Journal of Agriculture (JoA)
Volume: 05 | Number 02 | July 2026
E-ISSN: 2829-2421
https://doi.org/10.47709/JoA.v5n02.8661

Comparison of Polymer (*Polypropylene*) and Boiler Ash (*Bottom Ash*) as Adsorbents for Beta Carotene Adsorption in CPO

Rafiko Alfahri Purba[1], Rafael Remit Winardi[2]
[1,2]*Institut Teknologi Sawit Indonesia, Medan, Sumatera Utara*
Corresponding Email: rafikoalfahri@gmail.com[1], rafael@itsi.ac.id[2]

Received: 2026-05-25
Accepted: 2026-07-01
Publication: 2026-07-04

Abstract
Crude Palm Oil (CPO) contains abundant natural beta-carotene compounds, but under heat and oxygen exposure during storage, these antioxidant compounds can change into pro-oxidants that accelerate oil rancidity. The bleaching process using the adsorption method is an effective way to reduce these pigments, thereby increasing the oxidative stability of CPO. This study aims to compare the effectiveness of environmentally friendly granular adsorbents prepared from a combination of solid waste (palm oil mill boiler ash, bottom ash) activated with HCl and Aquades. Polypropylene was used to adsorb beta-carotene via the column method. The experimental design used a non-factorial Completely Randomized Design (CRD) by varying the ratio of the polymer mixture to the boiler ash, namely S0 (1:1), S1 (1:3), and S2 (3:1), using a column flow rate of 0.125 ml/second at an oil temperature of 60°C. The CPO quality parameters evaluated included beta carotene content, Deterioration of Bleachability Index (DOBI) value, Free Fatty Acid (FFA) content, and water content. Based on statistical results from the One-Way ANOVA test, variations in adsorbent composition had a significant effect on the reduction in beta-carotene content and the DOBI value. Conversely, variations in the ratio did not significantly affect the FFA and water content parameters. Treatment S1 (ratio 1:3) was identified as the optimal composition, producing the highest absorption effectiveness and reducing beta-carotene levels and DOBI values. All treatments after the adsorption process were shown to maintain CPO quality parameters at acceptable standards without compromising the oil's chemical stability. Based on these findings, increasing the silica content of boiler ash was empirically shown to increase porosity and the number of active sites for the adsorption of non-polar organic compounds in CPO.

Keywords: Adsorbent; Adsorption; Beta Carotene; Boiler Ash; CPO; Polypropylene

Introduction

Indonesia is the world's largest producer and exporter of palm oil. Palm oil (Elaeis guineensis) is a major plantation product in Indonesia, expected to contribute to supporting the national economy sustainably. Crude Palm Oil (CPO) is a vegetable oil that can be used as a source of terpenoid compounds in the form of natural carotenoids that function as pro-vitamin A. The carotenoid composition contained in CPO is estimated to be 15-300 times higher than the composition found in carrots and green leafy vegetables. Crude Palm Oil also contains compounds such as saturated and unsaturated fatty acids, tocopherols, tocotrienols, phospholipids, and phytosterols. CPO that will be used as food products such as cooking oil requires prior processing to meet established standards. One processing stage is bleaching, which aims to reduce carotene levels through an adsorption process. Adsorption has the advantage of being applied in the processing of various materials, providing answers to applicable regulatory requirements. Several

This is an Creative Commons License This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

Journal of Agriculture (JoA)
Volume: 05 | Number 02 | July 2026
E-ISSN: 2829-2421
https://doi.org/10.47709/JoA.v5n02.8661

adsorbents have been investigated such as zeolite, silica gel and activated carbon which can be good adsorbents (Nainggolan, 2024)

The beta-carotene content in CPO significantly affects the color of crude palm oil, requiring a refining process to improve oil quality. Excessive beta-carotene can cause the oil to become darker in color and reduce its oxidative stability during storage and heating. Therefore, the adsorption process is an effective method for reducing the carotene pigment content in CPO (Saputra Harahap et al., 2020).

An adsorbent is a solid substance that can absorb specific components from a fluid phase. Most adsorbents are highly porous materials, and adsorption occurs primarily on the pore walls or at specific locations within the particle. Because the pores are typically very small, the internal surface area is several orders of magnitude larger than the external surface, reaching up to 2000 m^3/g. Commercially used adsorbents are divided into two groups: polar and nonpolar. Polar adsorbents are also called hydrophilic, while nonpolar adsorbents are also called hydrophobic(Fatimah & Siswarni, 2013).

