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Implementation of Taguchi Method in Optimizing Virgin Coconut Oil Extraction by Cooling and Centrifugation Techniques

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Abstrak
Ekstraksi Virgin Coconut Oil (VCO) melalui teknik pendinginan dan sentrifugasi menjadi metode yang banyak digunakan karena mampu mempertahankan kualitas minyak. Namun, optimalisasi yield dan kualitas ekstraksi masih menjadi tantangan. Penelitian ini bertujuan untuk mengidentifikasi faktor optimal dalam proses ekstraksi VCO, dengan fokus pada yield dan kualitas fisikokimia, melalui penerapan metode Taguchi. Faktor yang diuji meliputi kecepatan sentrifugasi, waktu sentrifugasi, suhu penyimpanan, dan lama penyimpanan, masing-masing dengan tiga level, menggunakan orthogonal array L9(3^4). Selain itu, analysis of variance (ANOVA) digunakan untuk menganalisis pengaruh dan kontribusi tiap faktor. Hasil percobaan menunjukkan bahwa kecepatan sentrifugasi dan suhu penyimpanan berpengaruh signifikan terhadap yield VCO, sedangkan waktu sentrifugasi dan lama penyimpanan memberikan pengaruh minimal. ANOVA mengonfirmasi bahwa kecepatan sentrifugasi berkontribusi sebesar 88,31% dan suhu penyimpanan sebesar 7,68% terhadap yield. Untuk parameter kualitas VCO, meliputi kadar air, asam lemak bebas, angka asam total, dan nilai peroksida, tidak ditemukan faktor yang berpengaruh signifikan. Hal ini menunjukkan bahwa metode ini efektif mempertahankan kualitas dalam berbagai kondisi. Temuan ini mengindikasikan bahwa optimalisasi kecepatan sentrifugasi dan suhu penyimpanan dapat meningkatkan yield VCO tanpa menurunkan kualitas. Penelitian ini memberikan kontribusi berupa wawasan praktis bagi produksi VCO yang efisien dan berkualitas sesuai dengan Standar Nasional Indonesia (SNI 7381:2022). Selain itu, produsen VCO, termasuk usaha mikro dan kecil, dapat menghasilkan VCO secara konsisten dalam skala besar dengan menjaga kualitas melalui pengaturan kecepatan sentrifugasi dan suhu penyimpanan.

Kata kunci: *ekstraksi, pendinginan, sentrifugasi, Taguchi, VCO*

Abstract
Virgin Coconut Oil (VCO) extraction through refrigeration and centrifugation techniques has become the preferred extraction technique due to its ability to maintain oil quality. However, optimization of extraction yield and quality remains a challenge. Therefore, this study aims to identify the optimal factors in VCO extraction, focusing on yield and physicochemical quality, through the application of the Taguchi method. The factors tested included centrifugation speed, centrifugation time, storage temperature, and storage duration, each with three levels, using an orthogonal array L9(3^4). In addition, analysis of variance (ANOVA) was used to investigate the effects and contributions of each aspect. The experimental results indicated that centrifugation speed and storage temperature had significant effects on VCO yield, while centrifugation time and storage duration had minimal effects. Analysis of Variance (ANOVA) confirmed that centrifugation speed contributed 88.31% and storage temperature 7.68% to the yield. For the quality parameters of VCO content, such as moisture content, free fatty acids, total acid number, and peroxide value, no factor significantly affected the quality of VCO, indicating that this method is effective in maintaining quality under various conditions. These findings suggest that optimization of centrifugation speed and storage temperature can increase VCO yield without compromising quality. This research contributes to providing practical insights for efficient and high-quality VCO production, in accordance with the Indonesian National Standard (SNI 7381:2022) for VCO quality. Furthermore, VCO producers, including micro and small scale businesses, can produce large scale and consistent VCO without having to reduce product quality by optimizing centrifugation speed and storage temperature during the VCO manufacturing process.

