Eksergi
Chemical Engineering Journal
Vol 22, No. 1. 2024

ISSN: 1410-394X
e-ISSN: 2460-8203

Comparison of Different Types of Bleaching Earth on the Quality of Bleaching Palm Oil (BPO)

Miftahul Khairati, Apsari Puspita Aini*, Enny Nurmalasari, Agung Kurnia Yahya

Politeknik ATI Padang, Padang, Koto Tangah, 25171, Indonesia

Article history:

Submitted 16 August 2024
Revision 26 November 2024
Accepted 29 November 2024
Online 15 December 2024

ABSTRACT: Bleaching Earth (BE), primarily derived from Bentonite, is widely used in the bleaching process of Crude Palm Oil (CPO). Its efficiency depends on the proportions of SiO_2 and Al_2O_3, which enable effective pigment absorption. This study evaluates the performance of unmodified Bentonite, nano SiO_2-modified Bentonite, and commercial BE in producing Bleached Palm Oil (BPO). The novelty lies in the nano SiO_2 modification, designed to enhance the structural properties and absorption capabilities of Bentonite. Characterization of BE was conducted using Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM), while BPO quality was assessed through parameters like moisture content, acid value, Free Fatty Acid (FFA) levels, (Deterioration of Bleachability Index (DOBI), and β-carotene concentration. The results showed that BPO processed with nano SiO_2-modified Bentonite had the lowest β-carotene concentration (443%) and a DOBI value of 1.453, demonstrating superior bleaching performance compared to unmodified and commercial BE. Other parameters, including FFA levels and moisture content, exhibited minimal variation. Color analysis revealed that BPO processed with nano SiO_2-modified Bentonite achieved a comparable color value (1.5/15) to commercial BE. These findings highlight the potential of nano SiO_2-modified bentonite for improving oil quality by reducing FFA and acid value while maintaining optimal moisture content, offering a novel and effective alternative to unmodified bentonite in oil refining.

Keywords: bleaching; crude palm oil; bleaching earth; bentonite-nano SiO_2; β-carotene

1. Introduction

The palm cooking oil production process involves a series of refining stages, where the bleaching stage is one of the critical points to achieve the desired quality standards. On an industrial scale, degumming and bleaching processes are often carried out simultaneously to improve production efficiency (Anis et al., 2022). The degumming stage aims to remove phospholipid components, such as phospatides, proteins, residues, carbohydrates, water, and resins. In contrast, the bleaching process is focused on improving the color of the oil according to quality standards. Bleaching earth acts as a bleaching agent and adsorbent in achieving Bleaching Palm Oil (BPO) color quality standards in the CPO-based refinery industry (Syafira et al., 2022). The use of the right type of bleaching earth with optimal concentration is very important to maintain the quality of Bleaching Degumming Palm Oil (DBPO) and Refined Bleached Deodorized Palm Oil (RDBPO). The bleaching ability of bleaching earth depends on the proportion of SiO_2 and Al_2O_3 in its composition, which enables it to absorb pigments in the oil effectively (Elisabeth, 2023).

Bleaching Earth (BE) is used from the CPO bleaching process to become Spent Bleaching Earth (SBE). In 2022, Indonesia's palm oil production reached 46.7 million tons, generating more than 450,000 tons of Spent Bleaching Earth (SBE) waste (PASPI-Monitor, 2022). Some argue that SBE still contains high oil content, posing environmental risks due to its hazardous components and high flammability. SBE from the oil refining process may have an oil content ranging from 20-40% of its mass. Therefore, improving the effectiveness of BE is necessary to reduce SBE production (Abdelbasir et al., 2023).

The use of bentonite in the bleaching process is based on its high adsorption capacity, making it effective in absorbing contaminants and pigments responsible for the dark colour of the oil (Abedi et al., 2021). Pratiwi et al., (2022) developed ZnO-bentonite composites, demonstrating significant potential for adsorption applications. Yuliana et al., (2020) modified bentonite using cetyltrimethylammonium bromide (CTAB) for the CPO bleaching process, achieving BE capable of reducing carotene content by 71.04%. Hardyanti et al., 2017) modified bentonite and SiO_2 for use as adsorbents for heavy metals like Fe in batik wastewater. Their findings indicated

---

* Corresponding Author:
Email: apsaripuspitaaini@poltekatipdg.ac.id

that a stirring time of 40 minutes was optimal for silica, reducing Fe levels from 0.287 ppm to 0.145 ppm, whereas bentonite reduced Fe levels from 0.939 ppm to 0.912 ppm.

