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Model design of white copra mechanical extrusion process to produce virgin coconut oil

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Abstract: This study aims to design a mechanical extrusion process model - namely the process of extracting oil from vegetable materials using a screw press - in the production of virgin coconut oil (VCO) from white copra. White copra is coconut meat that preserved by a proper drying process to avoid microbial infection during storage. The focus of this study is to determine the relationship between the physical process parameters of extrusion and the yield and quality of the resulting VCO. This study addresses the limitations of conventional VCO extraction methods such as fermentation, enzymatic, and centrifugation processes, which although produce high-quality VCO, but have shortcomings in time and cost efficiency for industrial scale. The experiment was arranged using a Completely Randomized Design (CRD) with a factorial pattern consisting of three levels of copra moisture content (C_1 = 6%, C_2 = 8%, and C_3 = 10%), two extrusion temperatures (T_1 = 60°C and T_2 = 80°C), and two screw speeds (S_1 = 30 rpm and S_2 = 60 rpm). The combination of these three factors formed 12 treatments and was carried out three replications, thus requiring 36 experimental batches. 100 g of grated white copra was provided for each batch of extrusion experiments. The observed VCO yield parameters included: oil yield, free fatty acid content, and peroxide value. The results of the study showed that the treatment factors of water content (C), extrusion temperature (T), and screw speed (S), significantly affected the oil yield and quality. The highest VCO yield (64.47%) was obtained in the treatment of 6% water copra content, 80°C process temperature and 60 ppm screw speed ($C_1T_2S_2$), with a regression model $Y_1 = 54.82 - 0.65C + 2.15T + 3.24S$. In terms of VCO quality, it turned out that the lowest FFA content (0.254%) occurred in the $C_1T_1S_1$ treatment, while the highest (0.581%) occurred in the $C_3T_2S_2$, explained by the model $Y_2 = -0.050 + 0.035C + 0.143T + 0.119S$. Peroxide values increased with increasing temperature and screw rotation speed, following the model $Y_3 = 1.623 + 0.078C + 0.065T + 0.510S$. Overall, increasing temperature and screw speed increased the oil extraction efficiency but reduced the chemical stability of VCO due to increased lipid oxidation and hydrolysis. The resulting regression model effectively describes the empirical relationship between extrusion process parameters and oil yield, allowing optimization of extrusion conditions to produce high-yield and high-quality VCO.

Keywords: free fatty acids, mechanical extrusion, process modeling, virgin coconut oil, white copra.
Abbreviations: VCO_Virgin coconut oil; CRD_Completely randomized design; FFA_Free fatty acid; SNI_Standar Nasional Indonesia; PV_Peroxide value; DMRT_Duncan's Multiple Differences Test.

Introduction

The centrifugation and freeze-thaw methods as initial mechanical approaches have demonstrated superior quality, with a moisture content of 0.12%, free fatty acid (FFA) of 0.058%, and an adequate yield of 31.42%. However, these methods require a processing time of more than 48 hours for freezing and operate in batch mode (Pulungan et al., 2020). Centrifugation demands a large capital investment for high-speed equipment (Jo et al., 2024). This method is less optimal in meeting industrial needs for scalability and cost efficiency.

Vegetable oil extraction using screw extruders has become the industry standard due to its continuous processing capability and high yield. In coconut oil pressing research, the highest yield achieved was 63.62%, attained with high thermal application between 100 °C and 125 °C (Zikri et al., 2020). Although coconut oil produced at 125 °C technically meets SNI 01-2902:1992 standards with a moisture content of 0.41% and free fatty acid (FFA) of 0.32%, applying heat at this level violates the virgin coconut oil (VCO) principle, which requires a non-thermal process (Indahsari and Ramadhani, 2024).

The technical gap above shifts the research focus from equipment application to the design and modeling stage of process engineering. In extrusion processes, mechanical energy applied through screw rotation speed and compression pressure

inevitably converts into thermal energy via friction, which can raise the internal temperature of the material. The model must be able to predict the frictional heat generation rate based on screw speed and pressure.
Based on the above explanation, it is necessary to design and model a mechanical extrusion process that can link physical parameters with an optimal VCO oil yield, thus ensuring the production of high-quality VCO. The objective of this research is to develop innovative process design and modeling for VCO production using a mechanical extrusion system. The scientific contribution of this study is expected to fill the knowledge gap in extrusion modeling for thermally sensitive emulsion materials.