Keywords: *centrifugation, cooling, extraction, Taguchi, VCO*

1. Introduction

Virgin Coconut Oil (VCO) is an edible oil derived from fresh and mature coconuts. VCO is extracted mechanically or naturally from fresh coconuts without chemical processes such as refining, bleaching, or deodorizing, resulting in a purified oil (Ghani et al., 2018;

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Ng et al., 2021; Zeng et al., 2024). Philippine national standards and the Bureau of Agricultural Product Standards define VCO as an edible oil obtained from fresh, ripe coconut fruits through mechanical or natural processes, with or without the use of heat to maintain the quality of the content therein (Srivastava et al., 2016). Since VCO is produced differently from Refined, Bleached, and Deodorized (RBD) coconut oil, the produced oil differs in sensory characteristics. VCO is almost colorless with a fresh coconut aroma. Meanwhile, RBD coconut oil is characterized as yellow in color, slightly salty, with no distinct aroma and taste (Rohman et al., 2021; Villarino et al., 2007).

VCO has many uses and is utilized by various food industries, medicines, cosmetics and various skin care products (Satheeshan et al., 2020; Zeng et al., 2024). Based on biological function, VCO contains antioxidant, anti-inflammatory, antibacterial, and antiviral properties (Famurewa et al., 2021; Narayanankutty et al., 2018). In addition, VCO also has potential therapeutic effects on chronic degenerative diseases (Rahim et al., 2017; Ramesh et al., 2021). One of the important characteristics of VCO is the content of phenolic compounds, which is the fundamental reason for its antioxidant properties (Ghani et al., 2018). Murillo et al. (1999) revealed that the content of phenolic compounds, metal composition, and antioxidants in VCO can affect the oxidation rate, nutritional value, and shelf life. However, to obtain the best quality, VCO depends on the extraction method applied (Mohammed et al., 2021).

In general, there are two methods of extracting VCO: wet and dry methods (Bawalan & Chapman, 2006; Ghani et al., 2018). The wet method is a technique of extracting VCO directly from the flesh of fresh and ripe coconuts by using cooling and centrifugation, fermentation, enzymatic, pH methods, or a combination of methods to destabilize the coconut milk emulsion without drying (Ghani et al., 2018; Raghavendra & Raghavarao, 2010). Dry method, in which the coconut pulp is first dried with a controlled heating device to remove moisture and prevent microbial invasion and then pressed (Ghani et al., 2018). Several factors affect VCO yield, such as harvesting time, coconut age, and plantation location, but the VCO extraction technique is the key factor in producing high VCO yield (Carandang, 2008). Several previous studies have investigated the quality and extraction methods of VCO (Amri, 2011; Aytaç, 2022; Ghani et al., 2018; Negi et al., 2024; Rohman et al., 2021; Zeng et al., 2024). In addition, not all quality characteristics of VCO in the Asia and Pacific region are reported, including the physicochemical quality of VCO extracted from various coconut industries in Indonesia.

The cooling and centrifugation method is the best method for producing and maintaining the quality of VCO content, but the drawback lies in the low VCO yield (Agarwal & Bosco, 2017; Aytaç, 2022; Ng et al., 2021; Rohman et al., 2021; Zeng et al., 2024). While other methods, such as fermentation, enzymatic and dry methods, are known to produce high VCO yields, the physicochemical content of VCO cannot be maintained (APPC, 2009; Ghani et al., 2018; Mohammed et al., 2021; Ng et al., 2021; Soo et al., 2020; Zeng et al., 2024) Therefore, this study aims to optimize the yield level and maintain the quality of VCO content with cooling and centrifugation extraction techniques. This research is experimental-based using the Taguchi method. So far, there is no experimental-based literature on VCO extraction using the Taguchi method, especially using cooling and centrifugation extraction techniques.

The Taguchi method is a method that can optimize performance characteristics based on the best combination of factors (Lestari et al., 2024; Purnomo et al., 2019; Zulfia et al., 2022). Compared to other experimental methods, the Taguchi method can estimate the optimum value with consideration of specific response values, including finding the best combination with efficient experiments (Dutta & Kumar Reddy Narala, 2021; Nagaraja et al., 2023; Shojaei et al., 2021; Uray et al., 2022). Lestari et al. (2024) revealed that the Taguchi method can estimate the impact of a factor on the response variable by limiting the influence of uncontrolled elements, including streamlining time, cost, and the number of experiments appropriately, given the limitations of refrigeration and centrifugation techniques in producing VCO yield. Therefore, through the implementation of the Taguchi method, it is expected that the results of this experiment can make a significant contribution, especially in producing high VCO yield through a combination of factors, levels, and number of experiments. Ultimately, the results of this study can serve as a reference for industry players in the VCO field in producing more economical and consistent VCO without sacrificing the VCO content that is useful for human health.