Despite these advancements, the literature indicates limited studies comparing nano SiO_2-modified bentonite with commercial bentonite, particularly in terms of their physicochemical properties and performance in the bleaching process. This study aims to adress this gap by utilizing bentonite modified with nano SiO_2 as one type of BE for the CPO bleaching process. The purpose is to compare the performance of different types of BE for bleaching CPO into bleached palm oil (BPO). The types of BE used include unmodified bentonite, nano SiO_2-modified bentonite, and commercial BE commonly used in the industry, each applied at varying concentrations. Material characterization of the BE will be conducted using SEM and FTIR. At the same time, BPO quality will be assessed using several parameters, including β-carotene concentration, DOBI value, acid number, free fatty acid (FFA) content, and moisture content. These findings are expected to deepen understanding of the most effective BE for colour absorption during the CPO-to-BPO bleaching process.

2. Materials and Methods

The materials used in this research included bentonite sourced from Indonesia, nano SiO_2 (Merck), commercial bleaching earth from an industry in Padang (name undisclosed), crude palm oil (CPO) obtained from a CPO factory in Padang, 95% n-hexane (Merck) for analysis, and 96% ethanol (Merck) for modification purposes.

2.1. Preparation of Bleaching Earth Types

The first type, Bentonite-nano SiO_2, was prepared by weighing 50 g of bentonite and adding 15% nano SiO_2 in 150 mL of ethanol. The mixture was stirred for 3 hours at 70°C, then filtered and dried at 100°C for 5 hours (Yahya et al., 2024). The second type, unmodified bentonite, underwent physical activation by heating in a furnace at 350°C for 3 hours. The final type was commercial BE obtained from an industry in Padang (name undisclosed).

2.2. Bleaching Process of Crude Palm Oil (CPO)

The CPO bleaching process was carried out using three different types of BE at varying concentrations of 0.1, 0.3, 0.5, 0.8, and 1% w/v. Prior to bleaching, the CPO underwent degumming by adding 0.5% v/v H_3PO_4 to 100 mL of CPO, followed by continuous stirring at 70°C for 30 minutes. The bleaching process was then performed by adding BE at the specified concentrations and stirring for 30 minutes at 70°C (Chinenyenwa Nkeiruka et al., 2024). The best type of BE was determined based on the quality of the resulting BPO, evaluated by the reduction in β-carotene concentration and other quality parameters.

2.3 Analysis and Characterization

DOBI analysis was performed by diluting a 0.1 g sample of CPO to 25 mL with 95% n-hexane. The mixture was stirred until thoroughly homogenized. The absorbance of the solution was then measured using a UV-Vis spectrophotometer (Shimadzu, 1800) at wavelengths of 446 nm and 269 nm. The DOBI value and β-carotene concentration were calculated using Equations 2 and 3, where A446 represents the absorbance at 446 nm, A269 the absorbance at 269 nm, and w the weight of the CPO sample (Wong et al., 2023). The DOBI value can be calculated using the following equation 1 and β-carotene concentration with equation 2:

$$\text{DOBI Number: } \frac{\text{Absorbance at 446 nm}}{\text{absorbance at 269 nm}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$C\beta = \frac{A446\ \text{x}\ 283\ \text{x}\ 25}{S\ \text{x}100} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where Cβ is β-carotene concentration in ppm, A466 is absorbance at 466 nm, S is mass of the sample in milligram.

All data on DOBI values and β-carotene concentrations were validated using ANOVA to ensure the statistical reliability and significance of the results. The ANOVA test was performed to determine whether there were significant differences between the means of the groups being analyzed, providing a robust method for evaluating the effectiveness of the different types of bleaching earth used in the study.

FFA analysis was performed by mixing a 5 g CPO sample with 50 mL of 96% ethanol at boiling temperature until homogeneous. Phenolphthalein was added, and the solution was titrated with NaOH (Lengke et al., 2024). The FFA percentage was calculated using Equation 3.

$$\%FFA = \frac{V\ \text{x}\ N\ \text{x}\ 25{,}6}{S} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where V is volume of titration in mL, N is normality of NaOH in N, S is mass of the sample in milligram.

The morphologies of BE and BE-SiO_2 were analyzed using Scanning Electron Microscopy (JSM-6510 LV JEOL,Tokyo, Japan) at 20 kV and 10,000× magnification. Functional group changes were analyzed using FTIR spectroscopy (Perkin Elmer Spotlight 200, USA) across a wavenumber range of 4000–400 cm^{-1}.

3.Results and Discussion

3.1 Characterization of Bleaching Earth Types

FTIR characterization was conducted to identify and analyze the functional groups present (Nurmalasari et al., 2023) in each type of bleaching earth (BE) used. Based on these functional groups, the ones that play a crucial role in the CPO bleaching process can be determined. The FTIR characterization results show that the FTIR spectra obtained from unmodified bentonite, commercial BE, and bentonite-nano SiO_2 exhibit significant differences. The results of the characterization results can be seen in Figure 1.

The analysis results show that the spectrum of unmodified bentonite shows a characteristic peak at 3620 cm^{-1}, indicating the presence of hydroxyl (–OH) groups due to hydrogen bonding between water molecules. There is also a peak at 1030 cm^{-1} related to the Si–O–Si stretching, which is characteristic of silicate minerals in bentonite.