Results and Discussion

Oil yield

Analysis of variance shows that the combination of moisture content (C), temperature (T), and screw speed (S) significantly affects the oil yield obtained from the extrusion process of white copra. As shown in Table 1, the highest the VCO yield was achieved under treatment $C_1T_2S_2$ (low moisture content, high temperature, high speed), at 64.473%. This is due to increased oil flow efficiency caused by decreased material viscosity at higher extrusion temperatures and speeds (Sulhatun et al., 2020). Meanwhile, treatment $C_3T_1S_1$ produced the lowest yield of 57.213%.
Low moisture content facilitates easier oil release during copra pressing (Mizera et al., 2023). Similarly, higher temperature, both from preheating and screw friction, enhances oil flow (Zikri et al., 2020). Meanwhile, high screw speed applies maximum pressing and friction forces required to efficiently extract the prepared oil from copra pulp, resulting in the highest VCO yield (Abdilova et al., 2023).
Regression analysis for the independent variables—copra moisture content (C), extrusion temperature (T), and extrusion speed (S)—on the VCO yield (Y_1) produced the following equation:
$Y_1 = 54.82 - 0.65C + 2.15T + 3.24S$
This regression model indicates oil yield increases with temperature and screw speed but slightly decreases with higher moisture content. The screw speed factor (S) has the greatest influence on increasing oil yield.
Simultaneously, the treatments of moisture content, temperature, and speed affect copra oil yield. Increasing temperature and speed improve oil yield (Zikri et al., 2020; Abdilova et al., 2023), whereas increasing moisture content reduces it (Mizera et al., 2023). The mechanical extrusion of white copra at low moisture, higher temperature, and high screw speed results in the highest VCO yield because these factors synergistically optimize oil separation from the copra solid material.

Free fatty acid (FFA) content

Based on Duncan's further test results (Tabel 1), the lowest oil FFA content was found in treatment $C_1T_1S_1$ (0.254%), while the highest was observed in $C_3T_2S_2$ (0.581%). Generally, increases in material moisture content (C), extrusion temperature (T), and screw speed (S) tend to raise the oil's FFA content. There is a trend where combinations of high moisture, high temperature, and high screw speed produce the highest FFA compared to other combinations. FFA content increases with rising temperature (Ng et al., 2021), moisture (Divya et al., 2023), and extrusion speed (Feng et al., 2014). This confirms that extreme extrusion conditions accelerate oxidation and hydrolysis of the oil.
The combination of high copra moisture (reactant), high temperature (reaction accelerator), and high screw speed (heat generator and reactant releaser) creates optimal conditions for hydrolysis reactions, directly increasing FFA levels in VCO. High FFA content is the main cause of rancid odor and taste in the oil (Song et al., 2022).
The regression relationship between copra moisture content (C), extrusion temperature (T), screw speed (S), and FFA content in VCO (Y_2) is expressed as:
$Y_2 = -0.050 + 0.035C + 0.143T + 0.119S$
This regression model shows that FFA content increases with temperature and screw speed but slightly decreases as moisture content rises. The screw speed factor (S) has the largest effect on oil yield increase. The model indicates all factors tend to increase FFA, with temperature (T) having the most significant effect. Higher temperature and screw speed accelerate fat hydrolysis, thus increasing free fatty acid content. Simultaneously, moisture, temperature, and speed treatments influence copra oil FFA levels. Increasing moisture, temperature, and speed will raise the copra oil FFA content (Ng et al., 2021; Divya et al., 2023; Feng et al., 2014).
Increasing moisture, temperature, and extrusion speed during mechanical extrusion of white copra can increase the FFA content in the produced VCO. This FFA increase indicates a decline in oil quality because these three factors stimulate and accelerate hydrolysis and thermal degradation reactions.

