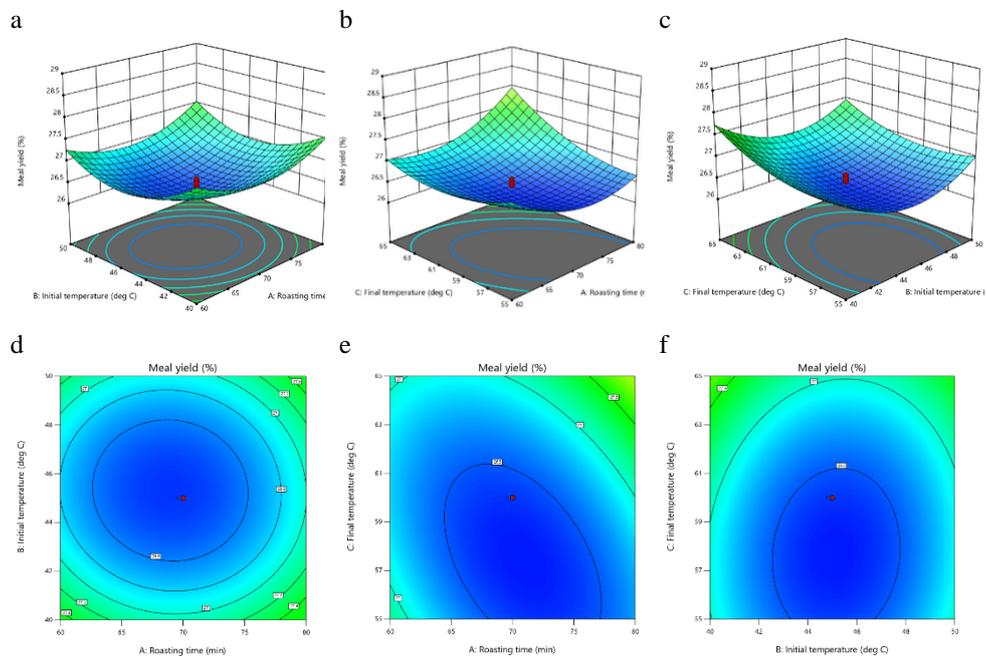
The interaction effects of the extraction parameters - roasting time ( $X_1$ : 60-80 minutes), initial temperature ( $X_2$ : 40-50 °C), and final temperature ( $X_3$ : 55-65 °C) – on the process responses were evaluated. The optimization of these factors can enhance the VCO yield while simultaneously minimizing the by-product yield (meal). The individual effects of  $X_1$ ,  $X_2$ , and  $X_3$  on the responses  $Y_1$  (water evaporated during drying),  $Y_2$  (VCO yield), and  $Y_3$  (meal yield) are graphically represented through response surface and contour plots in Figures 2-4. Specifically, the relationships  $Y = f(X_1, X_2)$ ,  $Y = f(X_1, X_3)$  and  $Y = f(X_2, X_3)$  were modeled to visualize the optimal parameter regions.