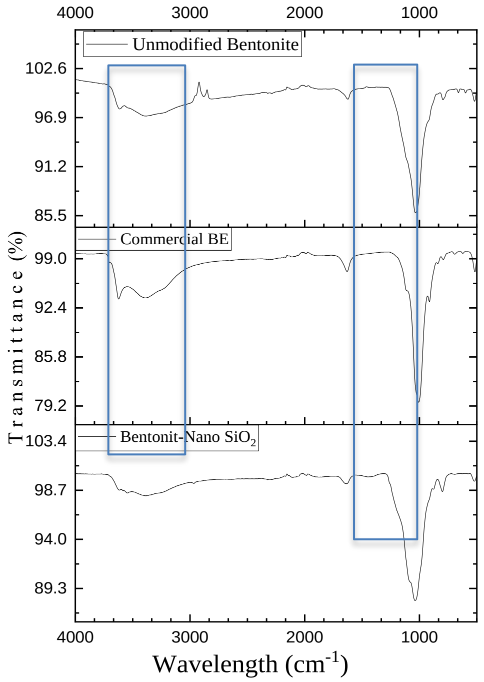

Figure 1. FTIR Results of Unmodified Bentonite, Commercial BE, and Bentonite-nano SiO_2

The peak at 1650 cm^{-1} indicates bound water in the bentonite structure, which remains unchanged (Maged et al., 2020). In contrast, the spectrum of commercial BE shows a decrease in intensity at 3620 cm^{-1}, indicating a reduction in hydroxyl groups due to dehydration during activation (Musie & Gonfa, 2023). A shift in the peak around 1100 cm^{-1} reflects modifications to the Si–O–Si structure, suggesting that activation altered the silicate framework of the bentonite (Pratiwi et al., 2022).

The bentonite-nano SiO_2 spectrum shows more significant changes, with a sharp peak around 1100 cm^{-1}, indicating strong interactions between the nano SiO_2 particles and the bentonite matrix, leading to changes in the Si–O bonds (Torkashvand & Bagheri-Mohagheghi, 2021). The decrease in intensity at 3620 cm^{-1} also indicates a reduction in hydroxyl groups due to interactions between bentonite and SiO_2 nanoparticles (Bukit et al., 2014). From this comparison, it is clear that both activation and the addition of SiO_2 nanoparticles significantly alter the chemical structure of bentonite. The bentonite-nano SiO_2 shows the most significant changes, demonstrating the success of the modification in enhancing the material's properties, such as thermal stability and catalytic activity (Alkizwini & Alquzweeni, 2021).

The results of the Scanning Electron Microscopy (SEM) analysis provide detailed insights into the samples' surface morphology, which is essential for understanding their microscopic structure and physical characteristics (Nurmalasari et al., 2022). In this study, SEM analysis was employed to evaluate the morphology of each type of Bleaching Earth (BE), highlighting the relationship between surface structure and the performance of different BE types in the CPO bleaching process. The SEM characterization results are presented in Figure 2.

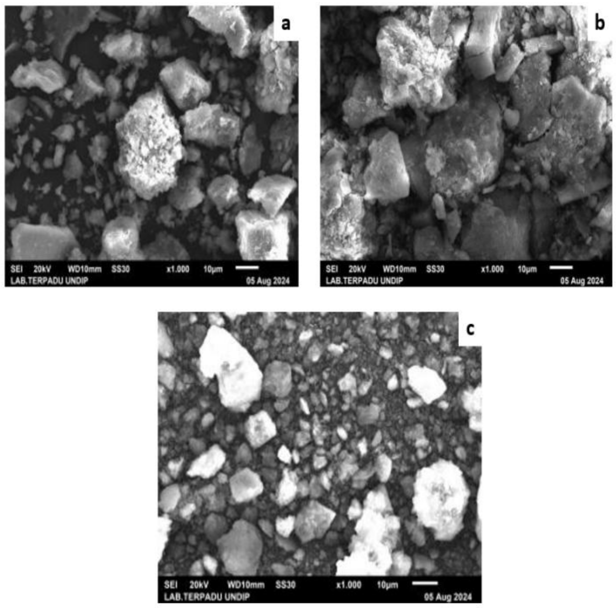

Figure 2. SEM characterization includes: (a) commercial BE, (b) unmodified bentonite, and (c) nano-SiO_2 modified bentonite

Figure 2 illustrates the distinct morphological differences among commercial BE, unmodified bentonite, and nano-SiO_2 modified bentonite. Based on Figure (a), commercial BE exhibits a relatively uniform structure with spherical particles and smooth edges, reflecting industrial processing designed to achieve consistent particle size and distribution. In contrast, Figure (b) reveals a rough and irregular morphology, with larger particle sizes and noticeable agglomeration. The uneven surface texture and lack of homogeneity indicate the absence of refinement processes, which could limit its effectiveness in applications requiring high surface area and particle dispersion. Meanwhile, Figure (c) demonstrates significant morphological improvements compared to unmodified bentonite. The particles are dispersed, and agglomeration is significantly reduced due to the role of nano-SiO_2 as a dispersing agent (Sharma et al., 2023). These findings are consistent with earlier research that modified bentonite using cetyltrimethylammonium bromide (CTAB). The study reported that the modification improved the bentonite's morphology, resulting in a smoother surface and more uniform pores with smaller sizes (Wang et al., 2021).