Peroxide value

Analysis of variance results indicate that all three tested factors—material moisture content (C), extrusion temperature (T), and screw speed (S)—affect the peroxide value of the resulting oil. The screw speed factor has the greatest effect on increasing peroxide value, followed by extrusion temperature, while moisture content shows an effect but with lower intensity (Table 1).
Peroxide value is an early indicator of fat oxidation. An increasing value indicates the formation of peroxide compounds from the reaction between oxygen and unsaturated fatty acids. Higher temperature and extrusion speed accelerate oxidative reactions, causing peroxide values to rise. PV significantly increase at high moisture, temperature, and speed. The highest value of 3.361% was recorded for treatment $C_3T_2S_2$, indicating enhanced fat oxidation due to high temperature and friction during extrusion. These three factors create conditions that maximize oxidation rate (high temperature and friction) and

Table 1. The effect of copra water content, temperature, and extrusion speed of white copra on the yield, FFA content, and peroxide value of oil.

Treatments	Y_1 = Oil yield (%)		Y_2 = FFA content (% b/b)		Y_3 = Peroxide value (meq O_2/kg)	
$C_1T_1S_1$	59.570	bc	0.254	a	2.199	a
$C_1T_1S_2$	63.477	efg	0.393	bc	3.272	cd
$C_1T_2S_1$	61.143	cd	0.398	bc	2.875	b
$C_1T_2S_2$	64.473	g	0.473	cd	3.373	d
$C_2T_1S_1$	58.473	ab	0.281	A	2.268	a
$C_2T_1S_2$	62.817	def	0.402	bc	3.231	cd
$C_2T_2S_1$	60.973	cd	0.385	bc	2.919	bc
$C_2T_2S_2$	63.920	fg	0.513	d	3.332	d
$C_3T_1S_1$	57.213	a	0.294	a	2.171	a
$C_3T_1S_2$	61.637	de	0.436	cd	3.090	bc
$C_3T_2S_1$	60.563	cd	0.509	d	2.937	b
$C_3T_2S_2$	64.047	fg	0.254	e	3.361	d

Note: Numbers followed by the same letter in each column indicate no difference according to Duncan's Multiple Range Test (DMRT).

Table 2. Combination of factors and treatment levels formed.

Water content of copra	Extrusion temperature	Extrusion speed	
		S_1 (30 rpm)	S_2 (60 rpm)
C_1 (6%)	T_1 (60°C)	$C_1T_1S_1$	$C_1T_1S_2$
	T_2 (80°C)	$C_1T_2S_1$	$C_1T_2S_2$
C_2 (8%)	T_1 (60°C)	$C_2T_1S_1$	$C_2T_1S_2$
	T_2 (80°C)	$C_2T_2S_1$	$C_2T_2S_2$
C_3 (10%)	T_1 (60°C)	$C_3T_1S_1$	$C_3T_1S_2$
	T_2 (80°C)	$C_3T_2S_1$	$C_3T_2S_2$

Table 3. Analysis of variance of experimental data.

Source of Variance	Sum of Square (SS)	Degree of Freedom (df)	Mean of Square (MS) = SS/df	F_{Cal}	F_{Table}
C	SS_C	a -1	MS_C	F_C	
T	SS_T	b -1	MS_T	F_T	
S	SS_S	c -1	MS_S	F_S	
Error	SS_E	df_E	MS_E	-	-
Total	SS_{Total}	N -1	-	-	-

cause vulnerable substrates to oxidize due to high moisture and FFA levels, all leading to increased peroxide compounds and decreased VCO quality (Chandran et al., 2017; Agung and Rismaya, 2024; Harimurti et al., 2024). Increasing moisture, temperature, and extrusion speed during mechanical extrusion of white copra can raise the peroxide number in VCO. An increase in PV is a key indicator of oil quality degradation due to primary oxidation.

Regression analysis for the effects of copra moisture content (C), extrusion temperature (T), and extrusion speed (S) on PV in VCO (Y_3) is expressed as:

$$Y_3 = 1.623 + 0.078C + 0.065T + 0.510S$$

The study shows that physical process factors (moisture content, temperature, and extrusion speed) significantly affect all quality parameters of oil extracted from white copra. Thus, there is a compromise between extraction efficiency (high yield) and chemical stability of the oil (low FFA and PV). Optimal processing conditions can be determined by balancing these two aspects. Oil yield increases at high temperature and screw speed because viscosity decreases and extrusion pressure rises. However, FFA and PV also increase under these conditions due to more intense oxidation and hydrolysis processes.