Research into adsorbent development continues, utilizing inexpensive and readily available alternative materials, particularly industrial waste. Using waste as an adsorbent is considered capable of reducing production costs while mitigating environmental pollution caused by the accumulation of industrial solid waste (Ayu et al., 2022).

Boiler Ash: According to (Marfitania et al., 2024) the use of boiler ash as an adsorbent can reduce carotene levels with a maximum efficiency of 97.3%. Boiler ash contains 31.45% SiO2, 15.2% CaO, and 1.6% Al2O3. The adsorption capacity of boiler ash is derived from these oxides. reported that boiler ash from palm oil mills contains 40% SiO2 and 6% Al2O3, which has the potential to be recycled into new products with significant economic value.

Adsorption is the process of separating specific components from a fluid by transferring them to the surface of an absorbing solid (adsorbent) (Ayu et al., 2022).In this study, adsorption is one of the most widely used and inexpensive alternative technologies for separating beta-carotene from crude palm oil (CPO). Numerous adsorbents have been tested to adsorb beta-carotene from CPO, including rice husk ash, silica gel, alumina, clay, palm kernel shells, and activated carbon (Misran et al., 2016). The excessively high beta-carotene content in crude palm oil (CPO) causes the oil to darken in color and reduces its oxidation stability during storage and heating. This can trigger pro-oxidant properties that accelerate oil rancidity. Furthermore, beta-carotene is often destroyed by heat during conventional refining processes in cooking oil production. An alternative, inexpensive, and environmentally friendly beta-carotene separation technology is needed. Therefore, an innovation was made by creating a granular bio-adsorbent from a mixture of boiler ash waste and polypropylene polymer. This study used a non-factorial Completely Randomized Design (CRD) with three treatments varying the ratio of polymer to boiler ash: S0 (1:1), S1 (1:3), and S2 (3:1). Based on the statistical analysis of the One-Way ANOVA Test and the discussion of the results presented in the report, your research hypothesis can be formulated explicitly. The statistical test results show a significant difference between the treatments (especially between S1 and S2). Increasing the proportion of boiler ash significantly increased the adsorption capacity of beta carotene and decreased the DOBI value. The results of the ANOVA test showed that the significance value for ALB ($p = 0.070$) and water content ($p = 0.661$) was greater than 0.05 ($p>0.05$), which means that the variation in the adsorbent ratio did not have a real or statistically significant effect on these two parameters.

Previous studies have tested various types of low-cost adsorbents to adsorb beta carotene from CPO, such as rice husk ash, silica gel, alumina, clay, palm kernel shells, activated carbon, and

This is an Creative Commons License This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

Journal of Agriculture (JoA)
Volume: 05 | Number 02 | July 2026
E-ISSN: 2829-2421
https://doi.org/10.47709/JoA.v5n02.8661

boiler ash itself. However, the use of these materials is usually applied singly or without a specific structural binder/combinant. There has been no research that formulates boiler ash (after being activated with HCl acid and NaOH base) by homogenizing/mixing directly with melted Polypropylene polymer to form an adsorbent in granular form. The use of Polypropylene polymer as a granular binding matrix is the main difference from previous studies.

By using this column adsorption method using granular adsorbent, it is hoped that beta carotene absorbed on the surface of the adsorbent can be separated and re-extracted for secondary use as a health supplement/pro-vitamin A, instead of being wasted and destroyed during the cooking oil refining process.

Literature Review

This research is based on the integration of several interrelated scientific concepts, namely the utilization of palm oil industry waste in the form of boiler ash (bottom ash) and polypropylene polymer waste as a granular adsorbent hybrid material to absorb beta-carotene compounds in crude palm oil (CPO). The relationships between the main concepts supporting this research are detailed in the sub-chapters below.

Crude Palm Oil (CPO) is one of Indonesia's main agricultural products and largest export commodity. It is rich in terpenoid compounds, a type of natural carotenoid that determines the oil's visual and chemical stability. The carotenoid content in CPO has been widely explored because it is 15 to 300 times more abundant than the levels found in carrots and other green leafy vegetables. Within this carotenoid group, the most dominant component is beta-carotene. Although beta-carotene functions as a natural antioxidant and pro-vitamin A, which is highly beneficial for the human body, its presence in high concentrations in CPO intended as a raw material for food products (such as cooking oil) presents several technical challenges.