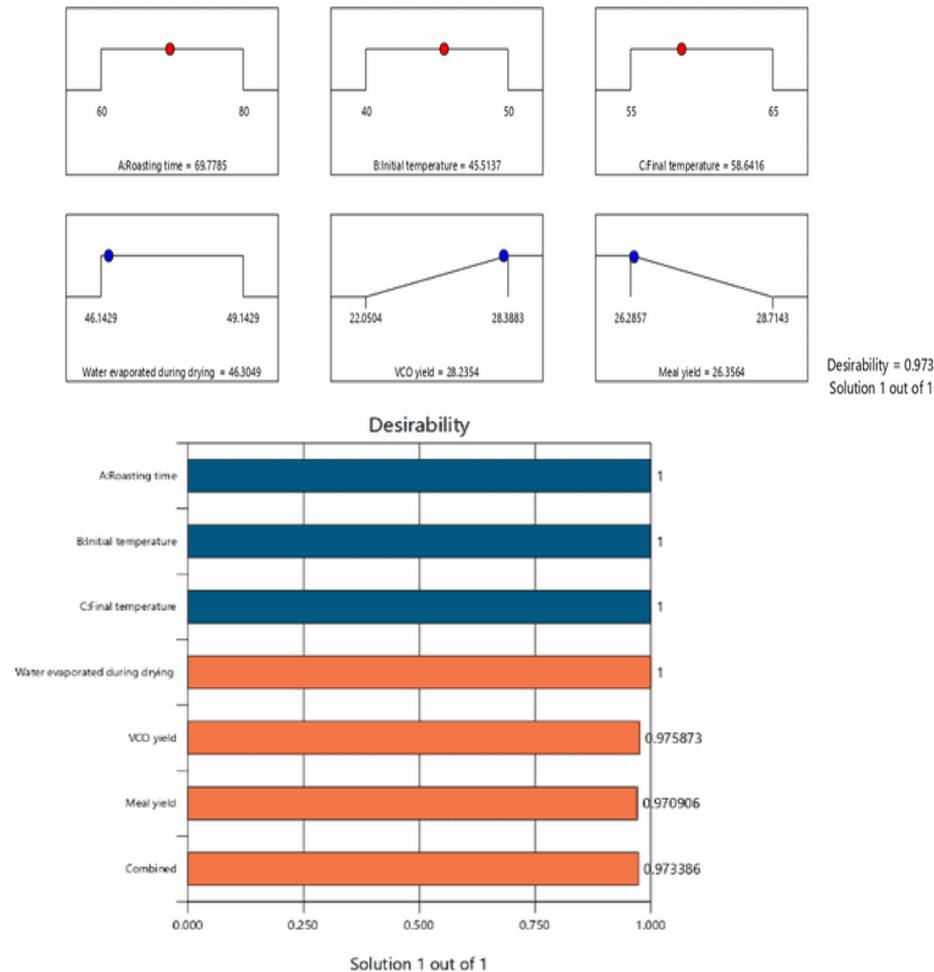
**Figure 2.** The effect of extraction parameters on water evaporated during drying, illustrated through (a)-(c) 3D response surface plots and (d)-(f) contour plots



**Figure 3.** The effect of extraction parameters on VCO yield, illustrated through (a)-(c) 3D response surface plots and (d)-(f) contour plots



**Figure 4.** The effect of extraction parameters on meal yield, illustrated through (a)-(c) 3D response surface plots and (d)-(f) contour plots



**Figure 5.** (a) Desirability ramp for numerical optimization of goals, and (b) Pareto chart representing the contribution of each variable to the combined response desirability

The quadratic models, shown through contour plots and 3-dimensional response surfaces, represent the outcomes of the first process, which consisted of water evaporated during drying. Figure 2 (a-f) illustrates the water evaporated during drying, represented by the blue color, which exhibits a minimum point at 46.14 - 46.42%. The minimum point was also observed at lower roasting times (<80 minutes), lower initial temperatures (<50 °C), and lower final temperatures (<65 °C). The quadratic models, as visually illustrated by contour plots and 3-dimensional response surfaces, further revealed that higher VCO yields, with a maximum point exceeding 28%, were obtained at lower roasting times (<80 minutes), lower initial temperature (<50 °C), and lower final temperatures (<65 °C), as shown in Figure 3 (a-f). Regarding meal yield, the minimum point (<27%) was similarly recorded at lower roasting time (<80 minutes), lower initial temperatures (<50 °C), and lower

final temperatures (<65 °C), as presented in Figure 4 (a-f). In comparison, higher initial temperatures (>45 °C), higher final temperatures (>60 °C), and longer roasting times (>70 minutes) resulted in higher meal yields.