3.2. Deterioration of Bleached Oil (DOBI) Value analysis

The Deterioration of Bleached Oil (DOBI) analysis in Bleaching Palm Oil (BPO) evaluates the level of oxidative damage and stability of the oil after the bleaching process. The DOBI analysis indicates the effectiveness of the bleaching process in removing contaminants that could lead to oil degradation. A lower DOBI value indicates that the oil has undergone effective bleaching, resulting in better quality and higher oxidative stability (Wong et al., 2023). The results of the DOBI value analysis can be seen in Figure 3.

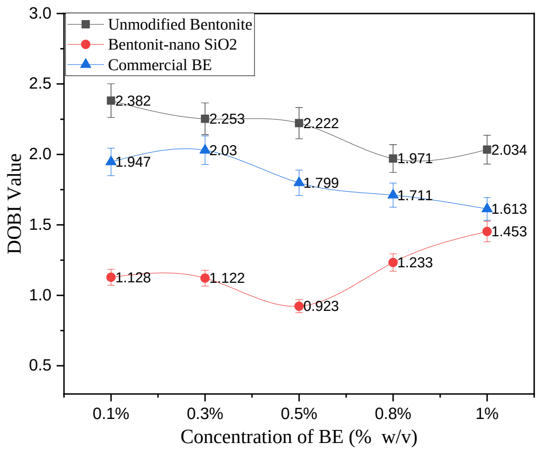

Figure 3. DOBI Value of BPO

Figure 3 illustrates the DOBI values of the three BE types across varying concentrations. The figure clearly shows that each adsorbent exhibits different performance levels. Unmodified bentonite consistently displays the highest DOBI values compared to the other two adsorbents at all BE concentrations. At a concentration of 0.1% w/v, the DOBI value is 2.382, and even at a concentration of 1% w/v, the DOBI value remains above 2, specifically at 2.034. This result indicates that unmodified bentonite has the lowest bleaching efficiency. Its high DOBI values suggest limited adsorption capacity for impurities.

In contrast, bentonite-nano SiO_2 achieves the lowest DOBI values across all BE concentrations, indicating superior adsorption performance. At a concentration of 0.1% w/v, the DOBI value is already below 2, at 1.128, and at a concentration of 0.5% w/v, the DOBI value decreases further to 0.923. These results are consistent with the SEM characterization, which shows that the surface of bentonite-nano SiO_2 has more pores compared to other types of BE. Modifying bentonite with nano SiO_2 enhances its specific surface area and affinity for impurities such as carotenoids and phosphatides.

Table 1. Mean, standard deviation, and standard error of DOBI Value

Type of BE	N Analysis	Mean	Standard Deviation	SE of Mean
Unmodified Bentonite	5	2.1724	0.16778	0.07504
Bentonit-nano SiO_2	5	1.1718	0.19308	0.08635
Commercial BE	5	1.82	0.16985	0.07596

Meanwhile, commercial BE performs better than unmodified bentonite but needs more bentonite-nano SiO_2. As the bleaching earth (BE) concentration increases, the DOBI value decreases. This finding is consistent with the research conducted by (Hasibuan, 2018) which states that higher concentrations of BE lead to a more significant reduction in impurities and an improvement in oil clarity. Furthermore, (Yahya et al., 2024) reported that the reduction in DOBI value occurred after the bleaching process, particularly at a BE concentration of 1% w/v.

A one-way ANOVA statistical analysis was performed to assess whether there is a significant difference in the Degree of Bleaching Index (DOBI) values among different types of Bentonite used in the palm oil bleaching process. This test aims to determine whether the mean DOBI values of Unmodified Bentonite, Bentonite-nano SiO_2, and Commercial BE are significantly different. The results of the ANOVA test can be seen in Table 1 and Table 2.

Table 2. The main components of an ANOVA (Analysis of Variance) of DOBI Value

	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	2.57591	1.28796	40.98261	4.33795E-6
Error	12	0.37712	0.03143		
Total	14	2.95304			

Table 1 Descriptive statistics show the mean values for each group, with 2.1724 for Unmodified Bentonite, 1.1718 for Bentonite-nano SiO_2, and 1.82 for Commercial BE. The standard deviation reflects the variability within each group, with Bentonite-nano SiO_2 having the highest value of 0.19308, indicating slightly more variation than the other groups.