2. Research Methods

2.1. Materials and Tools

The main raw material for VCO extraction comes from fresh and ripe coconuts that are about 10-12 months old. In this experiment, 10 fresh and ripe coconuts purchased at a traditional local market were used. Furthermore, the materials needed consist of: clean water, filter cloth, filter paper, and latex gloves. At the same time, the equipment used was coconut cutting tools, peeling machines, freezer machines, centrifugal machines, mixer machines, manual stirrers, plastic containers, test tubes, and filters.

2.2. Extraction Methods

The extraction methods applied in this study are cooling and centrifugation methods. Both extraction methods are applied after peeling the coconut fruit to make coconut milk. The cooling and centrifugation methods are used to destabilize the oil-in-water emulsion (Patil et al., 2017). Gunetileke and Laurentius (1974) revealed that protein and oil can be separated from coconut cream obtained from centrifuging coconut milk by cooling it at a certain temperature and time, then liquefying it at a certain temperature. During the melting process, the oil droplets will coalesce and form large-sized droplets (Patil et al., 2017). It is known that both methods can produce quality VCO content standardized by SNI 7381: 2022 and APPC standards in 2009, but the yield of VCO is still relatively low (Agarwal & Bosco, 2017; Aytaç, 2022; Ng et al., 2021; Rohman et al., 2021; Zeng et al., 2024). Therefore, to optimize the yield, this study used the Taguchi method as an experimental design by considering important factors that can increase yield, including the quality of VCO content.

2.3. Experiment Procedure

The experimental procedure is as follows: First, the coconut fruit was peeled, and the flesh was grated finely to facilitate the coconut milk extraction process. Second, about 500 ml of clean water is added to each coconut that has been finely grated. Then the squeezing process is carried out with a filter cloth and a sieve. The finished coconut milk was then poured into nine plastic containers, each with 300 ml. Third, each container containing coconut milk is put into the freezer with freezer temperature conditions that have been set according to the specified orthogonal array matrix, see Table 3. Fourth, after sufficient storage time in the freezer, the coconut milk is removed, and then the coconut cream is taken. A mixer process is carried out here to homogenize the texture of the cream formed during the cooling process. Using a mixer, coconut cream can be mixed again evenly, resulting in a smoother and more stable texture. Fifth, the melted coconut milk cream is transferred into a chemical test tube for insertion into the centrifuge machine. The speed and duration of centrifugation were adjusted according to the orthogonal array matrix, see Table 3. After the centrifugation process, the first layer of VCO oil was taken, filtered and stored in a sterile plastic container. The obtained VCO oil was then tested for yield and quality at the Laboratory of Chemistry and Biochemistry of Agricultural Products, Faculty of Agriculture, Mulawarman University, Samarinda, East Kalimantan.

2.4. Experiment Procedure

The experimental design in this study aims to optimize the results of Virgin Coconut Oil (VCO) extraction based on the level of yield and quality of VCO content. The quality level of VCO content obtained was then analyzed in accordance with VCO quality standards according to SNI 7381:2022. This research uses the Taguchi method to design experiments, which is an effective experimental approach in determining the optimal combination of factors and levels to improve performance characteristics with high efficiency (Lestari et al., 2024). The Taguchi method is renowned for its ability to minimize yield variation and maximize product quality by considering the most influential factors in the extraction process (Lestari et al., 2024; Purnomo et al., 2019; Zulfia et al., 2022).