Excessive beta-carotene causes the visual color of CPO to become intense (dark red-brown). When oil is continuously exposed to high thermal energy and oxygen during processing or storage, beta-carotene can undergo structural degradation and shift its properties to become a pro-oxidant, accelerating the rate of oil rancidity.

Therefore, the adsorption process, or absorption of substances onto a thin interfacial layer of a porous solid (adsorbent), is an economical and effective technology for removing color pigments. In this system, beta-carotene molecules act as adsorbates, physically attracted by van der Waals forces and polar-nonpolar interactions into the internal pores of the adsorbent, thus optimally maintaining the oxidative stability of palm oil products. Beta Carotene Content and DOBI (Deterioration of Bleachability Index) Value: There is a strong, linear, and unidirectional correlation between beta carotene content and the DOBI index value in crude palm oil. The DOBI value is calculated based on the ratio of the UV-Vis spectrophotometric absorbance at a wavelength of λ446 nm (the beta carotene absorption peak) to λ269 nm (the absorption peak for secondary oil oxidation products). When the boiler ash ratio is increased in the granular adsorbent formulation (1:3 ratio treatment), the density of silica active sites per unit volume increases, resulting in a sharp increase in the beta carotene removal rate (dropping to an average of 466 ppm from an initial level of 485 ppm). This reduction in carotenoid pigment concentration automatically decreases the absorbance at λ446 nm, leading to a mathematical decrease in the post-adsorption DOBI value to an average of 2.33. Nevertheless, all granular adsorbent composition treatments maintained stable final DOBI values above the required commercial quality threshold (>2.3), demonstrating that the bleaching performance of this hybrid adsorbent was optimal without compromising the oil's original purity index.

This is an Creative Commons License This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

Journal of Agriculture (JoA)
Volume: 05 | Number 02 | July 2026
E-ISSN: 2829-2421
https://doi.org/10.47709/JoA.v5n02.8661

Free Fatty Acid (FFA) Content: Statistical analysis of variance (one-way ANOVA) showed that variations in the polymer-to-boiler ash mixing ratio did not significantly impact the fluctuation of the 1% saturated fatty acid content. The free fatty acid (FFA) content of CPO oil after adsorption, where the average FFA value remained stable in the range of 3.50% to 3.52% from the initial 3.55%. The characteristics of FFA as a long-chain carboxylic acid compound make it a stable, polar organic molecule formed by the chemical reaction of internal triglyceride hydrolysis by post-harvest enzymatic activity. This hybrid granular adsorbent is designed to be physically nonpolar to target hydrophilic pigment compounds, thus lacking a sufficiently specific or reactive chemical affinity to break or bind these external FFA groups from the oil emulsion system.

Moisture Content: Similar to the FFA parameter, variations in the composition of the granular adsorbent were also shown to have no statistically significant effect on changes in the percentage of CPO moisture content, with post-treatment results remaining uniform and constant at an average of 0.13% (with a slight physical decrease from the initial 0.16%). The water content in the crude palm oil fraction produced by the mill (vacuum dryer) is largely tightly bound in the form of a stable liquid-phase micro-emulsion. The capillary pores of the boiler ash are capable of absorbing only a small fraction of the free water vapor molecules that migrate around the outer surface of the granular material through a simple capillary physical entrapment mechanism, but do not have the dominant thermal capacity or hygroscopic affinity to break the water-oil emulsion bonds on a large scale.

Research Method

Research Location and Time

This research was conducted at the Plantation Product Processing Technology Study Program Laboratory, Indonesian Palm Oil Institute (ITSI). Sample quality parameter testing was conducted at two locations: the Research & Development Center Laboratory of PT Nusa Pusaka Kencana Analytical & QC Laboratory and the Laboratory of PT Perkebunan Nusantara IV Regional II Adolina Palm Oil Mill (PKS) in Perbaungan, Serdang Bedagai Regency, North Sumatra Province.

