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Potential Utilization of Palm Oil Liquid Waste as Downstream Agroindustry Products with Proximate Test and β-Carotene Concentration

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Abstract
Since 2006, Indonesia has led global production and export of palm-based edible oils. Government policies focused on advancing agriculture and agro-industries, particularly in downstream product development, provide opportunities to increase the economic value of these products, including palm oil products. Efforts to enhance downstream products include maximizing all palm oil potentials, including its waste. Global CPO production based on 2024 data is 79.6 million tons per year, with Indonesia contributing 59%. The potential waste is also very large, including the final waste which still contains around 20-25% oil and 3-5% phytonutrients. Proximate analysis and β-carotene content studies are used to evaluate the potential of CPO liquid waste for poultry feed. Proximate analysis results show low nutrient levels, including protein (<0.04%), carbohydrates (1.37%), total carbohydrates (<0.02%), total energy (5.20%), and crude fiber (<0.02%), making it unsuitable as a poultry feed substitute. However, based on β-carotene data, the waste can be used as an additive in poultry feed if stored for less than 28 days. The β-carotene degradation process follows zero-order reaction at heating and storage conditions (under room and dark storage).
Keywords: *β-carotene, CPO waste, palm oil, poultry feed, reaction order*

Abstrak
Sejak tahun 2006 Indonesia memimpin produksi dan ekspor minyak pangan dunia dari sumber sawit. Kebijakan pemerintah untuk menggarap sektor pertanian dan agroindustri pada pengembangan produk hilir memberi peluang meningkatnya nilai ekonomi setiap produk tersebut, termasuk produk sawit. Di antara upaya meningkatkan produk hilir adalah pemanfaatan seluruh potensi sawit, termasuk limbahnya. Produksi CPO dunia berdasarkan data tahun 2024 sebesar 79,6 juta ton/tahun, dengan kontribusi Indonesia sebesar 59%, potensi limbah juga sangat besar, termasuk limbah akhir yang masih mengandung sekitar 20-25% minyak dan fitonutrien sebesar 3-5%. Analisis kandungan proksimat dan β-karoten digunakan sebagai tolok ukur kajian potensi pemanfaatan limbah cair produksi CPO untuk pakan unggas. Hasil analisis proksimat diperoleh kadar yang rendah, meliputi protein (<0,04), karbohidrat (1,37%), karbohidrat total (<0,02%), energi total (5,20%) dan serat kasar (<0,02%) sehingga tidak tepat digunakan sebagai bahan substitusi pakan unggas. Namun jika mengacu data β-karoten, limbah dapat dimanfaatkan untuk tambahan bahan pembuatan pakan unggas pada proses penyimpanan kurang dari 28 hari. Proses reaksi penurunan β-karoten mengikuti orde 0 pada pemanasan dan penyimpanan (kondisi ruang maupun kondisi gelap).
Kata kunci: *β-karoten, limban CPO, orde reaksi, pakan unggas, sawit*

1. Introduction

Palm oil is a highly valuable natural resource for Indonesia, as it serves as a key source of foreign exchange in the non-oil and gas sector[1]. Since 2006, Indonesia has been the world's largest supplier of CPO (Crude Palm Oil)[2]. In 2021-2022, global CPO production reached 75.5 million tons per year in 2022[3] and is projected to reach 79.629 million tons in 2024[4], with contributions of 59% from Indonesia, 25% from Malaysia, and 16% from other countries[3].

The large volume of CPO production generates significant processing waste, which needs to be utilized further, including waste from the processing of palm fruit bunches into CPO. Liquid waste from CPO processing, accounting for approximately 25%, is estimated to still contain phytonutrient compounds and can be utilized as a supplement in poultry feed.

The dominant phytonutrient component in palm oil processing liquid waste is β-carotene. This waste, which constitutes about 20-25% of the total output, still contains β-carotene and thus has the potential to be developed as a raw material for poultry feed to improve meat and egg quality.

This study focuses on the potential of palm oil liquid waste in terms of its main micronutrient component, β-carotene. This compound is a pro-vitamin A that can be metabolized in the body into vitamin A[5]. The analysis of the potential of palm oil processing liquid waste was conducted by testing its proximate composition (protein, carbohydrates, energy, fiber) and β-carotene concentration.

This study aims to conduct a proximate analysis of liquid waste from CPO processing and analyze the β-carotene content influenced by processing as a parameter for evaluating the potential use of palm oil processing liquid waste for downstream agro-industrial products (including as a substitute for poultry feed raw materials), determine the reaction order of β-carotene, and assess the potential of CPO processing liquid waste for utilization as downstream agro-industrial products.