Factors considered in this study include centrifugation speed, centrifugation time, freezer storage temperature, and storage duration. These factors were selected based on relevant literature, where each factor is expected to affect the process of separating VCO oil from other components, both in terms of the speed of separation of VCO emulsion and the final quality of the product (Negi et al., 2024; Rohman et al., 2021; Soo et al., 2020; Zeng et al., 2024). In the extraction process, these four factors are the key factors considered to maintain the quality of the VCO produced. Each factor was tested at three levels, namely for the centrifugation speed factor with three speed levels of 2800 rpm, 3600 rpm, and 5000 rpm; the centrifugation time factor with time levels of 15 minutes, 20 minutes, and 25 minutes; the freezer storage temperature factor with levels of 5°C, 10°C, and 15°C; and the freezer storage duration factor with durations of 4 hours, 5 hours, and 6 hours, refer to table 1. These factors were selected based on a review of relevant literature, where each factor is expected to affect the process of separating VCO oil from other components, both in terms of separation speed and the final quality of the VCO product (Negi et al., 2024; Rohman et al., 2021; Soo et al., 2020; Zeng et al., 2024). This experimental design was designed using Minitab software version 19, which supports the application of the Taguchi method in determining the optimal combination of factors and levels that gives the best results with a minimum number of experiments (Lestari et al., 2024; Purnomo et al., 2019). The experimental design is based on an orthogonal array L9 (3^4), which is a matrix arrangement that allows the optimal combination of the four factors studied with three levels for each factor and requires only nine trials for time and cost efficiency, as shown in Tables 2 and 3.

Table 1. Factors and Level Design

Factors	Level			symbol
	1	2	3	
centrifugation speed	2.800 rpm	3.600 rpm	5.000 rpm	A
centrifugation time	15 minutes	20 minutes	25 minutes	B
freezer storage temperature	5°C	10°C	15°C	C
Freezer storage time	4 hours	5 hours	6 hours	D

Table 2. Orthogonal Array $L_9 3^4$

Experiment Number	Factors			
	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	2
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 3. *Orthogonal Array* $L_9 3^4$ After being converted by Level and Factors

Experiment number	Factors			
	A	B	C	D
1	2.800 rpm	15 minutes	5°C	4 hours
2	2.800 rpm	20 minutes	10°C	5 hours
3	2.800 rpm	25 minutes	15°C	6 hours
4	3.600 rpm	15 minutes	10°C	5 hours
5	3.600 rpm	20 minutes	15°C	4 hours
6	3.600 rpm	25 minutes	5°C	5 hours
7	5.000 rpm	15 minutes	15°C	5 hours
8	5.000 rpm	20 minutes	5°C	6 hours
9	5.000 rpm	25 minutes	10°C	4 hours

In the Taguchi method, a Signal-to-Noise (S/N) ratio is used to assess the performance of each combination between factors and levels. To measure the results of the VCO yield level test, the S/N type "large is better" is used. While to measure the quality of VCO content, the S/N used is "smaller is better". In addition, statistical testing, namely Analysis of Variance (ANOVA), was also applied in this study. ANOVA is used to determine which factors have a significant influence on the extraction yield of Virgin Coconut Oil (VCO). After using the Taguchi method to design experiments, ANOVA serves as a verification step. It ensures that the optimization results obtained are statistically significant and not just the result of random variability.

3. Results and Discussion

3.1. Taguchi-based Response Factors

In this study, the observed responses were VCO yield and the quality of VCO content tested in the laboratory. The factors considered consisted of centrifugation speed, centrifugation rotation time, freezer storage temperature and freezer storage time. The levels applied were three levels based on the L934 Orthogonal Array metrics. Experimental results related to VCO extraction using refrigeration and centrifugation techniques are shown in Table 4.

Table 4 shows the experimental results of VCO extraction with cooling and centrifugation techniques through the Taguchi method. There are two responses or test parameters, namely the yield rate and the quality of VCO content. The VCO yield level indicates the amount of VCO oil obtained through the extraction process, which utilizes cooling and centrifugation techniques. Meanwhile, the quality of VCO content is measured through several physicochemical parameters. However, due to the limited tools and materials in the laboratory of Chemistry and Biochemistry of Agricultural Products, Faculty of Agriculture, Mulawarman University, Samarinda, only four parameters, including color, odor, and taste, were tested.

In comparison, the parameters of fatty acids and their derivatives, heavy metal contamination and their derivatives, and iodine number were not tested. For color, odor and taste parameters based on the test results obtained are classified as normal. When compared with the SNI 7381:2022 standard regarding the quality standards of VCO content, then these parameters are declared to have met the quality standards, refer to table 5.