The hypotheses tested were that the null hypothesis (H_0) suggests no significant difference in the mean DOBI values among the three bentonite types, and the alternative hypothesis (H_1) suggests a significant difference in the mean DOBI values between the groups. The ANOVA analysis gave an F value of 40.98261 and a Prob > F value of 4.33795E-6 in Table 2. Since the Prob > F is much smaller than 0.05, the null hypothesis (H_0) is rejected, showing a significant difference between the mean values of the three groups with 95% confidence. This result confirms that the mean DOBI values differ significantly across the three bentonite types.

The significant ANOVA findings support using a one-way ANOVA to compare the means of three or more independent groups and test for significant differences. In this case, the F-value suggests that at least one bentonite type differs from the others in terms of DOBI values, highlighting the significant impact the bentonite type has on the bleaching process.

3.3. Analysis of β-carotene concentration

Analyzing β-carotene concentration during the CPO bleaching process provides essential insights into the efficiency of different adsorbents in removing unwanted pigments. Understanding the concentration of β-carotene is

Table 5. Moisture Content and Colour of BPO

BE concentration	**Moisture Content (%)**			**Colour (Red/Yellow)**		
	unmodified bentonite	bentonite-nano SiO_2	commercial BE	unmodified bentonite	bentonite-nano SiO_2	commercial BE
0.10%	0.065	0.066	0.086	1.8/18	1.6/16	1.6/17
0.30%	0.066	0.064	0.065	1.6/16	1.5/15	1.6/17
0.50%	0.064	0.107	0.111	1.7/17	1.6/16	1.5/15
0.80%	0.107	0.086	0.066	1.7/17	1.5/15	1.5/15
1%	0.086	0.119	0.083	1.5/15	1.5/15	1.5/15

crucial because it directly impacts the quality of the final product (Ahmed et al., 2023). High β-carotene content in edible oils, such as CPO, can affect the oil's colour, stability, and nutritional properties (Md Sarip et al., 2023). The analysis results of β-carotene concentration in BPO from the bleaching process using different types of bleaching earth (BE) are shown in Figure 4.

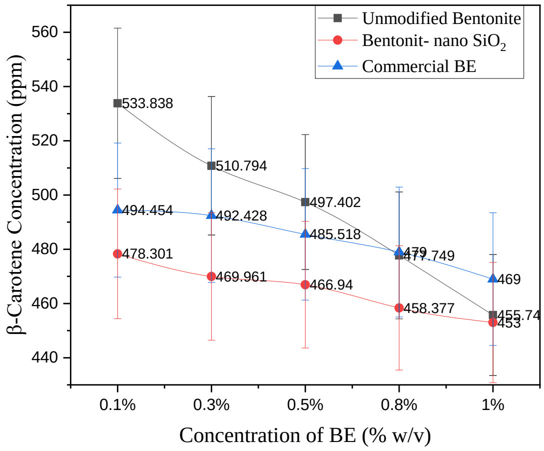

Figure 4. The concentration of β-carotene in BPO

Figure 4 illustrates the adsorption performance differences between unmodified bentonite, bentonite-nano SiO_2, and commercial BE during the CPO bleaching process based on β-carotene concentration. Unmodified bentonite shows the highest β-carotene concentration at all BE concentrations. At 0.1% w/v BE concentration, the β-carotene concentration is 633.638 ppm; at 1% w/v, it drops to 155.74 ppm. These results indicate the lowest adsorption efficiency due to limited surface area and fewer active sites. This result is consistent with the FTIR characterization, where the peak at 1030 cm^{-1} related to Si–O–Si stretching is less sharp than the other BE types(Moussout et al., 2018).

Table 3. Mean, standard deviation, and standard error concentration of β-carotene

Type of BE	**N Analysis**	**Mean**	**Standard Deviation**	**SE of Mean**
Unmodified Bentonite	5	495.1064	30.00746	13.41975
Bentonit-nano SiO_2	5	465.3158	9.90779	4.4309
Commercial BE	5	484.08	10.39939	4.65075

The one-way ANOVA results compare the mean values for three types of Bentonite, with 495.1064 for Unmodified Bentonite, 463.3158 for Bentonite-nano SiO_2, and 488.08 for Commercial BE. The most considerable variability is observed in Unmodified Bentonite, with a standard deviation of 41.48901. The ANOVA analysis yields an F value of 2.15803 and a Prob > F of 0.15827, which exceeds 0.05. Thus, the null hypothesis (H_0) cannot be rejected, indicating no statistically significant difference between the means at a 95% confidence level.