The novelty of this research lies in obtaining supporting data to evaluate the potential use of palm oil industrial liquid waste for downstream agro-industrial products (including poultry feed) and acquiring data on the reaction order of β-carotene degradation.

The research stages included preliminary treatment of the sample, which involved sample filtration, storage at room temperature in a light-free environment, and selecting suitable solvents for the analytical process. Subsequently, the sample underwent proximate analysis and β-carotene concentration analysis. β-carotene was analyzed using the HPLC method[6], [7]. Additionally, the effects of storage and heating treatments were analyzed by measuring β-carotene concentration at various treatment points. Finally, the reaction order was determined by analyzing β-carotene c concentration after heating at a selected temperature for 15 minutes, 30 minutes, 45 minutes, 60 minutes, 75 minutes, and 90 minutes, and by storing the samples under normal room conditions and in a dark room (UV-free) for 70 days, with data recorded every 14 days.

2. Research Methodology

2.1. Equipment and Materials

The primary laboratory equipment used includes glassware for Pyrex measurements (100 ml graduated cylinder; 10 ml, 50 ml, and 100 ml volumetric flasks; 20 ml beakers), weighing tools, an oven for heating, an electric heater, a magnetic stirrer, 1 ml and 5 ml pipettes with tips. The main instruments for analysis include a UV-Vis spectrometer from Thermo and an HPLC instrument for β-carotene analysis from Shimadzu.

The raw materials for liquid waste samples and crude palm oil (CPO) were obtained from Palm Oil Mill (PKS, Pabrik Kelapa Sawit) PT Agro Niaga Amanah in Lebak Banten and Palm Oil Mill PT Condong Garut West Java. The samples used included fresh CPO, recycled liquid waste 1, recycled liquid waste 2, and final liquid waste. The samples were stored in brown bottles and kept in light-free environments.

The chemicals used include standard β-carotene, ethanol, methanol, hexane, and iso-octane. Chemicals for antioxidant activity tests and β-carotene analysis by the spectrometry method were purchased from SIGMA Aldrich, while solvents were purchased from E-Merck.

The research was conducted at the BJ Habibie Science and Technology Area (KST) in Serpong, South Tangerang.

2.2. Work Procedure

1.2.1. Proximate Analysis

The analysis was carried out using the AOAC standard method. *AOAC, 1995*[8]. *Official Method of Analysis (16th ed.)*. Virginia: The Association of Official Agricultural Chemists and its development procedures.

1.2.2. β-Carotene Concentration Analysis

β-carotene determination was conducted using the HPLC method (Barba, 2006; Varzakas, 2016), with the Shimadzu instrument:

- **HPLC Column**: Scentis® Si, 5 µm particle size, L × I.D. 15 cm × 4.6 mm
- **Mobile Phase Component**: 2-Propanol 99.5%, HPLC grade
- **Standard**: Xanthophyll, Astaxanthin ≥97% (HPLC)
- **Column**: Ascentis Si, 15 cm × 4.6 mm I.D., 5 µm particles (581512-U)
- **Flow Rate**: 1.0 mL/min
- **Column Temperature**: 30 °C
- **Detector**: UV, 452.3 nm
- **Dilution Factor**: 100

- **Injection Volume**: 20 µL

Treatments:

- **No Treatment**: Fresh
- **Heat Treatment**: 60°C, 100°C, 140°C, and 180°C
- **Dark Storage**: 14, 28, 42, 56, and 70 days
- **Normal Storage**: 14, 28, 42, 56, and 70 days

3. Results and Discussion

3.1. Samples and Preliminary Treatments

The samples used in this study were CPO and palm oil processing waste obtained from two locations: the Palm Oil Mill (PKS) of PT Agro Niaga Amanah (PT ANM) in Lebak, Banten, and the Palm Oil Mill (PKS) of PT Condong Garut (PT CG) in Garut, West Java. Two different samples were used to observe data trends from different processes. To obtain comprehensive and comparable data between CPO and its waste, the study analyzed fresh CPO, liquid waste 1 and 2 (samples from PKS ANM), as well as fresh CPO, recycled liquid waste 1, liquid waste 2, and final liquid waste (samples from PKS CG). The samples were stored in brown bottles and kept in light-free rooms to minimize phytonutrient degradation during transportation and storage.

3.2. Proximate Analysis of Samples to Assess the Potential of CPO Processing Waste for Downstream Products

Proximate analysis is essential for evaluating the potential use of CPO processing waste. The analysis included fat content and total fat, protein, carbohydrates, and energy.