Table 4. Experimental Results of VCO Extraction by Cooling and Centrifugation Techniques

Experiment number	Factors				VCO yield (ml)	Quality of VCO content			
	A	B	C	D		Moisture Content (%)	Free Fatty Acid (%)	Total Acid Number (g KOH/g)	Peroxide Value (mg O_2/100g)
1	2.800 rpm	15 minutes	5°C	4 hours	101	0.1576	0.1720	0.1029	0.7000
2	2.800 rpm	20 minutes	10°C	5 hours	92	0.1767	0.1080	0.1055	0.7000
3	2.800 rpm	25 minutes	15°C	6 hours	83	0.1891	0.1440	0.1403	0.7800
4	3.600 rpm	15 minutes	10°C	5 hours	107	0.0119	0.0480	0.0549	0.7000
5	3.600 rpm	20 minutes	15°C	4 hours	101	0.0278	0.0640	0.0651	0.7600
6	3.600 rpm	25 minutes	5°C	5 hours	124	0.0139	0.0360	0.0393	0.7400
7	5.000 rpm	15 minutes	15°C	5 hours	119	0.0189	0.0500	0.0495	0.7500
8	5.000 rpm	20 minutes	5°C	6 hours	152	0.0159	0.0440	0.0482	0.7600
9	5.000 rpm	25 minutes	10°C	4 hours	127	0.0576	0.0560	0.0527	0.7200

Table 5. Quality Standards for VCO Content According to SNI 7381: 2022

Number	Test criteria	Unit	Quality standard
1.	Color	-	normal
2.	Odor	-	normal
3.	Taste	-	normal
4.	Water content	Mass fraction, %	mx. 0,2
5.	Iod number	g iod/100 g	4,1-11,0
6.	Peroxide value	mek O_2/kg	max. 2,0
7.	Free fatty acid	Mass fraction, %	max. 2,0

3.2. Signal-to-noise (S/N) Ratios

Signal-to-noise ratio (S/N) is a measure used to quantify the quality of a product or process. The S/N Ratio compares the "signal" (which represents the desired characteristics of the product or process) to the "noise" (which represents variation or uncertainty in the process). The goal is to maximize the signal and minimize the noise. In this experiment, the S/N ratio used was large is better for the VCO yield parameter and smaller is better for the VCO content quality parameter. The S/N ratio test results are shown in tables 6 and 7.

Based on Table 6 and Figure 1, the most influential factor on VCO yield is centrifugation speed, with the highest delta value of 3.16 and ranked first. This indicates that changes in centrifugation speed have the most significant effect on increasing VCO yield. The optimal centrifugation speed level for the highest VCO yield is at level 3 (42.41 dB), as shown in the main effect plot graph, which shows an increasing trend of centrifugation speed. The second influential factor is freezer storage temperature, with a delta value of 1.87, where level 1 (41.86 dB) produces higher yields than other levels. The next factor was centrifugation time, with a smaller delta value of 0.27, followed by freezer storage time with the smallest delta of 0.14. Overall, centrifugation speed is the dominant factor in the VCO yield optimization process, while centrifugation time and storage duration have a relatively small influence on VCO yield.

Table 6. Response Value for S/N ratios (Large is Better) for VCO yield

Symbol	Factors	Level			Delta	Rank
		1	2	3		
A	Centrifugation speed	39.25	40.85	42.41	3.16	1
B	Centrifugation time	40.73	41	40.78	0.27	3
C	Freezer storage temperature	41.86	40.65	39.99	1.87	2
D	Freezer storage time	40.75	40.89	40.87	0.14	4