Gradually lowering the water content through internal and final temperatures aims to prevent the browning of the grated coconut or case hardening, which causes damage to food ingredients (Deepa *et al.*, 2015). These findings emphasize the influence of roasting conditions on water evaporation, VCO yield, and meal yield, offering important information for process optimization. Idrus *et al.* (2013) reported that extraction temperature and time are key parameters influencing the process and oil extraction yield. Temperature is a critical environmental factor affecting the kinetics of extracting substances from the solid matrix (Mussatto *et al.*, 2011).

Figure 5a presents the desirability ramp from the numerical optimization process, which identifies the ideal conditions for maximizing VCO yield and minimizing meal yield. Figure 5b illustrates the Pareto chart, showing the relative influence of each independent variable on the overall response desirability.

The optimal limits and the corresponding maximum or minimum achievable responses are summarized in Figure 5a. The effect of each factor – roasting time ( $X_1$ ), initial temperature ( $X_2$ ), and final temperature ( $X_3$ ) – on the individual responses  $Y_1$  (water evaporated during drying),  $Y_2$  (VCO yield),  $Y_3$  (meal yield), and the overall composite desirability ( $Y$  combined) is depicted. The desirability values range from 0.97 to 1.00, with a combined desirability of 0.973, indicating a strong correlation between predicted and actual outcomes. This suggests that 97% of the response variation can be explained by the model, demonstrating excellent predictive accuracy.

In Figure 5b, the 3D surface plot generated by Response Surface Methodology (RSM) for the variables  $X_1$ ,  $X_2$ , and  $X_3$  confirms the model's high precision, as evidenced by a desirability value approaching 1. This indicates a minimal deviation between predicted and actual values, further validating the reliability of the optimization model.

The experimental validation results under the optimum extraction conditions (Table 4). The predicted VCO yield was 28.97%, while the actual experimental value was  $28.83 \pm 0.046\%$ , resulting in low percentage error of  $0.47 \pm 0.16\%$ . This yield is 10-12% higher than previously reported values using the dry method with Direct Micro Expelling (DME), as in the studies of Pradhana *et al.* (2019) and Trivana, *et al.* (2023), which utilized higher temperature ranges (38 - 100 °C). In contrast, the optimized temperature range in the present study was 45.19-58.92 °C, which produced more favorable results.

It is important to note that, if the coconut material remains too wet (i.e., insufficient drying), oil extraction will be inefficient, with much of the oil remaining trapped along with residual coconut milk. Conversely, over-drying can increase the resistance during pressing, making the process more labor-intensive and resulting in reduced oil yield. Dewi *et al.* (2019) optimized VCO production using pulsed electric field (PEF) pretreatment, with RSM-based predictions ranging from 14.05% to

18.45%, and a verified yield of 17.57%, which remains lower than the results obtained in the current study.

**Table 4.** Optimization results of cold pressing grated coconut and validation of predicted and experimental values under optimum conditions

Optimum conditions			Parameters	Data validation		Percentage Error
Roasting time (minute)	Initial temperature (°C)	Final temperature (°C)		Response optimized	Actual result	
69.86	45.19	58.92	Water evaporated during drying (%)	46.06	46.42 ± 0.006	0.77 ± 0.012
			VCO Yield (%)	28.97	28.83 ± 0.046	0.47 ± 0.16
			Meal Yield (%)	26.12	26.51 ± 0.049	1.52 ± 0.18

### Quality of VCO

Rangana and Wickramasinghe (2023) reported that the water content of VCO extracted via the cold press method from Bodiri Tall coconuts was 0.15%. In contrast, the value obtained in this study was considerably lower, at 0.019%. This reduced moisture level was influenced by controlled pre-pressing conditions, in which the moisture content of the raw material was maintained below 3%. In the present study, VCO extracted from Mapanget Tall coconut (MTT) exhibited a moisture content of 0.019%, well below the maximum acceptable limit of  $\leq 0.1\%$  (Table 6). Additionally, the free fatty acid (FFA) content was relatively low, measured at  $0.024 \pm 0.003\%$ , and complied with the ICC standard, which sets the maximum allowable FFA content at  $\leq 0.2$  (ICC, 2009).