3.2.1. Analysis of ANM (Agro Niaga Amanah) and CG (Condong Garut) Samples

The results of the proximate analysis of CPO and waste samples from Palm Oil Mill (PKS) PT ANM are presented in Table 1 and from Palm Oil Mill (PKS) PT CG are presented in Table 2.

Tabel 1. Proximate Analysis Results of PKS PT ANM Samples

No	Analysis Item	Sample A1	Sample A2	Sample A3
1	Moisture Content (%)	0.010	97.85	99.13
2	Ash Content (%)	<0.02	0.49	0.38
3	Protein Content (%)	<0.04	<0.04	<0.04
4	Carbohydrate Content (%)	0	1.37	0.71
5	Total Fat Content (%)	99.01	<0.02	<0.02
6	Fat Energy (Kcal/100 g)	912.13	0	0
7	Total Energy (Kcal/100 g)	912.13	5.20	2.81
8	Crude Fiber (%)	<0.02	<0.02	<0.02

Notes:

- Data represents the average of three repetitions.
- A1 = Fresh CPO sample; A2 = Liquid waste sample 1 (recycled); A3 = Final liquid waste sample.

Tabel 2. Proximate Analysis Results of PKS PT CG Samples

No	Analysis Item	Sample A1	Sample A2	Sample A3	Sample A4
1	Moisture Content (%)	0,012	98,24	98,7	99,84
2	Ash Content (%)	<0,02	0,48	0,35	0,08
3	Protein Content (%)	<0,04	<0,04	<0,04	<0,04
4	Carbohydrate Content (%)	0	1,32	0,68	0,08
5	Total Fat Content (%)	98,98	<0,02	<0,02	<0,02
6	Fat Energy (Kcal/100 g)	898,92	0	0	0
7	Total Energy (Kcal/100 g)	898,92	5,21	2,76	0,32
8	Crude Fiber (%)	<0,02	<0,02	<0,02	<0,02

Notes:

- Data represents the average of three repetitions.
- A1 = Fresh CPO sample; A2 = Liquid waste sample 1 (recycled-1); A3 = Liquid waste sample 2 (recycled-2); A4 = Final liquid waste sample.

The proximate data for CPO and waste samples obtained from PT ANM and PT CG are nearly identical. Protein and carbohydrate content were not detected in either the CPO or its waste samples. The fat content in CPO is high but decreases sharply in the waste, following the same pattern as energy content. The high energy

content in CPO is attributed to its fat content. Fiber content is very low (<0.02%) in both CPO and its waste. Based on this proximate data, CPO and its processing waste are not suitable for development as poultry feed.

Raw materials used for poultry feed typically contain significant amounts of protein, carbohydrates, and fiber. According to **SNI 01-3931-2006**[9] regarding the standard for broiler finisher feed, the requirements for poultry feed are as follows:

- Maximum moisture content: 14.0%
- Minimum crude protein: 18.0%
- Maximum crude fat: 8.0%
- Maximum crude fiber: 6.0%
- Maximum ash: 8.0%
- Calcium (Ca): 0.9–1.20%
- Total phosphorus (P): 0.60–1.00%
- Available phosphorus (P): minimum 0.40%
- Maximum total aflatoxin: 50.00 µg/kg
- Minimum metabolizable energy (ME): 2,900 kcal/kg
- Minimum amino acid lysine: 0.09%
- Minimum methionine: 0.30%
- Minimum methionine + cystine: 0.50%

Based on these requirements, the nutrient content of CPO processing waste is still significantly below the SNI 01-3931-2006 standard.

3.2. β-Carotene Analysis of Samples to Assess the Potential of CPO Processing Waste for Downstream Products

β-carotene is the most abundant carotenoid component in CPO and functions as an antioxidant compound in CPO. This compound is beneficial if utilized as an additive in poultry feed production, with the potential to improve the quality of poultry meat and eggs.

CPO contains a very high level of carotenoid compounds, but during refining and processing into cooking oil, these carotenoid compounds are degraded or lost. The loss of β-carotene in cooking oil production also occurs due to the bleaching process, which is intended to make the oil color more appealing (yellowish and clean).

The β-carotene concentration in this study is presented in Table 3 for samples from PT ANM and in Table 4 for samples from PT CG.