Table 4. The main components of an ANOVA (Analysis of Variance) concentration of β-carotene

	DF	**Sum of Squares**	**Mean Square**	**F Value**	**Prob>F**
Model	2	2268.59424	1134.2971	3.0746	0.08355
Error	12	4427.03851	368.91988		
Total	14	6695.63275			

The R-Square value of 0.26453 suggests that the model explains 26.45% of the variability in the data, while a coefficient of variation of 0.05272 indicates low variability relative to the mean of 482.1674. Although the means differ among the groups, these differences are not statistically significant, and further tests may be needed to explore potential variations.

3.4. Analysis of other parameters for Bleached Palm Oil

Free fatty acid (FFA) content is a critical parameter in determining oil quality, as higher levels of FFA can reduce oil stability and shelf life (Tan et al., 2023). The results of the FFA analysis are shown in Figure 5. Figure 5 illustrates the FFA values of BPO after bleaching using three different types of BE. The results indicate that unmodified bentonite exhibited high FFA levels, ranging from 4.096% to 4.505%. FFA content decreased from 4.505% at a concentration of 0.1% w/v to 4.096% at 1% w/v. In comparison, nano SiO_2-modified bentonite showed lower FFA levels, ranging from 2.688% to 3.584%. A significant reduction was observed, with FFA dropping from 3.584% at 0.1% w/v to 2.688% at 1% w/v. These findings align with the, Deterioration of Bleachability Index (DOBI) values analysis, where nano SiO_2-modified bentonite showed better performance than unmodified bentonite.

Meanwhile commercial BE recorded FFA levels between 3.712% and 4.224%. This result highlights that using nano SiO_2-modified bentonite could be a practical approach to reducing oil's free fatty acid content

(Aprilia2023). The results of this study indicate that as the concentration of BE increases, the FFA content decreases across all types of BE. (Hasanudin et al., 2022) reported similar findings, stating that increasing the adsorbent concentration enhances FFA adsorption, reducing the FFA percentage.

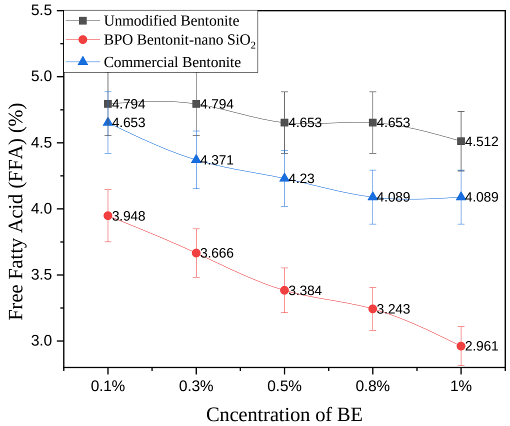

Figure 5. The Free Fatty Acid (FFA) of BPO

Table 5 outlines additional BPO quality parameters, such as moisture content and colour (red/yellow). Research by (Novelena & Komari, 2022) indicates a significant correlation between these factors and oil quality. As per SNI a (SNI) 01-2901-2006, these parameters are essential in palm oil quality standards to guarantee the integrity of the final product.

Moisture content in palm oil is a critical parameter that determines its quality and stability. Research by R. (Novelena & Komari, 2022) identified high moisture levels in palm oil samples as a critical factor in reducing oil stability. Their findings revealed that the moisture content in the three types of BE ranged from 0.064% to 0.119%, with the highest level recorded at 0.119% for commercial BE at a concentration of 1.0%. In contrast, BE with nano SiO₂ consistently exhibited the lowest moisture levels, ranging from 0.064% to 0.107%. Despite these differences, the moisture content of BPO obtained through bleaching with all

BE types remained well within the limits set by the Indonesian National Standard (SNI) 01-2901-2006, which allows a maximum moisture content of 0.5%. Consequently, the resulting BPO is less prone to microbial spoilage. High moisture levels in oil are known to enhance microbial activity, potentially leading to oil degradation and adversely affecting the product's sensory properties (Amsasekar et al., 2022).

Table 5 highlights that oil colour serves as a critical quality indicator, reflecting the presence of pigments such as carotenoids and chlorophyll, which can degrade or be adsorbed during the refining process. The data reveals that using bentonite-nano SiO₂ results in a lighter oil colour (ranging from 1.6/16 to 1.5/15) compared to unmodified bentonite, which produces a stronger colour (from 1.8/18 to 1.5/15). Although commercial BE provides consistent results in the range of 1.6/17 to 1.5/15, it is less effective than bentonite-nano SiO₂ in enhancing oil brightness. These findings suggest that bentonite-nano SiO₂ exhibits effectiveness comparable to commercial BE. Furthermore, this outcome aligns with β-carotene concentration results, where bentonite-nano SiO₂ demonstrates higher adsorption capacity than unmodified bentonite.

