The Effect of Color on β-Carotene Content in the Processing Stage of Red Palm Olein (RPOn)

Deny Sumarna*, Dutho Suh Utomo Utomo, Nova Solina Purba, Taufikillah Romadhon, Nuzlul Musdalifah

Department of Agricultural Product Technology, Faculty of Agriculture, Mulawarman University, Jl. Tanah Grogot, 75119 Samarinda, Indonesia
*dsumarna@faperta.unmul.ac.id

Abstract. This study investigated how the color and β-carotene content of crude palm oil (CPO) vary as it is processed into Red Palm Olein (RPOn). Significant changes in color and β-carotene content (measured by ΔE values) were observed at each refining stage, including water degumming (ΔE = 8.15), fractionation (ΔE = 7.31), and deodorization (ΔE = 6.88). β-carotene decreased by 2.77 ppm at the water degumming step and by an additional 1.92 ppm at the fractionation stage. Interestingly, during deodorization, the β-carotene content slightly increased to 51.39 ppm compared to the initial value of 53.59 ppm. The final RPOn product retained a β-carotene content of 53.48 ppm, nearly matching the initial CPO level despite notable color changes. This study confirms that proper refining techniques can retain most of the nutrients in palm oil but significantly affect the color characteristics.

Keywords: CPO, RPOn, β-carotene, oil refining, color change

1 Introduction

Color is an important indicator of the quality of food ingredients, including palm oil. The color of food ingredients can reflect the content of bioactive and functional components, such as carotenoids and anthocyanin pigments, which not only provide color but also health benefits [1]. In palm oil, carotenoids are the primary compounds responsible for its distinctive bright orange color, especially β-carotene, which is known to have antioxidant effects and is important for human health, including maintaining healthy eyes and skin [2] - [3].

Crude palm oil (CPO) is rich in minor components such as beneficial β-carotene and tocopherols. However, the palm oil refining process, which involves high temperatures and chemicals, can degrade these components [4]. One of the main stages in the CPO refining process is bleaching, which is designed to remove color from oil. Unfortunately, this process also removes most of the carotene content; therefore, the final product loses many of the nutritional benefits of crude CPO [5] – [6].

K. P. Candra et al. (eds.), *Proceedings of the International Conference of Tropical Agrifood Feed and Fuel 2024 (ICTAFF 2024)*, Advances in Biological Sciences Research 47,
https://doi.org/10.2991/978-94-6463-825-7_10

As awareness of the importance of the nutritional value of palm oil, especially concerning the content of its minor components, has increased, various refining techniques aimed at maintaining these components have been developed. One approach is temperature modification and elimination or reduction of the bleaching process to maintain the carotenoid content, producing a final product known as Red Palm Olein (RPOn) or red palm oil [7] – [8]. This product has a higher β-carotene content and is considered more nutritious than conventional palm oil [9] – [11].

Research on the effects of heat and chemical treatments on the CPO refining process has shown that modifications to the refining process can increase the content of minor components, such as β-carotene and tocopherol, which can be visually identified through changes in oil color [12]. Therefore, further research is needed on the effect of each stage of the CPO processing process on β-carotene content, especially based on color measurements (Lab color), as the main indicator for determining changes in the nutrient content of palm oil during the processing process.

2 Material and Methods

2.1 Material

The materials used included processed-ready CPO sourced from a palm oil processing plant in East Kalimantan, citric acid, ethanol, NaOH, distilled water, phenolphthalein indicator (PP), and isooctane. The main equipment used consisted of a heating tank/reactor for water degumming, dry fractionation apparatus, deodorization unit, UV-Vis spectrophotometer, Chromameter CR300, and other laboratory support tools.

2.2 RPO Processing

The RPOn processing in this study consists of water degumming, fractionation, and deodorization processes.