Table 3. β-Carotene Concentration of Samples from PKS PT ANM

No	Sample Code	Sample Name	β-karoten Concentration (mg/Kg)			
			Data-1	Data-2	Data-3	Average
1	A_1	CPO	263.42	261.17	257.21	260.60
2	A_2	CPO Waste-1	25.43	26.47	24.71	25.54
3	A_3	CPO Waste-2	ND	ND	ND	ND

Notes:
ND = Not Detected

Tabel 4. β-Carotene Concentration of Samples from PKS PT CG

No	Sample Code	Sample Name	β-karoten Concentration (mg/Kg)			
			Data-1	Data-2	Data-3	Average
1	A_1	CPO	250.23	251.11	251.27	250.87
2	A_2	CPO Waste-1	20.54	20.42	19.78	20.25
3	A_3	CPO Waste-2	ND	ND	ND	ND
4	A_4	CPO Waste-3	ND	ND	ND	ND

Notes:
ND = Not Detected

From **Tables 3** and **4**, the β-carotene concentration in CPO and Waste 1 (recycled) is categorized as low (below standard). According to the Codex Alimentarius Commission (CAC, 2001), the β-carotene standard is 500-2000 ppm, and as per CAC 2005, the β-carotene concentration in CPO is 400-2000 ppm[10].

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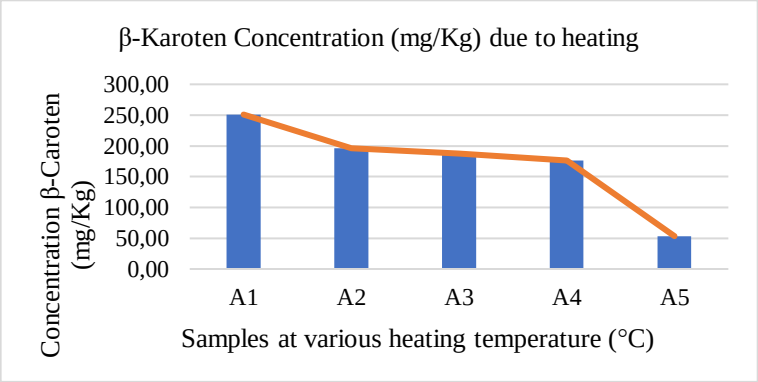
The carotene levels in CPO are influenced by several factors, including variety, maturity level, and the heating process in palm oil processing units. Additionally, poor plantation infrastructure and adverse weather can lead to delays in harvesting (restan), which lowers the quality of CPO[11].

Field data indicates that the recycled waste A1 still contains approximately 3-5% CPO. From the data in **Tables 3** and **4**, the average β-carotene concentration is 25.54% for PT ANM (9.80% of the CPO content) and 20.25% for PT CG (8.07% of the CPO content).

Low β-carotene concentration in CPO and its waste is particularly vulnerable to processes involving high temperatures (above 100°C), as elevated temperatures reduce β-carotene levels. Consequently, β-carotene concentration in poultry feed products may be very low or even depleted.

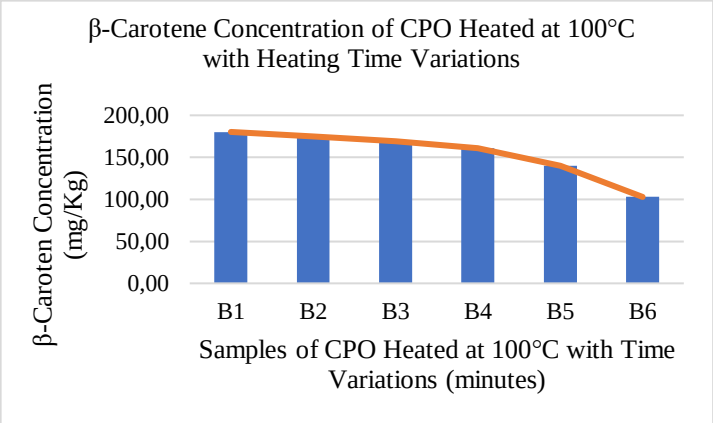
3.3. Analysis of β-carotene Concentration in Samples to Determine the Potential of Palm Oil Mill Waste for Downstream Products

Analysis of β-carotene concentration due to storage and heating treatments was conducted on CPO, while for the waste, no analysis was performed because the waste samples were undetectable after 28 days of storage. The results of the β-carotene analysis due to heating at temperatures of 60-180°C are presented in **Figure** 1. The results of the β-carotene analysis due to heating at temperatures 100°C with heating time variationsare presented in **Figure 2**. The results of the β-carotene analysis due to heating at temperatures 180°C with heating time variationsare presented in **Figure 3**. The results of β-carotene concentration of CPO stored under normal conditions with varying storage durations from 0 to 70 days presented in **Figure 4**. The results of β-carotene concentration of CPO stored in a dark room with varying storage durations from 0 to 70 days.