Materials and Methods

Materials and equipment

White copra is coconut meat that preserved by a proper drying process to avoid microbial infection during storage as main material, dried to the appropriate moisture content: 6%, 8%, and 10%. This white copra was made from ripe coconut flesh from a tall variety obtained from smallholder coconut plantations on Cikalong Beach, Tasikmalaya Regency.

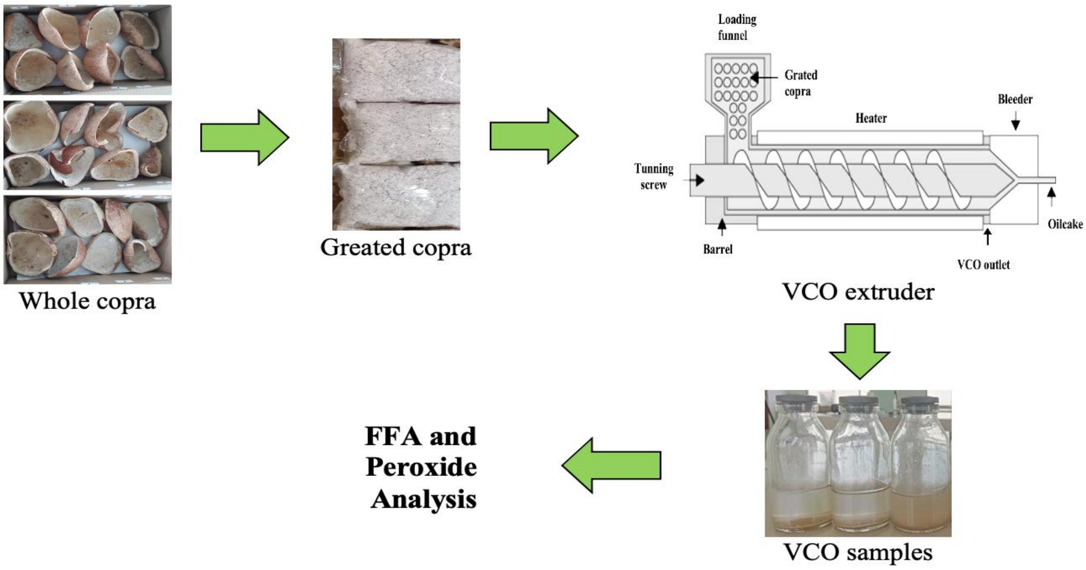

Figure 1. VCO extrusion process from white copra to determine yield, FFA content, and PV.

The Ossel Type OS-D035 oil extrusion machine for laboratory scale is equipped with a 452-watt Ceramic Band United Heater with automatic temperature control, a titration unit, and a 200-watt SG coconut grater. In addition, supporting equipment is available, such as analytical balances, graduated pipettes, beakers, etc.

Experimental design

The experiment consisted of three treatment factors, each with its own level: C: copra moisture content (6%, 8%, and 10%); T: extrusion temperature (60°C and 80°C); and S: screw speed (30 rpm and 60 rpm). The treatments were arranged in a 3×2×2 Completely Randomized Design, resulting in 12 treatment combinations, as shown in Table 2.
Each treatment combination was repeated three times, so that 36 experimental units were provided.

Experimental procedure

Three levels of whole white copra moisture were each grated separately to facilitate the extrusion process to extract virgin coconut oil. Each experimental unit was prepared with 100 g of grated white copra for each treatment. Each unit was loaded into the extruder with the temperature and speed settings specified for the treatment combination mentioned above. The VCO from the copra extruded was then weighed to calculate its yield and placed in labeled bottles for each treatment. The VCO in these bottles was prepared for analysis of FFA content and PV (Figure 1).

Observation parameters

1) Oil yield

The VCO yield produced from every 100 g of white copra is calculated using the following formula (Anwar and Salima, 2016):

$$Oil\ yield\ \ (\%) = \frac{Mass\ of\ VCO}{Mass\ of\ copra} \times 100\%$$

2) Free fatty acids

Determination of the free fatty acid (FFA) content in VCO is performed using the acid-base titration method, which neutralizes the free fatty acids present in the VCO with a standard base solution of NaOH (Uçar et al., 2024). The general formula for calculating the free fatty acid content in percentage is:

$$FFA\ Content\ (\%) = \frac{V \times N \times MW \times 100}{S}$$

Where: V = volume of NaOH solution (standard) used (in mL); N = normality of NaOH solution; MW = molecular weight of fatty acid as standard fatty acid (e.g. oleic acid = 282 g/mol); S = weight of oil sample (in mg or g, adjusted units)
The FFA content indicates the percentage of free fatty acids in total oil and is an indicator of oil quality, where high FFA levels indicate triglyceride hydrolysis and decreased oil quality (Anwar and Salima, 2016; Tan et al., 2023)