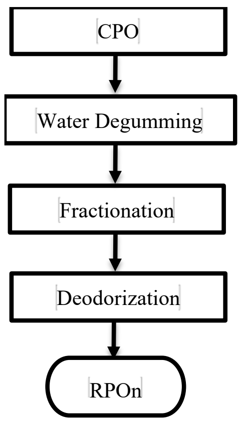

Fig. 1. RPO processing process

CPO (P1). CPO is a type of palm oil obtained from the extraction of mesocarp or mustard palm pulp

Water degumming (P2). Water degumming is performed to remove phosphatides (gum) from crude vegetable oils, such as soybean oil or palm oil, using water. In this process, water was added to the crude oil and heated to 60–70°C while stirring using a magnetic stirrer. A solution of 85% phosphoric acid was added at a concentration of 0.05% (v/w). The oil mixture was then transferred into a separating funnel and hot water at 60–70°C was sprayed evenly over the surface of the oil. The mixture was left to stand until the separation of the oil, gum, and water occurred. The gum that accumulated at the bottom of the separating funnel was discharged by opening the middle valve. The neutrality of the wash water was checked using a litmus paper. If the water was not neutral, the washing process was continued by adding hot water until it reached a neutral condition.

Fractionation (P3). Dry fractionation was used as the fractionation method. The dry fractionation process was carried out to separate the oil into two fractions based on their different melting points, without the use of solvents or chemicals. These fractions were the liquid fraction (olein) and solid fraction (stearin). The CPO was first heated to a temperature of 80–90°C to remove moisture and then cooled in a water bath to a temperature of 20°C. Olein has a lower melting point and remains in liquid form, whereas stearin has a higher melting point and precipitates as a solid. The olein fraction was collected and further processed through deodorization to produce Red Palm Olein (RPOn).

Deodorization (P4). This method is one of the stages of the oil purification process that aims to remove unwanted odors, tastes, and volatile compounds from vegetable oils. This process was carried out by heating the oil to a temperature of 80^{0}C with a vacuum pressure of 80 mbar for 1 h, which allowed volatile compounds, such as free fatty acids, aldehydes, and ketones, to evaporate and exit the oil.

RPOn (Red Palm Olein). RPOn is a liquid fraction palm oil, in this study it goes through several stages of the process, including water degumming, fractionation, and deodorization.

2.3 β-Carotene and Color Analysis

Determination of β-Carotene. β-carotene content was analyzed using a UV-visible spectrophotometer at a wavelength of 443 nm (Shimadzu UV-1800, double beam, Japan). Each 0,1 g of oil sample was diluted with n-hexane to obtain a clear solution that was suitable for spectrophotometric analysis. The absorbance of the solution was measured at 443 nm using n-hexane as blank. The β-carotene concentration was expressed as mg/kg of oil.

Total Color Difference [13]. Color measurements were performed using a Chromameter CR300 Minolta (Konica Minolta Sensing Singapore Pte Ltd., Pandan Gardens, SG). Oil samples (0,1 g of the processing process were placed on transparent plates and measured using a chromameter. A color model system using CIE Lab was used to describe human visual perception. Components from the CIE Lab produce L* (lightness), a* (redness), and b* (yellowness) values. The L* (lightness) value indicates brightness from dark to light (0-100). The value of a*(redness) indicates the chromatic color from red to green, with a^+ for red and a^- for green. The value of b* (yellowness) indicates a chromatic color from blue to yellow, with b^+ indicating yellow and b^- indicating blue. The color value of CPO was used as a reference. The total color difference was calculated using the following equation:

$$\Delta E = \sqrt{(\Delta L *)^2 + (\Delta a *)^2 + (\Delta b *)^2}$$

Note: ΔE = color changes; ΔL* = difference in lightness (L*); Δa* = difference in the red-greenness (a*); Δb* = difference in the yellow-blueness (b*)

3 Result and Discussion

3.1 Chromatic Color Change from Red to Green (Δa)

A positive value of a* indicates a shift towards the red color, whereas a negative value indicates a shift towards the green color. Δa*= (a* standard sample–a*) = Difference between red and green (+=red, -= green)

The changes in at each stage of the purification process are shown in the following table.

Table 1. Values a* and Δa a* in the RPOn processing process

Process	a*	Process color difference	Δa*
P1	6.58	P2 - P1	-3.99
P2	2.59	P3 - P1	-3.57
P3	3.01	P4 - P1	-3.41
P4	3.17	P3 - P2	-3.57
		P4 - P2	0.58
		P4 – P3	0.16

Based on the data presented in Table 1, which details the a* and Δa* values during the processing of Red Palm Olein (RPOn), it is evident that P1 (CPO) has the highest a* value of 6.58. This shows that the color of crude palm oil tends to be redder. After the P2 (Water Degumming) process, the a* value dropped dramatically to 2.59, indicating that the color of the oil was closer to green than red. This shows that the gum removal process has a significant effect on the color change. At P3 (fractionation), there was a slight increase to 3.01, which indicates a slight recovery in red color after fractionation, and P4 (deodorization) had an a* value of 3.17, indicating that after the deodorization process, which is the final product of Red Palm Olein (RPOn), there was a slight increase in red color compared to fractionation, although this value was still lower than that of the original CPO.