Low moisture and FFA contents are crucial quality parameters, as they contribute to extended shelf life and prevent rancidity in VCO. Excess water in VCO can promote triglyceride hydrolysis, leading to the release of free fatty acids and accelerating deterioration. FFA is formed through the hydrolytic breakdown of triglycerides into glycerol and free fatty acids. Elevated FFA levels can impart off-flavors and undesirable odor, as well as accelerate oxidative rancidity, thereby reducing the product's shelf life (Ng *et al.*, 2021; Negi *et al.*, 2024).

In terms of appearance, VCO typically appears clear or slightly white, with a subtle greenish hue (negative  $a^*$  value), compared to the bright white appearance of the meal. This coloration is attributed to trace amounts of chlorophyll pigments (typically  $<0.1$  ppm) (Rukmini and Raharjo, 2010). In this study, VCO extracted from Nias Yellow Dwarf (NYD) and Bali Yellow Dwarf (BYD) coconuts exhibited a more yellowish tone, which may be due to higher  $\beta$ -carotene content. This observation aligns with the findings of Marina *et al.* (2009), who reported the presence of carotenoid pigments in VCO.

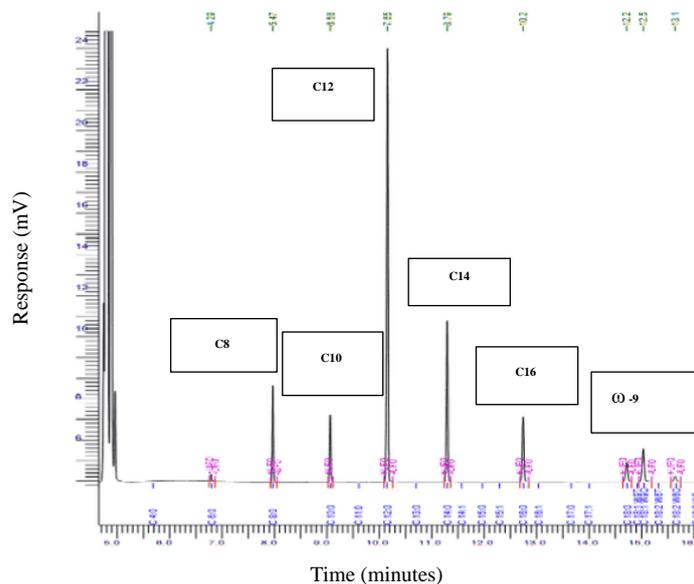
### Fatty acid composition of VCO

Trivana *et al.* (2023) reported that VCO derived from Palu coconut (PUT) had a lauric acid content of 47.08%, which is lower than the value observed in the present study using Mapanget Tall coconuts (MTT) treated with method two, resulting in a

lauric acid content of 48.50% and the highest total medium-chain fatty acid MCFA content of 63.44% (Table 5).

This value complies with the VCO export standards set by the International Coconut Community (ICC), which stipulate lauric acid content between 45-56%, and the Indonesian National Standard (SNI 7381-2008), which requires a range of 45.1-53.2%. Novariant and Tulalo (2007) reported that MTT processed via the wet method with defensive heating yielded lauric acid content between 39.59% and 43.19%, while natural fermentation produced 43.07%. Srivastava and Semwal (2015) reported that fatty acids profile of VCM was predominantly lauric acid (54.37%), followed by myristic acid (20.13%), palmitic acid (8.61%), capric acid (5.81%), oleic acid (5.49%), stearic acid (3.14%), linoleic acid (1.55%), and caprylic acid (0.69%).