Notes:
A1 = CPO without heating treatment
A2 = CPO heated at 60°C for 30 minutes
A3 = CPO heated at 100°C for 30 minutes
A4 = CPO heated at 140°C for 30 minutes
A5 = CPO heated at 180°C for 30 minutes

Figure 1. β-Carotene Concentration (mg/Kg) due to Heating 60 – 180ºC



Notes:
B1 = CPO heated at 100°C for 15 minutes
B2 = CPO heated at 100°C for 30 minutes
B3 = CPO heated at 100°C for 45 minutes
B4 = CPO heated at 100°C for 60 minutes
B5 = CPO heated at 100°C for 75 minutes
B6 = CPO heated at 100°C for 90 minutes

Figure 2. β-Carotene Concentration of CPO to Heating at 100°C with Heating Time Variations of 15–90 Minutes

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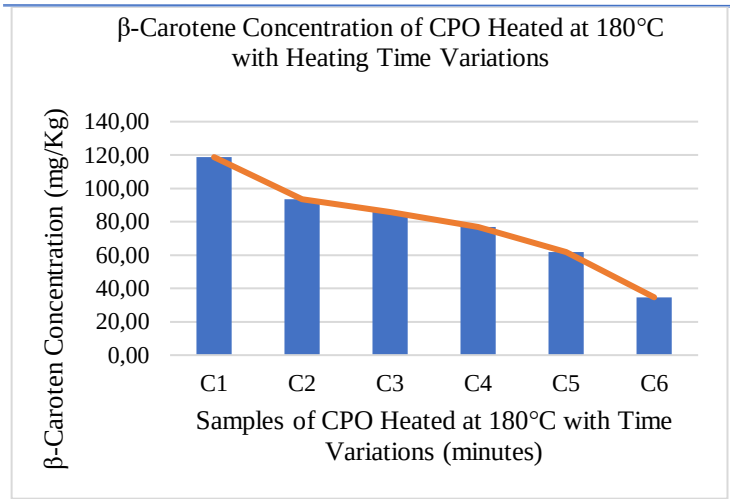
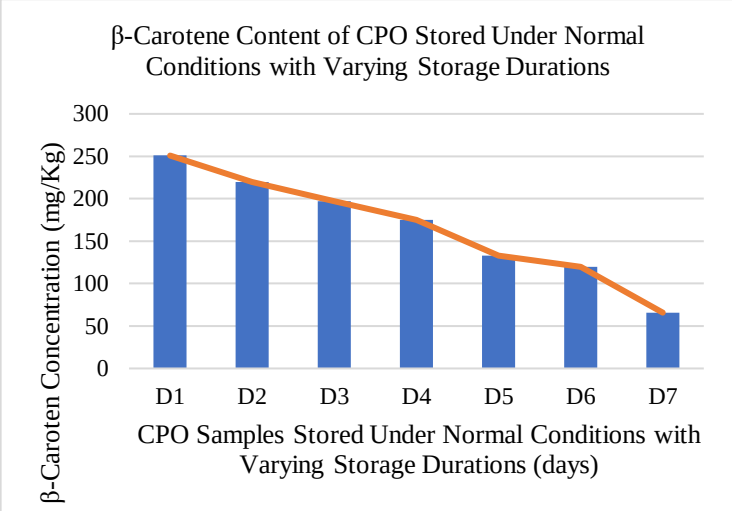


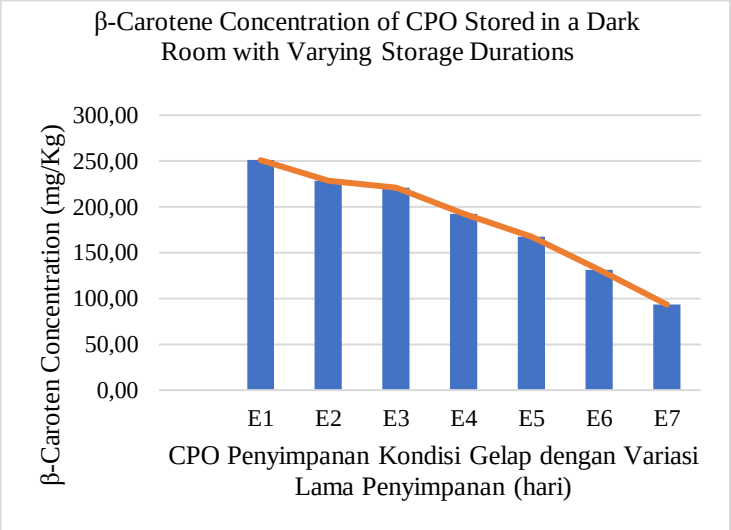
Notes:
C1=CPO heated 180ºC for 15 minutes
C2= CPO heated 180ºC for 30 minutes
C3= CPO heated 180ºC for 45 minutes
C4= CPO heated 180ºC for 60 minutes
C5= CPO heated 180ºC for 75 minutes
C6= CPO heated 180ºC for 90 minutes