The modification of bentonite with metals, oxides, or other compounds enhances its ability to adsorb colour pigments, making it highly effective in reducing colour intensity. In the bleaching process of crude coconut oil, bentonite modified with biochar demonstrated the ability to remove up to 99.2% of the oil's colour, significantly reducing pigment content such as β-carotene and chlorophyll (Suhadi et al., 2018).(Almoselhy et al., 2020) described the bleaching process of soybean oil, corn oil, and sunflower oil using nano-sized adsorbents, achieving up to 71% effectiveness in pigment removal. This superior result is attributed to the nano technology's unique properties, including smaller particle size, larger surface area, higher porosity, and enhanced chemical interactions, which collectively outperform conventional bleaching methods (Soylu et al., 2024). A one-way ANOVA was conducted to evaluate whether significant differences exist in Free Fatty Acid (FFA), Moisture Content, and Colour among the three bentonite types. The results of the ANOVA analysis are presented in Table 6.

Table 6. ANOVA of FFA, Moisture Content, and Colour of BPO

Parameters	**Standard Deviation**			**Prob>F**
	Unmodified Bentonite	**Bentonite-nano SiO₂**	**Commercial BE**	
FFA	0.11797	0.38096	0.23594	2.98101E-5
Moisture Content	0.0188	0.02442	0.01873	0.7192
Colour	1.14018	0.54772	1.09545	0.17798

Table 6 analyzes Unmodified Bentonite, Bentonite-nano SiO₂, and Commercial BE based on Free Fatty Acid (FFA), Moisture Content, and Colour parameters. The FFA parameter showed a significant statistical difference (Prob>F = 2.98101E-5). Bentonite-nano SiO₂ exhibited the highest variation (standard deviation 0.38096) compared to Unmodified Bentonite (0.11797) and Commercial BE (0.23594), indicating less stability in reducing FFA. In contrast, Unmodified Bentonite demonstrated the most consistent performance.

For Moisture Content, the Prob>F value of 0.7192 indicated no statistically significant differences among the three bentonite types. However, Bentonite-nano SiO₂ had the highest variation (standard deviation 0.02442) compared to Unmodified Bentonite (0.0188) and Commercial BE (0.01873). Regarding Colour, Bentonite-nano SiO₂ showed the lowest variation (standard deviation 0.54772) compared to Unmodified Bentonite (1.14018) and Commercial BE (1.09545). Despite this, the Prob>F value of 0.17798 suggested that the colour differences among the three types were not statistically significant.

Overall, the ANOVA analysis for the BPO parameters, including DOBI value, β-carotene concentration, FFA, moisture content, and colour, revealed significant differences for certain parameters based on the type of bleaching earth (BE) used. The results showed that only DOBI value and FFA exhibited statistically significant differences among the BE types. This data validates the correlation between DOBI value and FFA percentage. In contrast, β-carotene concentration, moisture content, and colour did not show statistically significant differences. Based on these findings, Bentonite-nano SiO_2 is recommended for applications requiring visual stability, reduction of colour pigments, and moisture content. Meanwhile, Unmodified Bentonite is more suitable for applications prioritizing FFA reduction. Although Commercial BE demonstrated fairly stable performance across all parameters, its overall effectiveness remains suboptimal for specific parameters.

Nano SiO_2-modified bentonite demonstrated significant improvements in reducing free fatty acid (FFA) content and enhancing particle dispersion, which align well with findings from other studies emphasizing the role of nano additives in boosting adsorption and catalytic properties. These enhancements suggest its potential in applications requiring efficient removal of impurities or enhanced reaction kinetics, such as in oil bleaching or wastewater treatment. However, the minimal impact on moisture content, despite structural modifications, indicates that nano SiO_2 may not significantly influence hydrophilic interactions within the bentonite matrix. This limitation could result from incomplete surface coverage or insufficient interaction between the silanol groups of nano SiO_2 and the bentonite's hydroxyl sites, as suggested in previous studies.

To contextualize these findings, comparisons with similar studies reveal that while nano SiO_2-modified materials often exhibit superior adsorption properties, their moisture interaction depends heavily on the uniformity and density of the nano-layer deposition. The challenges in achieving consistent modification could stem from factors like agglomeration of nanoparticles or heterogeneity in bentonite surfaces. Addressing these challenges through techniques like controlled sol-gel processes or coupling agents might improve modification consistency. However, the trade-offs of such modifications, such as increased production costs and potential environmental concerns from nanoparticle leaching, must also be considered. Future research should focus on optimizing the modification process to balance performance enhancements with practical scalability and environmental safety.

4. Conclusions

Overall, the ANOVA analysis for the BPO parameters, including DOBI value, β-carotene concentration, FFA, moisture content, and colour, revealed significant differences for specific parameters based on the bleaching earth (BE) used. The results showed that only DOBI value and FFA exhibited statistically significant differences among the BE types. This data validates the correlation between DOBI value and FFA percentage. In contrast, β-carotene concentration, moisture content, and colour did not show statistically significant differences. Based on these findings, Bentonite-nano SiO_2 is recommended for applications requiring visual stability, reduction of colour pigments, and moisture content. Meanwhile, Unmodified Bentonite is more suitable for applications prioritizing FFA reduction. Although Commercial BE demonstrated relatively stable performance across all parameters, its overall effectiveness remains suboptimal for specific parameters.