Table 1 shows that the Δa* value decreased in red during the processing process. In the transition between P1 (CPO) and P2 (Water Degumming), Δa* is also large, i.e. -3.99, indicating that the process of degumming greatly affects the color change. The removal of phospholipids, rubber, and impurities involves the use of water. This process often reduces some of the color pigments dissolved in water or compounds that contribute to the color [8], [4]. A smaller color change occurs at the next stage, with a very small Δa*between P4 and P2 and P4 – P3, 0.58 and 0.16, respectively, indicating that process fractionation and deodorization have less impact on color change than the initial process.

The values of a* and Δa* indicate that the water degumming (P2) process has the greatest impact on color change, which is indicated by a large decrease in the value of a*. Finally, the RPOn (P4) product has a color closer to green, with a lower a* value than the initial CPO. The color change between the subsequent stages of processing was smaller, indicating that a large change in the color component occurred in the early stages of refining.

After fractionation, Δa* increased slightly to 3.01. This process separates the solid fraction (stearin) and liquid fraction (olein), with the red pigment tending to be more concentrated in the olein fraction. This small increase can be attributed to the redistribution of pigments during fractional separation [14] – [15].

The deodorization process employs high temperatures to eliminate volatile compounds, including carotenoid pigments, responsible for the color of the oil. Although the primary purpose of deodorization is to reduce odors, high temperatures can also lead to the degradation of red pigments. However, in this instance, there was only a slight increase in redness, as heating does not entirely destroy the pigments [16, 9].

Changes in the value of Δa* show how each stage of palm oil processing affects the intensity of the red color (component a*). Water degumming exerts the greatest influence, with a drastic decrease in red intensity, which may be caused by the removal of water-soluble pigments and compounds. Fractionation slightly increases the red color owing to the redistribution of pigments, while deodorization causes the degradation of heat-sensitive pigments. Fractionation (P3) and deodorization (P4) resulted in a small increase in red intensity but was not significant enough to restore color close to the initial CPO.

The final product after deodorization (Red Palm Olein) has a considerable difference in red color from CPO; however, the fractionation and deodorization processes provide a slight improvement compared to the yield after degumming. This analysis indicates that the most significant change in the intensity of red occurs in the degumming process, whereas later stages provide smaller changes in color.

3.2 Chromatic color change from blue to yellow (Δb)

A positive value of b* indicates a shift towards blue, while a negative value indicates a shift towards yellow. Δb*= (b* sample–b* standard) = blue and yellow differences (+= blue, − = yellow).

The change in the value of b at each stage of the purification process is shown in the following table:

Table 2. Values of b* and Δb* in the RPOn processing process

Process	b*	Process	Δb*
P1	18.36	P2 - P1	-7.06
P2	11.3	P3 - P1	-6.35
P3	12.01	P4 - P1	-5.97
P4	12.39	P3 - P2	0.71
		P4 - P2	1.09
		P4 - P3	0.38

Table 2 shows that P1 (CPO) has a b* value of 18.36, which indicates that crude palm oil tends to have a yellow color. After the P2 (Water Degumming) process, the b* value dropped drastically to 11.3, indicating that the yellow color in palm oil was significantly reduced after the degumming process. P3 (fractionation) results in a slight increase in the value of b* to 12.01, which indicates that fractionation restores a slight yellow color to the oil. P4 (deodorization), which is the final product, yielded a b* value of 12.39, which indicates a slight further improvement in yellow color, but much lower than the initial CPO.