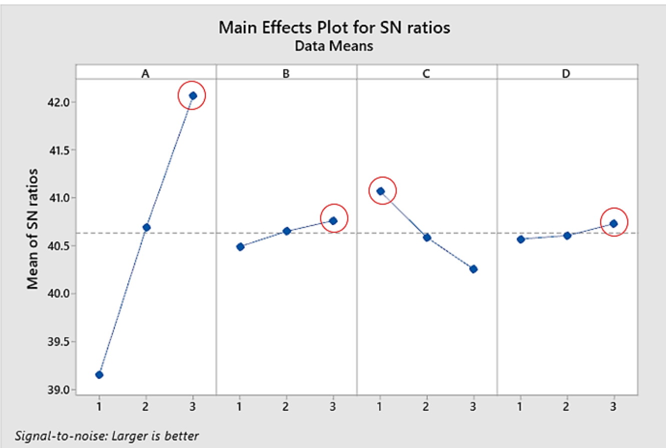

Figure 1. S/N Ratios VCO yield

Based on Table 6, the most influential factor on VCO yield is centrifugation speed with the highest delta value of 3.16 and ranked first. This indicates that changes in centrifugation speed have the most significant effect on increasing VCO yield. The optimal centrifugation speed level for the highest VCO yield was at level 3 (42.41 dB), as shown in the main effects plot graph, which shows an upward trend in centrifugation speed. The second influential factor was the freezer storage temperature, with a delta value of 1.87, where level 1 (41.86 dB) resulted in a higher yield than the other levels. The next factor was centrifugation time, with a smaller delta value of 0.27, followed by freezer storage duration with the smallest delta of 0.14.

Figure 1 shows the SN ratios for VCO yield. The most significant factor is centrifugation speed (A), as indicated by the steepest slope of the line and the difference in SN ratio between levels. The storage temperature factor (C) also has a significant effect, with the optimum level at level 1. Meanwhile, the factors of centrifugation time (B) and storage duration (D) showed relatively small changes in SN ratio between levels. With the SN ratio used as Large is Better, the optimal combination of factors and levels to produce high VCO yields are **A3**, **B3**, **C1,** and **D2**.

Based on Table 7, the most influential factor on the quality of VCO content is storage temperature (freezer), with the highest delta value of 0.684 and ranked first. This indicates that changes in storage temperature have a significant impact on the quality of VCO content, with the optimal level at level 3 (8.52 dB) to achieve the desired quality. Centrifugation speed ranked second with a delta value of 0.37, indicating that this factor also affects quality, although not as strongly as storage temperature. The next factor was centrifugation time, with a delta value of 0.35, which exerted a smaller influence, followed by storage duration, with the lowest delta value of 0.216, which showed the least influence.

In Figure 2, the main effects plot graph shows a decreasing trend for several factors, especially storage temperature (°C), indicating that optimal VCO content quality is achieved with lower values at certain levels, and the SN ratio varies greatly between levels, indicating high sensitivity to temperature changes. Since the method used is Smaller is Better, the optimal combinations to minimize the response variables and produce the best VCO quality are A2, B1, C2, and D2.

Table 7. Response Value for S/N Ratios (Smaller is Better) for VCO Content Quality

Symbol	Factors	Level			Delta	Rank
		1	2	3		
A	Centrifugation speed	8.303	8.673	8.549	0.37	2
B	Centrifugation time	8.709	8.709	8.709	0.35	3
C	Freezer storage temperature	8.52	8.52	8.52	0.684	1
D	Freezer storage time	8.57	8.57	8.57	0.216	4

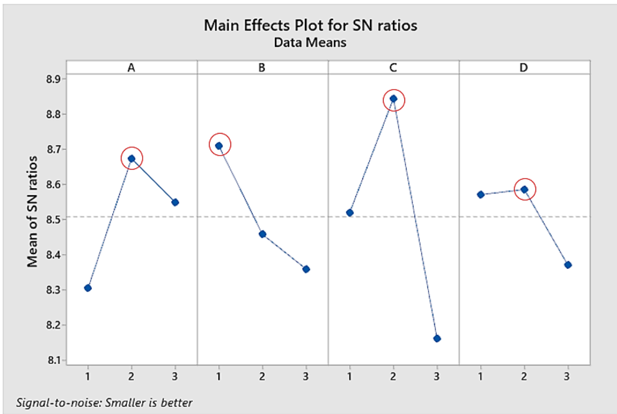

Figure 2. S/N Ratios VCO Content Quality

3.3. Analysis of Variance

Analysis of variance (ANOVA) was used to analyze data for experimental test results. Through ANOVA analysis, information can be obtained on how much influence each factor has on the results of the VCO extraction test. In addition, ANOVA analysis provides information about the degrees of freedom (DF), the adjusted number of squares (Adj SS), the average adjusted number of squares (Adj MS), the F value, and the P value. The results of ANOVA analysis of VCO yield and VCO content quality are shown in Tables 8 and 9.