Figure 3. β-Carotene Concentration of CPO to Heating at 180°C with Heating Time Variations of 15–90 Minutes



Notes:
D1 = CPO stored for 0 days
D2 = CPO stored for 7 days
D3 = CPO stored for 14 days
D4 = CPO stored for 28 days
D5 = CPO stored for 42 days
D6 = CPO stored for 56 days
D7 = CPO stored for 70 days

Figure 4. β-Carotene Concentration of CPO Stored Under Normal Conditions with Varying Storage Durations from 0 to 70 Days



Notes:
E1= CPO stored for 0 days
E2= CPO stored for 7 days
E3= CPO stored for 14 days
E4= CPO stored for 28 days
E5= CPO stored for 42 days
E6= CPO stored for 56 days
E7= CPO stored for 70 days

Figure 5. β-Carotene Concentration of CPO Stored in a Dark Room with Varying Storage Durations from 0 to 70 Days

In **Figure 1**, heating CPO above 140°C will significantly reduce β-Carotene. A different result occurs when heating is done below 140°C. In **Figure 3**, the decrease in β-Carotene concentration at a temperature of 180°C shows a more significant reduction compared to the decrease at 100°C (**Figure 2**). In **Figure 4**, the reduction in β-Carotene concentration during storage under normal conditions occurs more rapidly than during storage in the dark (**Figure 5**) because, under normal conditions, the sample is exposed to light, which contains UV rays.

Referring to the research report by Sahidin *et al*. (2000)[12], it is explained that the degradation of β-carotene by heat that is not too high (below 140°C) produces 6 main volatile compounds, namely 2-methyl hexane, 3-methyl hexane, heptane, cyclo-ktanone, toluene, and (ortho, meta, or para) xylene. According to the study by Byers *et al.* (1983)[13], at high heating temperatures (around 170°C), β-carotene undergoes degradation into non-volatile compounds, including (1) 1,12-bis-(2,6,6-trimethylcyclohex-1-enyl)-3,6,10-trimethyl dodeca-1,3,5,7,9,11-hexaene; (2) 1,12-bis-(2,6,6-trimethylcyclohex-1-enyl)-3,7-dimethyl dodeca-1,3,5,7,9,11-hexaene; (3) 1,6-bis-(2,6,6-trimethylcyclohex-1-enyl)-3-methylcyclohex-1,3,5-triene; (4) 1,6-bis-(2,6,6-trimethylcyclohex-1-enyl)-hexa-1,3,5-triene; (5) 1,12-bis-(2,6,6-trimethylcyclohex-1-enyl)-3,7,10-trimethyldodeca-1,3,5,7,9,11-hexaene; (6) 3,7-dimethyl-8-toluenyl-1-(2,6,6-trimethylcyclohex-1-enyl)-octa-1,3,5,7-tetraene; (7) β-apo-13-carotenone; (8) dihydro-aktinideolide; (9) 2-dihydroxy-methyl-1,3,3-trimethyl-1,2-cyclohexadiol; (10) β-apo-14-carotenol; and (11) 1-(2,6,6-trimethylcyclohex-1-enyl)-3-hydroxy-2-butanol.