The processing of CPO through the water degumming process (P2–P1 /water degumming–CPO) produces a Δb* of -7.06, indicating that the degumming process causes a large decrease in the intensity of the yellow color. Water degumming significantly reduced the intensity of the yellow color of the palm oil. This process may remove water-soluble pigments and phospholipids, which contribute to a decrease in the yellow color [9] – [17]. In the subsequent process, namely in the fractionation process (P3 - P1 / Fractionation - CPO), it produces a Δb* of -6.35, indicating that the fractionation process also produces a large change in color, although not much compared to the degumming process. This process separates the solid and liquid fractions, where the yellow pigment may be more concentrated in the olein fraction, resulting in a slight increase in the intensity of the yellow [1] – [18]. P4–P1 (deodorization–CPO) shows a change in delta b* of -5.97, which also shows a significant decrease in the intensity of the yellow color, indicating that the final product (Red Palm Olein) loses most of the intensity of the yellow color present in the initial CPO.

Water Degumming (P2) had the greatest influence on the decrease in the yellow intensity, as indicated by the large decrease in the b* value.
Later stages (fractionation and deodorization) had a smaller impact on the yellow color, suggesting that most of the color change occurred during the early stages of the purification process. These data show that the most significant decrease in yellow intensity occurs during the degumming process, with little recovery in the later stages; however, the final product still has a much lower yellow intensity than CPO.

3.3 Change from dark to light (ΔL)

A positive value of L* indicates a shift towards blue, while a negative value indicates a shift towards yellow. ΔL*= (L* sample–L* standard) = Difference between dark and light (+= dark, -= light)

Changes in the L value at each stage of the purification process are shown in the following table:

Table 3. L* and L* delta values in RPOn processing

Process	L*	Process	ΔL *
P1	25.88	P2 - P1	0.85
P2	26.73	P3 - P1	0.56
P3	26.44	P4 - P1	0.3
P4	26.18	P3 - P2	0.56
		P4 - P2	-0.55
		P4 - P3	-0.26

Based on the data provided in Table 3, the following is an analysis of L* and ΔL* values during the processing of Red Palm Olein (RPOn). P1 (CPO) has an L* value of 25.88, which indicates the initial brightness of the crude palm oil. A lower L* value indicates darker oil. P2 (Water Degumming) experienced an increase in the L* value to 26.73, indicating that the oil became brighter after degumming. P3 (fractionation) decreased slightly to 26.44, indicating that fractionation restored some of the oil darkness, but was still lighter than the initial CPO. P4 (deodorization) yields an L* value of 26.18, which indicates that after the deodorization process, the oil is slightly darker than after fractionation but remains lighter than raw CPO.

P2–P1 (water degumming–CPO) produced a ΔL* of 0.85, indicating a significant increase in the brightness of the oil after degumming. P3–P1 (Fractionation-CPO) shows a ΔL* of 0.56, suggesting that fractionation results in the oil being slightly darker than the degumming outcome, yet still lighter than the original CPO. P4–P1 (deodorization–CPO) produces ΔL* by 0.3, indicating that deodorization makes the oil slightly darker, although not significant. P3 - P2 (Fractionation-Degumming) shows ΔL* of -0.55, which indicates that fractionation slightly reduces the brightness produced by degumming. This small drop indicates that the fractionation process separates the pigments that can affect the brightness. The liquid olein fraction may be slightly darker than the stearin fraction [1] – [8].

P4–P2 (deodorization–degumming) showed a ΔL* of -0.26, which also showed a slight decrease in brightness after deodorization compared to the degumming results. P4–P3 (deodorization–fractionation) showed a ΔL* of -0.26, indicating that the brightness difference between fractionation and deodorization was very small.

The Water Degumming (P2) process provides the greatest increase in brightness, and the oil becomes brighter after this process. This suggests that degumming significantly

reduces the amount of dye in the oil, which makes it darker. Fractionation (P3) and deodorization (P4) caused slight darkening, but the difference in brightness between the processes was relatively small compared with the changes that occurred in the degumming stage. Deodorization (P4) showed that palm oil remained lighter than CPO, although it underwent slight darkening during this process. This suggests that this process does not significantly affect brightness. Although high temperatures can cause pigment degradation, this decline is still within a moderate range, suggesting that most pigments that cause dark colors may have already degraded before this process [14], [18].
The ΔL* value shows that the water degumming process has the greatest impact on increasing the brightness of the palm oil. Fractionation and deodorization caused only a small change in brightness, while the final product of Red Palm Olein retained a lower brightness than the degumming result but was still brighter than raw CPO. This change in brightness reflects the degradation of pigments, such as carotenoids, during processing [14], [17] – [18].