The high lauric acid content (48.50%) observed in VCO derived from Mapanget Tall coconuts (Figure 6) offers significant functional advantages. Lauric acid, a medium-chain saturated fatty acid (C12:0), is rapidly converted in the human body into monolaurin—a compound known for its potent antimicrobial properties against Gram-positive bacteria, lipid-coated viruses (such as HIV, herpes, and influenza), fungi, and protozoa (Widhiarta, 2016). This positions VCO as a promising ingredient for functional foods with immune-enhancing and antimicrobial benefits. In addition, it can be utilized as a nutraceutical product, such as a VCO softgel supplement, due to its high lauric acid content. This formulation, typically presented in capsule form, is widely used to support overall health.



**Figure 6.** GC-MS chromatogram of fatty acid composition in VCO from MTT

**Table 5.** Fatty acid contents analysis

Fatty Acid (%)	VCO MTT	Standard VCO (ICC, 2009)	Codex standard (Codex, 2024)
Caproic Acid C6:0	0.58	0.10–0.95	Nd – 0.7
Caprylic Acid C8:0	8.07	4-10	4.6 – 10
Capric Acid C10:0	6.29	4-8	5.0 – 8.0
Lauric Acid C12:0	48.50	45-56	45.1 – 53.2
<b>Total MCFA</b>	63.44	-	-
Myristic Acid C14:0	17.95	16-21	16.8 – 21
Palmitic Acid C16:0	8.67	7.5-10.2	7.5 – 10.2
Stearic Acid C18:0	3.33	2-4	2 – 4
Oleic Acid C18:1 ( $\omega$ -9)	5.64	4.5-10	5 -10
Linoleic Acid C18:2 ( $\omega$ -6)	0.96	0.7-2.5	1 – 2.5
MUFA	5.64	-	-
PUFA	0.96	-	-
SFA	93.39	-	-
LCFA Total	36.55	-	-

Additionally, the metabolic pathway of lauric acid promotes rapid energy conversion in the liver, contributing to increased thermogenesis and reduced fat storage (Saraswathi *et al.*, 2020). This makes high-lauric VCO a potential component for dietary products targeting weight management. Lauric acid also provides oxidative stability, making VCO suitable for shelf-stable formulations and food applications requiring longer storage life. These properties, along with its natural aroma and safety profile, extend VCO's use to nutraceuticals, cosmetics, and infant nutrition, demonstrating its versatile industrial relevance.

#### **Color and Sensory Characteristics of VCO, VCM, and VCM flour**

In terms of visual appearance, VCO exhibited high lightness ( $L^* = 83.27 \pm 2.93$ ) and a slight yellowish hue, as indicated by a positive  $b^*$  value ( $8.33 \pm 0.00$ ). The VCM and its corresponding flour displayed similar brightness levels, with  $L^*$  values of  $83.27 \pm 2.93$  and  $83.41 \pm 0.42$ , respectively. Their chroma ( $C^*$ ) values were also comparable, at  $9.67 \pm 1.54$  and  $9.96 \pm 0.26$ , respectively, while the hue angles ( $h^\circ$ ) were recorded at  $71.25 \pm 4.79$  and  $70.91 \pm 0.38$ .

These color attributes are of critical importance, as visual perception significantly influences consumer acceptance of edible oils and food ingredients. Products that appear lighter, clearer, and exhibit neutral or slightly warm hues are generally perceived by consumers as fresher, purer, and more natural (Marina *et al.* 2009; Rukmini and Raharjo, 2010).

Specifically, the low  $a^*$  values (green-red axis) and moderate  $b^*$  values (blue-yellow axis) indicate minimal oxidative discoloration, suggesting high product quality and compliance with international standards. In premium edible oils, such as VCO, a clear and colorless appearance is typically associated with freshness and advanced processing methods. Similarly, the bright and slightly yellowish hue of VCM flour enhances its appeal as an ingredient in health-oriented food products, such as fiber-enriched baked goods or low-fat dairy alternatives, where visual whiteness and a

natural appearance are highly valued. Therefore, the color stability observed in this study supports not only the aesthetic desirability but also the functional market potential of VCO and its derivative meal products.