Table 8. The Analysis of Variance for VCO yield

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution
Centrifugation speed	2	3961.33	1980.67	158.45	0.000	88.31%
Centrifugation time	2	52.00	26.00	2.08	0.181	1.16%
Freezer storage temperature	2	345.33	172.67	13.81	0.002	7.68%
Freezer storage time	2	25.33	12.67	1.01	0.401	0.56%
Error	9	112.50	12.50			
Total	17	4496.50				

Table 9. The Analysis of Variance for VCO content quality

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution
Centrifugation speed	2	0.04360	0.021799	0.20	0.821	1.45%
Centrifugation time	2	0.00099	0.000497	0.00	0.995	0.03%
Freezer storage temperature	2	0.00295	0.001477	0.01	0.987	0.10%
Freezer storage time	2	0.00122	0.000610	0.01	0.994	0.04%
Error	27	2.96208	0.109707			
Total	35	3.01084				

Based on Table 8, the Centrifugation Speed factor made the largest contribution of 88.31% to the variation in yield, followed by Storage Temperature (7.68%), Centrifugation Time (1.16%), and Storage Time (0.56%). The very high contribution indicates that centrifugation speed is the main factor affecting VCO yield. This is in line with the physical principle of centrifugation, where the higher the speed, the greater the centrifugal force generated. Therefore, the separation of oil from water emulsion and solids becomes more efficient (Wong & Hartina, 2014). Then, the contribution of storage temperature amounted to 7.68%. Although not significant, storage temperature affects emulsion stability and oil viscosity. Storage at freezer temperatures can cause more efficient oil phase separation due to changes in the physical structure of the emulsion (Husain & Marzuki, 2021; Meijer et al., 2024).

Furthermore, the low contributions to VCO yield were centrifugation time (1.16%) and storage time (0.56%). The lack of contribution of centrifugation time is because, after a certain point, additional time does not improve separation significantly, especially if the centrifugation speed is already optimal. It is based on the centrifugation principle that centrifugation time contributes to the separation efficiency only as long as the sedimentation process is still ongoing. Once the components have separated and formed a pellet, additional centrifugation time does not provide significant additional benefits (Allison et al., 2020). Finally, the smallest contribution, storage time, showed a very low impact of freezer storage time on yield. This is due to the maximum temperature since the beginning of storage, and additional storage time does not significantly increase the separation efficiency of the VCO emulsion (Pulungan et al., 2020). These results indicate that to increase the yield, it is necessary to optimize the centrifugation speed and storage temperature. Other factors, such as centrifugation time and storage time, can be considered constant or have little effect on the response variable (yield).

Then, Table 9 shows that none of the factors, namely centrifugation speed, centrifugation time, storage temperature (freezer), or storage time (freezer), has a significant influence on the quality reduction of VCO content. This is indicated by the very large p-value (more than 0.05) for all these factors. This means that any change in these factors does not have a significant impact on the quality of VCO content. Instead, the quality of the VCO content was maintained. This result indicates that the extraction of VCO using refrigeration and centrifugation techniques by considering the factors of centrifugation speed, centrifugation time, storage temperature, and storage time does not significantly impact the quality of VCO content that is maintained or owned. This finding aligns with several previous studies, which have shown that cooling and centrifugation techniques can effectively produce and maintain the quality of VCO content (Rohman et al., 2021; Soo et al., 2020; Zeng et al., 2024).

Based on the results of experimental analysis and ANOVA, it was found that centrifugation speed and storage temperature (freezer) were the main factors that had a significant effect on VCO yield. In contrast, centrifugation time and storage duration did not show a significant effect. This suggests that an increase in VCO yield can be achieved by optimizing the centrifugation speed and setting a more appropriate storage temperature. Higher centrifugation speed tends to increase the force of oil separation from the raw material, thus producing more oil in the extraction process. Optimal storage temperature also plays a role in maintaining the stability of the material during the extraction process, resulting in higher oil content.

In contrast, centrifugation time and storage duration did not have a significant effect on VCO yield. The lack of contribution of centrifugation time is because after a certain point, additional time does not significantly increase the separation, especially if the centrifugation speed is already optimal (Allison et al., 2020). The maximum temperature from the beginning of storage, and the increase in storage period, did not increase the separation efficiency of VCO emulsion significantly (Pulungan et al., 2020). Both factors can be considered constant or do not require special attention in the VCO extraction optimization process.