3.4 Relationship Between β-Carotene Content and L*, a* and b*

Figure 2. shows the relationship between β-carotene content and Lab* color value during the palm oil refining process. The L value (brightness) did not show a clear pattern with β-carotene, which suggests that the brightness of palm oil is not necessarily directly correlated with the β-carotene content.

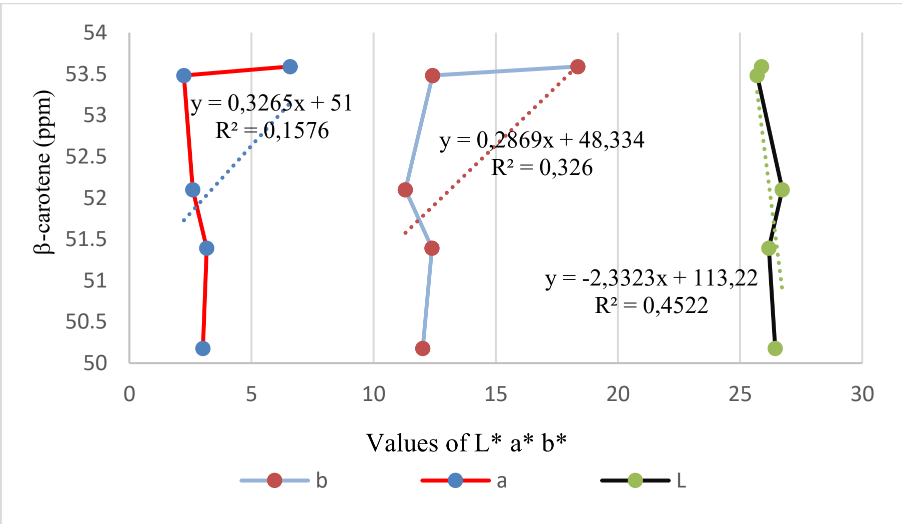

Fig. 2. Relationship between β-carotene content and color values L*, a* and b*

The a* value (red-green) indicates that a* decreased with increasing β-carotene content; however, there was an extreme value at the highest β-carotene content (6.58). This suggests that higher β-carotene content may reduce the red component of palm oil.

However, at certain concentrations, the red color increased significantly. Meanwhile, β-carotene showed an increasing trend in the value of b * (yellow-blue). The higher the β-carotene content, the more intense the yellow color component, which corresponds to the properties of β-carotene as a yellow-orange pigment. Overall, the **a*** and **b*** values in palm oil color can be used as visual indicators of β-carotene content, especially since β-carotene contributes to the yellow and red color spectra.

The Coefficient of Determination (R^2) measures how well a linear regression model explains variations in data. A higher R^2 value is closer to 1, indicating that the model is better at explaining variations, whereas a lower value indicates that the model is less able to explain the variables involved. Typically, an R^2 value ≥ 0.50 is considered significant in many studies [15] – [17]. In the context of the relationship between the Lab * values of β-carotene and palm oil ($R^2 = 0.15$), this value means that only 15% of the variation in color intensity can be explained by the regression model, indicating a very weak relationship. This is generally considered insignificant, especially in studies that aim to find a strong correlation between palm oil color and β-carotene content [14], [19]. $R^2 = 0.33$, with 33% variation described, and this relationship is moderately weak. Despite this correlation, these results are still less than ideal for prediction purposes or robust models, which are typically expected in chemical or biochemical studies [17]. $R^2 = 0.45$; this model was close to the category of moderate relationships. However, in many studies examining the relationship between carotenoid pigments such as β-carotene and color intensity, R^2 values greater than 0.50 are usually expected to show a strong association [14] – [15].

4 Conclusion

From the analysis of palm oil (CPO) to Red Palm Olein (RPOn) processing, it was shown that each stage of the refining process has a significant impact on β-carotene content and color change (ΔE). The largest decline occurred in the water degumming and fractionation stages, resulting in the loss of most carotenoids and other minor compounds. However, the deodorization process provided a slight recovery of the carotenoid content, while the final product (RPOn) almost returned to its initial value. This shows that, despite degradation during the process, efficient refining can retain most of the nutritional content of palm oil.

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