#### **Proximate composition of VCM and VCM flour**

VCM flour demonstrates promising potential as a low-fat food ingredient. For instance, following centrifugation, it can be utilized to produce skim coconut milk and is suitable for incorporation into low-fat ice cream formulations (Kasapoglu *et al.*, 2023). The carbohydrate content of VCM flour (37.07%) is significantly lower than that of wheat flour (73.52%), whereas its protein content of 16.71% (Table 6) is notably higher than that of wheat flour (13.5%) (Mutiar *et al.*, 2024).

The valorization of VCM into VCM flour (80 mesh) has been shown to increase its protein content. According to Srivastava and Semwal (2015), this increase can be attributed to physical processes such as milling and sieving, which significantly alter the nutritional composition by separating fine and coarse fractions (e.g., fibers). Furthermore, these mechanical processes may disrupt cell wall structures, thereby releasing proteins that were previously bound.

**Table 6.** Proximate composition of VCO, VCM and VCM flour from MTT coconut

Nutrient content %	VCO Cold Press	VCO Standard (ICC, 2009)	VCM	VCM flour (80 mesh)	Wet grated coconut (Lamdande <i>et al.</i> , 2018)
Moisture content	0.019±0.004b	≤0.1	9.15 ± 0.19h	8.29 ± 0.16i	49.40
Ash content	-	-	4.84 ± 0.08k	5.07 ± 0.03j	1.06
Fat	99.99 a	-	20.95 ± 0.14d	21.31 ± 0.12c	30.02
Protein	-	-	14.51 ± 0.11f	16.71 ± 0.08e	5.59
Crude fiber	-	-	17.14 ± 0.70e	11.56 ± 0.59g	-
Carbohydrate	-	-	33.40 ± 0.72b	37.07 ± 0.61a	-

Values within the same column followed by different letters indicate significant differences based on Duncan's multiple range test at  $p < 0.05$

The valorization of coconut meal supports the development of various functional food products, including functional coconut meal flour (characterized by high fiber, high protein, low fat, and a low glycemic index), high-fiber energy bars, and fiber- and prebiotic-rich supplement powders. These attributes position VCM flour as a valuable ingredient in the formulation of health-promoting food products aimed at nutritionally conscious consumers.

#### **Conclusions**

Mapanget Tall coconut (MTT), when processed using the cold press method combined with varietal screening, produced the highest VCO yield of 23.81%. Optimization through Response Surface Methodology (RSM) identified the ideal processing parameters: a roasting time of 69.86 minutes, an initial temperature of

45.19 °C, and a final temperature of 58.92 °C. Under these conditions, the experimental results closely matched the predicted values, with water evaporation at 46.42%, VCO yield at 28.83%, and meal yield at 26.51%, validating the accuracy and reliability of the model. The VCO produced from MTT was rich in lauric acid (48.50%) and total medium-chain fatty acid (MCFA) content (63.44%), complying with the International Coconut Community (ICC) standards. Meanwhile, the nutritional composition of VCM and its flour, containing 33.40–37.07% carbohydrates, 20.95–21.31% fat, 11.56–17.14% crude fiber, and 14.51–16.71% proteins, demonstrates its excellent potential as a functional food ingredient. These findings contribute to advancing sustainable coconut processing by optimizing VCO yield while valorizing VCM as a valuable, nutrient-dense by-product. The dual-outcome approach offers practical benefits for small- and medium-scale coconut processors through an energy-efficient extraction protocol, promoting resource efficiency and the creation of new market opportunities in the functional food sector. Furthermore, by minimizing waste and enhancing product diversification, this model supports global sustainability goals, particularly in enhancing food security and promoting responsible production and consumption, in alignment with the United Nations Sustainable Development Goals (SDGs).

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