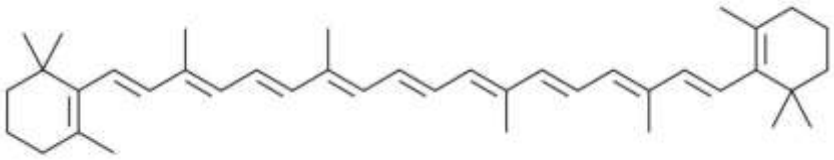


Figure 6. Structure of β-Carotene; referring to Rodrigues, 2004

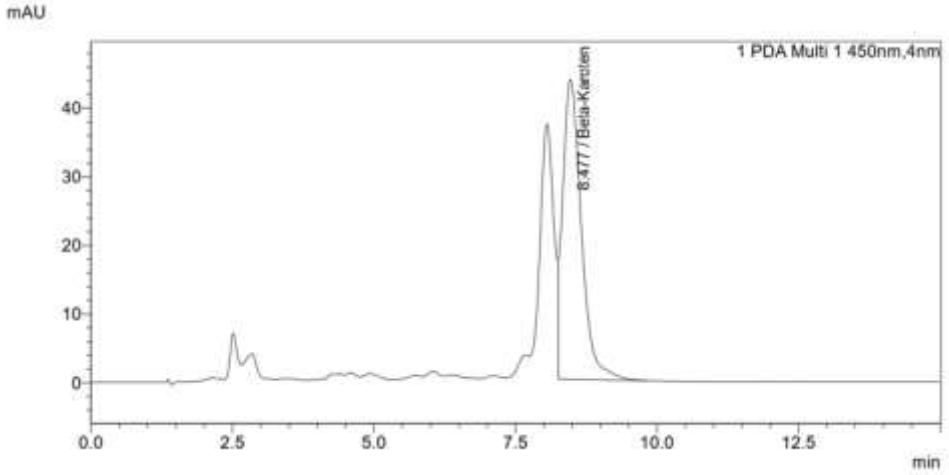


Figure 7. Chromatogram of β-Carotene analysis at a wavelength of 452.3 nm, UV detector

3.4. Determination of the Reaction Order of ß-Carotene

The determination of the reaction order of β-carotene was performed using the graphical method by observing the r^2 value of the graph that approaches 1 (100%).

For order 0, the graph follows the equation:

$$[A] = [A]_0 - kpt \quad or \quad (a - x) = a - kpt$$

For order 1, the graph follows the equation:

$$ln\,[A] = ln\,[A]_0 - kpt \quad or \quad ln\,(a - x) = ln\,a - kpt$$

For order 2, the graph follows the equation:

$$\frac{1}{[A]} = \frac{1}{[A]_0} + pkt \quad or \quad \frac{1}{(a-x)} = \frac{1}{a} + pkt$$

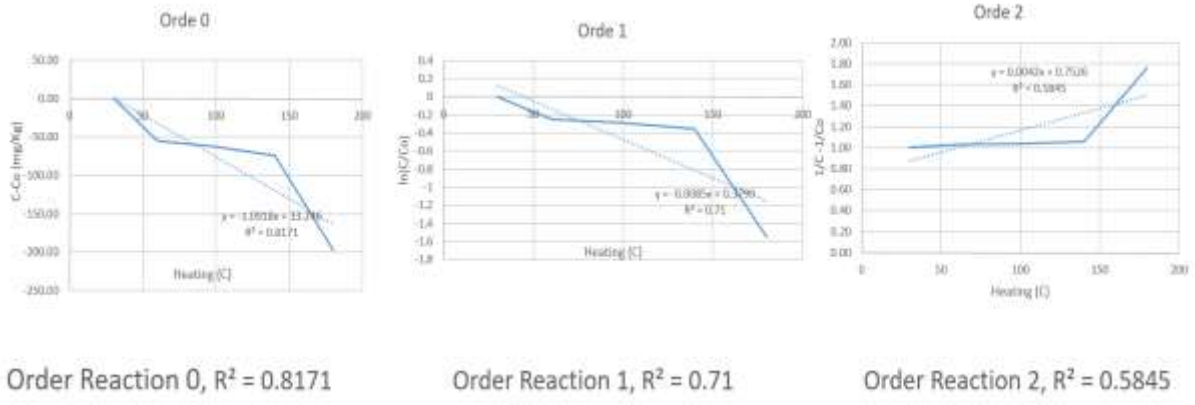


Figure 8. Reaction Order of β-Carotene Under Heating Treatment 60 – 180°C

The highest R^2 value = 0.8171, obtained in the zero-order reaction.