Research Design

The experimental method applied in this research was quantitative using a laboratory experimental approach. The experimental design used a non-factorial Completely Randomized Design (CRD). The treatment focused on varying the mixing composition ratio between polypropylene polymer and boiler ash (bottom ash) as the raw material for granular adsorbents. The treatments tested consisted of three ratio levels, namely. S0 = Ratio of polymer : boiler ash (1:1 or 10%:10%) S1 = Ratio of polymer : boiler ash (1:3 or 10%:30%) S2 = Ratio of polymer : boiler ash (3:1 or 30%:10%). Each treatment was carried out with three experimental repetitions, resulting in a total of 9 experimental units.

Tools and Materials

The main tools used include analytical scales, drying ovens, 80 mesh sieves, laboratory glassware (Erlenmeyer, burette, beaker glass), spatulas, porcelain dishes, UV-Vis spectrophotometers, mortars and pestles, and Foss Near-Infrared (NIR) analyzers. The main material used in this study is Crude Palm Oil (CPO) as the target adsorption fluid. The raw material for the adsorbent consists of boiler ash waste (bottom ash) obtained from the combustion of palm kernel shells and fibers in PKS, as well as polypropylene polymers. Chemicals supporting the activation process include hydrochloric acid (HCl) and sodium hydroxide (NaOH).

Experiment Stages

This is an Creative Commons License This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

Journal of Agriculture (JoA)
Volume: 05 | Number 02 | July 2026
E-ISSN: 2829-2421
https://doi.org/10.47709/JoA.v5n02.8661

Boiler Ash Preparation and Activation

Dry boiler ash is sieved first using an 80 mesh sieve to equalize the particle size. Boiler ash powder that passes through the sieve is then chemically activated by soaking in an HCl solution and substituted with NaOH to increase porosity and clean impurities on the active surface. After mixing the activator ingredients, the mixture is left for 24 hours. The activated adsorbent is filtered, rinsed until it reaches neutral conditions, and dried in an oven.

Making Composite Granular Adsorbents

Polypropylene polymer is melted using a heater in a controlled manner. The activated boiler ash is then added to the polymer melt according to the specified treatment ratio variations (1:1, 1:3, and 3:1). The mixture is stirred homogeneously until completely combined, then cooled and formed into a granular structure so that it is ready to be applied to the adsorption column system.

Beta-Carotene Adsorption Process on CPO

The separation or absorption process is carried out using a static column system method. Composite granular adsorbent from each treatment combination was inserted into the adsorption column. The CPO oil sample is passed into a column containing adsorbent with uniform operational conditions to provide an opportunity for physical contact between the active pores of the adsorbent and the target compound (beta-carotene). The collected CPO oil filtrate from the column was collected for further quality testing.

Results

Before the adsorption process is carried out, an analysis is first carried out on the initial quality of the Crude Palm Oil (CPO) used as a research sample.

Parameter	Nilai
ALB	3,55 %
Kadar Air	0,16 %
DOBI	2,45
Carotene	485 ppm

Nilai DOBI Crude Palm Oil (CPO) Setelah Perlakuan Adsorpsi

Perlakuan	Ulangan			Rata-rata
	I	II	III	
S0 (1:1)	2,34	2,35	2,38	2,36
S1 (1:3)	2,30	2,34	2,35	2,33
S2 (3:1)	2,38	2,39	2,38	2,38

Kadar Beta Karoten Crude Palm Oil (CPO) Setelah Perlakuan Adsorpsi

This is an Creative Commons License This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

Journal of Agriculture (JoA)
Volume: 05 | Number 02 | July 2026
E-ISSN: 2829-2421
https://doi.org/10.47709/JoA.v5n02.8661

Perlakuan	Ulangan			Rata-rata
	I	II	III	
S0 (1:1)	468	470	475	471
S1 (1:3)	460	468	470	466
S2 (3:1)	476	478	476	477

Kadar Asam Lemak Bebas (ALB) Crude Palm Oil (CPO) Setelah Perlakuan Adsorpsi

Perlakuan	Ulangan			Rata-rata
	I	II	III	
S0 (1:1)	3,50	3,48	3,51	3,50
S1 (1:3)	3,53	3,53	3,51	3,52
S2 (3:1)	3,49	3,49	3,51	3,50

Kadar Air Crude Palm Oil (CPO) Setelah Perlakuan Adsorpsi

Perlakuan	Ulangan			Rata-rata
	I	II	III	
S0 (1:1)	0,12	0,12	0,14	0,13
S1 (1:3)	0,13	0,12	0,13	0,13
S2 (3:1)	0,14	0,12	0,14	0,13