3) Peroxide value

Peroxide value (meq O2/kg) of VCO is determined using the following formula (Oktaviana et al., 2025):

$$Peroxide\ Value\ (meq\ O_2/kg) = \frac{V \times N \times 1000}{W}$$

Where: V: Volume of sodium thiosulfate ($Na_2S_2O_3$) solution used in the titration (in milliliters, mL); N: Normality of the sodium thiosulfate (usually 0.01 N or according to the titration standard used); 1000: Conversion factor to convert grams of sample to kilograms; W: Weight of the oil sample being titrated (in grams, g).
This formula calculates the number of equivalents of peroxide (active oxygen) in 1 kg of oil based on the volume of titrant required to react with the iodine formed from the peroxide oxidation process in the sample (Laga et al., 2023).

Data analysis

1) Analysis of variance

The design used was a completely randomized design (CRD) with three factors, an additive factorial pattern without interaction. Factor C had 3 levels, T had 2 levels, S had 2 levels, and each combination had 3 replications. The total number of observations was N = 3 × 2 × 2 × 3 = 36 experimental units.

Linear model of observation data after treatment

$Y_{ijkl}=\mu+C_i+T_j+S_k+\varepsilon_{ijkl}$

with: μ = general mean; Ci = effect of factor C at level i (i = 1..a); Tj = effect of factor T at level j (j = 1..b); Sk = effect of factor S at level k (k = 1..c); and εijkm ∼ IID N(0,σ2) (error).

Based on the linear model, the analysis of variance is compiled as shown in Table 3.

Hypothesis formulation:

Null hypothesis (H_0): All treatments have the same mean.

Alternative hypothesis (H_1): At least one treatment has a different mean.

Hypothesis testing:

Compare the calculated F value with the table F value at a specific significance level (e.g., 0.05).

If the calculated F value > table F value, reject the null hypothesis, indicating a significant difference between the treatments.

If a significant difference is found, conduct a Duncan's Multiple Differences Test (DMRT) to determine which treatment is different (Huzsvai et al., 2022). This method can be implemented using statistical software such as SPSS or Excel to facilitate calculations and significance testing (Assaad et al., 2015).

2) Regression analysis

Multiple Linear Regression. Used when more than one extrusion process factor simultaneously influences oil yield. The multiple linear regression model is as follows:

$$Y = a + b_1X_1 + b_2X_2 + \cdots + b_nX_n$$

Where X_1, X_2,..., X_n are the process factors being tested.

This analysis provides information on the contribution of each factor to oil yield and its statistical significance (Irvan et al., 2025).

Model Validation Analysis. Using this regression method, a mathematical model of the relationship between extrusion process factors and oil yield can be obtained, allowing for empirical optimization based on experimental data (Espínola et al., 2011; Mursalykova et al., 2023).

This reference provides a comprehensive explanation of various regression techniques frequently used in experimental data analysis, such as the influence of extrusion process factors on oil yield.

Conclusion

This regression model was designed to show that oil yield increases with increasing temperature and screw speed, but decreases slightly with increasing moisture content. The regression model also shows that FFA content increases with increasing temperature and screw speed, but decreases slightly with increasing moisture content. Factor V (screw speed) has the greatest influence on increasing oil yield. Increasing moisture content, temperature, and extrusion speed in the mechanical extrusion of white copra can increase the peroxide value (PV) in VCO. This increase is a primary indicator of oil quality deterioration due to primary oxidation. The results showed that the combination of moisture content (C), extrusion temperature (T), and screw speed (S) significantly affected the yield, free fatty acid (FFA) content, and PV of oil produced from the mechanical extrusion process of white copra.

Author Contributions

BR: project management, experimental design and manuscript revision. YN and IA: experiment conduction, data analysis, and manuscript drafting. ZN and TH: experimental design and data analysis.

Declaration of Competing Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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