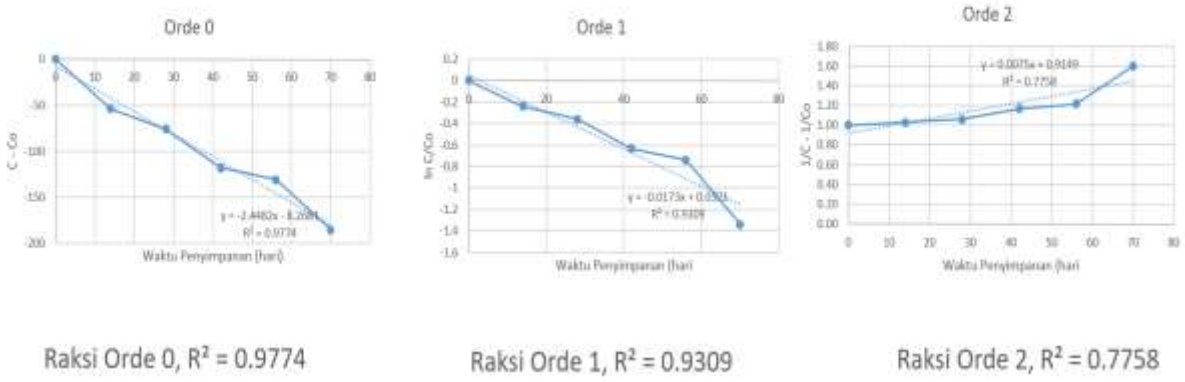


Figure 9. Reaction Order of β-Carotene During Storage in a Normal Room

The highest R^2 value = 0.9774, obtained in the zero-order reaction.

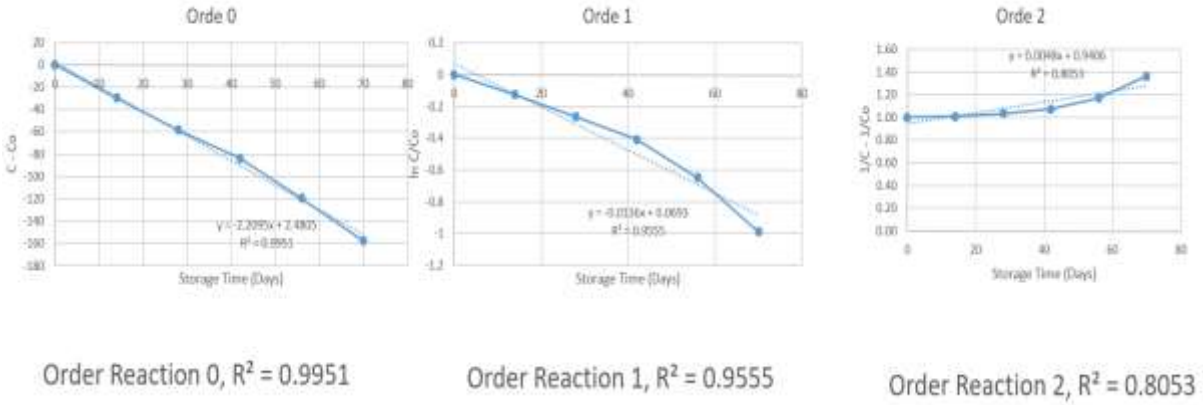


Figure 10. Reaction Order of β-Carotene During Storage in a Dark Room

The highest R^2 value = 0.9951, obtained in the zero-order reaction.

Table 5. Reaction Order of β-Carotene

No	Treatment	R² Value			Order
		Order 0	Order 1	Order 2	
1	Heating 60 - 180°C	**R² = 0.8171**	R² = 0.7100	R² = 0.5845	0
2	Normal Storage 14–70 days	**R² = 0.9774**	R² = 0.9309	R² = 0.7758	0
3	Dark Room Storage 14–70 days	**R² = 0.9951**	R² = 0.9555	R² = 0.8053	0

The results of determining the reaction order of β-carotene are shown in **Figures 8–10** and **Table 5**. Based on the highest R² value (approaching 100%), the reaction order of β-carotene is zero-order (for heating at 60–180°C and storage under normal and dark conditions).

4. Conclusions

The CPO samples from the two palm oil mills studied, namely PT Agro Niaga Amanah (Lebak, Banten) and PT Condong Garut (West Java), have low β-carotene content according to the standards of the Codex Alimentarius Commission (CAC, 2001; with a standard of 500–2000 ppm, and CAC, 2005; with a standard of 400–2000 ppm). The CPO concentrations in these mills are only about 250 ppm (below 400 ppm). The concentration in the recycled waste is 20–25 ppm.

Based on the proximate analysis results regarding the concentrations of protein, carbohydrates, energy, and crude fiber, CPO waste is not recommended as a substitute material for poultry feed production due to its low nutrient content (below 10%). Referring to other studies, downstream development for energy utilization could be a viable alternative.

Considering the β-carotene content in the recycled CPO waste, it can be recommended as an additive material for poultry feed production to improve the quality of meat and eggs. However, it is crucial to note that the raw material should not be stored for more than four weeks (one month) since the β-carotene content in the raw material becomes undetectable after one month.

5. References

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