Then, the quality of VCO content based on the analysis results showed that none of the factors had a significant effect on the quality parameters measured, namely water content, free fatty acids, acid number, and peroxide value. This indicates that the quality of VCO is not significantly affected by changes in centrifugation speed, centrifugation time, storage temperature, or storage duration. Extraction of VCO using refrigeration and centrifugation techniques, considering factors such as centrifugation speed, centrifugation time, storage temperature, and storage time, had no impact on the quality of the VCO content that was maintained or possessed. In other words, these two extraction techniques are very appropriate in maintaining the quality of the VCO content produced. This finding is consistent with several previous studies, which state that refrigeration and centrifugation methods are effective methods to produce high-quality VCO, as these processes can minimize damage to the oil components and maintain its natural properties. (Rohman et al., 2021; Soo et al., 2020; Zeng et al., 2024).

3.4. Managerial Implications

The managerial implication of the findings of this study is that companies producing VCO should consider increasing centrifugation speed and optimizing storage temperature as key steps in improving production efficiency. By focusing on these two factors, producers can increase the yield of VCO produced without having to sacrifice the quality of the final product. On the other hand, since the quality of VCO is not significantly affected by changes in centrifugation time and storage duration, producers can save resources and time by not prioritizing settings on these two factors. This has the potential to reduce operational costs and production time, thereby improving overall production efficiency. This is in line with some previous research findings that the combination of high centrifugation speed and optimum storage temperature can produce high VCO yields (Prasanna et al., 2024; Wong & Hartina, 2014; Yulianto et al., 2023).

The findings also highlight that the use of cooling and centrifugation techniques in the VCO extraction process is not only effective in producing high yields but also in maintaining the quality of the VCO content. For production managers, this means that these techniques can be standardized for efficient and economical VCO production. Companies can use this approach to produce VCO products that not only meet national quality standards (SNI 7381:2022) but are also highly competitive in the market. In addition, companies should consider a cost-benefit analysis before implementation, especially on an industrial scale, as the use of high-speed equipment and cooling systems requires large investments and energy consumption. With planned steps and supporting data, companies can increase productivity without sacrificing quality, while reducing operational costs and increasing competitiveness in the market.

4. Conclusion

Based on the experimental results, the conclusion of this research is to optimize the extraction of Virgin Coconut Oil (VCO) through cooling and centrifugation techniques. The factors of centrifugation speed and storage temperature (freezer) are proven to have a significant influence on the level of VCO yield. Increasing the centrifugation speed can effectively increase the amount of VCO oil produced, while setting the right storage temperature also plays a role in maintaining the stability of the material and increasing the yield. The factors of centrifugation time and storage duration did not have a significant effect on the yield, so they can be considered as constant or less important variables in this optimization process. Furthermore, for the quality of VCO content, none of the factors had a significant effect on quality parameters such as moisture content, free fatty acids, acid number, and peroxide value. This confirms that the cooling and centrifugation methods used are effective enough to maintain the quality of VCO in accordance with quality standards without being affected by variations in process factors. This study not only evaluates each factor separately but also provides a comprehensive picture of the effectiveness of combining refrigeration and centrifugation techniques in increasing yield without compromising the quality of VCO content.

Overall, to achieve optimization in the VCO extraction process, it is best to focus on setting the centrifugation speed and storage temperature to increase the yield. At the same time, the quality of VCO content can be well maintained through this technique without the need to significantly modify other parameters. These findings provide a strong basis for the VCO industry to improve production efficiency and quality, thereby producing products that meet quality standards and have high economic value. For future research, it is recommended to consider variations in other factors, such as coconut meat particle size or coconut fruit variety. Furthermore, it is recommended to include other quality parameters such as iodine number, fatty acid composition, and heavy metal contamination for a more complete assessment of VCO quality and to ensure that the product meets stricter quality standards. The quality of VCO is also highly dependent on its stability and durability during storage. Future research could focus on testing the stability and durability of VCO during long-term storage, especially under different storage conditions such as room temperature or low temperature. Thus, it is hoped that future research can make a more in-depth contribution to improving the quality and efficiency of the VCO extraction process, thus not only benefiting producers but also supporting higher quality standards and more sustainable production practices.

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