Kompilasi Parameter Mutu Crude Palm Oil (CPO) Sebelum dan Sesudah Perlakuan Adsorpsi

Perlakuan	Beta Karoten (ppm)	DOBI	ALB (%)	Kadar Air (%)
Awal	485	2,45	3,55	0,16
S0 (1:1)	471	2,36	3,50	0,13
S1 (1:3)	466	2,33	3,52	0,13
S2 (3:1)	477	2,38	3,50	0,13

Conclusion

A. Boiler ash (bottom ash)-based adsorbent activated using HCl and NaOH and combined with polypropylene polymer in several composition ratios (1:1, 1:3, and 3:1) was successfully produced into a granular adsorbent that can be used for the adsorption of Crude Palm Oil (CPO).

B. Of all the treatments, it can be concluded that treatment S1, with a polymer to boiler ash (bottom ash) ratio of 1:3, had the best beta-carotene adsorption capacity. Based on the observed parameters, the average beta-carotene, DOBI, FFA, and water content in treatment S1 were 466 ppm; 2.33; 3.52%; and 0.13%, respectively. This was followed by treatment S0 (1:1) with beta-carotene values of 471 ppm; DOBI 2.36; FFA 3.50%; and a water content of 0.13%, as well as treatment S2 (3:1) with a beta-carotene value of 477 ppm; DOBI 2.38; ALB 3.50%; and a water content of 0.13%.

This is an Creative Commons License This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License

Journal of Agriculture (JoA)
Volume: 05 | Number 02 | July 2026
E-ISSN: 2829-2421
https://doi.org/10.47709/JoA.v5n02.8661

C. It can be concluded that increasing the composition of boiler ash (bottom ash) in the adsorbent increases the adsorption capacity of beta-carotene in CPO, but does not significantly affect the ALB parameters and water content. This indicates that the adsorbent is more effective in adsorbing pigment compounds than other components in CPO, and that a balanced composition is required to obtain optimal oil quality.

References

Ayu, A., Azhari, Sulhatun, Suryati, & Meriatna. (2022). *Penurunan Kadar Ffa (Free Fatty Acid) Minyak Kelapa Sawit Menggunakan Adsorben Pencampuran Bentonit Dan Tanah Liat (Lempung) Melalui Proses Adsorpsi Ayu Sutia Amanda, Azhari *, Sulhatun, Suryati, Meriatna*. *1*(Mei), 82–92.

Fatimah, R., & Siswarni, M. (2013). *Alternatif Pada Pengurangan Kadar Klorin Dalam Air Olahan (Treated Water)*. *2*(2), 1–5.

Marfitania, T., Yunianto, Hariyanto, Saragih, K. P., & Januarti, R. (2024). Sintesis Zeolit-Karbon Aktif Berbasis Abu Boiler Pabrik Kelapa Sawit Sebagai Adsorben Asam Lemak Bebas Dan Karoten Pada Crude Palm Oil. *Jurnal Syntax Admiration*, *5*(1), 220–230. Https://Doi.Org/10.46799/Jsa.V5i1.978

Misran, E., Panjaitan, F., & Yanuar, F. M. (2016). *Pemanfaatan Karbon Aktif Dari Ampas Teh Sebagai Adsorben Pada Proses Adsorpsi B -Karoten Yang Terkandung Dalam Minyak Kelapa Sawit Mentah The Utilization Of Activated Carbon From Tea Waste As Adsorbent In Adsorption Process Of B -Carotene In Crude Palm Oi*. *11*(2), 92–98.

Nainggolan, F. (2024). *Jurnal Rekayasa , Teknologi Proses Application Of Bentonite For The Adsorption Of Beta Carotene From*. *9211*, 1–6.

Saputra Harahap, Puji, W., & Yulida, A. (2020). *Analisa Kandungan Beta Karoten Pada Cpo (Crude Palm Oil) Di Pusat Penelitian Kelapa Sawit (Ppks) Medan Menggunakan Spektrofotometri Uv-Vis Quimica : Jurnal Kimia Sains Dan Terapan Konsentrasi Beta Karoten Sampel A Konsentrasi Beta Karoten Sampel B Kon*. *2*(April).

This is an Creative Commons License This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License