Further research is recommended to explore the impact of varying nano SiO_2 concentrations in bentonite on oil bleaching efficiency at an industrial scale. Additionally, investigating the interactions between nano SiO_2 and other compounds present in oil could provide deeper insights into the adsorption mechanisms involved. Broadening the scope to include trials with different types of vegetable oils would help assess the wider applicability and effectiveness of nano SiO_2-modified bentonite across various industrial sectors.

Future studies might also examine the potential of modifying bentonite with alternative nanoparticles to target specific properties, such as enhanced thermal stability or catalytic activity. These investigations could lead to the development of tailored bentonite modifications, optimizing performance for diverse industrial needs and expanding its practical applications.

Acknowledgments

The author would like to thank ATI Polytechnic Padang for providing funding for this research with Contract Number 1476/BPSDMI/ATI-Padang/V/2024. The author would also like to thank all those who have participated in helping this research

Statement

During the preparation of this work, the authors utilized ChatGPT 4.0 to enhance the quality of the English language and proofread the text. After employing this tool/service, the authors thoroughly reviewed and revised the article as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Miftahul Khairati: Writing – original draft, , Data curation, **Apsari Puspita Aini:** Investigation, Formal analysis, **Enny Nurmalasari**: Writing – review & editing, Conceptualization, Visualization, **Agung Kurnia Yahya:** Project administration, Validation, Software

Declaration of competing interest

The authors declare that they have no financial interests or personal relationships that could influence the findings reported in this paper.

Data availability

The data that has been used is confidential.

References

Abdelbasir, S. M., Shehab, A. I., & Khalek, M. A. A. (2023). Spent bleaching earth; recycling and utilization techniques: A review. *Resources, Conservation and Recycling Advances, 17*(November 2022), 200124. https://doi.org/10.1016/j.rcradv.2022.200124

Abedi, E., Amiri, M. J., & Sayadi, M. (2021). The potential use of ultrasound-assisted bleaching in removing heavy metals and pigments from soybean oil using kinetic, thermodynamic and equilibrium modeling. *Environmental Science and Pollution Research, 28*(36). https://doi.org/10.1007/s11356-021-14180-2

Ahmed, S., Arefin, P., Mondal, K., & Miah, M. A. S. (2023). Comparison of Nutritional Quality and Storage Stability of β-Carotene Fortified Soybean Oil and Olive Oil. *Tropical Journal of Natural Product Research, 7*(3). https://doi.org/10.26538/tjnpr/v7i3.3

Alkizwini, R. S., & Alquzweeni, S. S. (2021). Modeling natural bentonite, thermal-modified bentonite and iron-modified bentonite with artificial neural network, sorption kinetics and sorption isotherms for simulated sorption tetracycline. *International Journal of Environmental Science and Technology*, *18*(9), 2633–2650. https://doi.org/10.1007/s13762-020-03004-4

Almoselhy, R. I. M., Eid, M. M., Abd-Elmageed, S. M. M., & Youness, R. A. (2020). Using nanotechnology in bleaching vegetable oils. *Egyptian Journal of Chemistry, 63*(7). https://doi.org/10.21608/EJCHEM.2020.23625.2407

Amsasekar, A., Mor, R. S., Kishore, A., Singh, A., & Sid, S. (2022). Impact of high pressure processing on microbiological, nutritional and sensory properties of food: a review. *Nutrition and Food Science* (Vol. 52, Issue 6). https://doi.org/10.1108/NFS-08-2021-0249

Anis, U., Millati, R., & Hidayat, C. (2022). Optimization of Crude Palm (Elaeis guineensis) Oil Bleaching using Zeolite-Fe by Response Surface Methodology. *AgriTECH, 42*(1). https://doi.org/10.22146/agritech.48114

Bukit, N., Ginting, E. M., Harahap, M. H., Fiska, J., Medan, U. N., Willem, J., & Psr, I. (2014). Preparasi Bentonit Alam Menjadi Nano Partikel Sebagai Filler Pada Termoplastik Hdpe. *Jurnal Saintika*, *14*(2), 95–107.

Chinenyenwa Nkeiruka, N., Ikenna Chukwudi, N., & Charles Ebuka, C. (2024). Bleaching Of Crude Palm Oil By Activated Nise Clay: Process Kinetics, Isotherm And Thermodynamic Studies. *Novateur Publications International Journal Of Innovations In Engineering Research And Technology, 11*, 2394–3696.

Elisabeth, J. (2023). Mitigation of 3-MCPDE and GE in palm oil in Indonesia. *E-Journal Menara Perkebunan, 91*(2). https://doi.org/10.22302/mp.v91i2.549

Ghorbanpour, M. (2018). Soybean oil bleaching by adsorption onto bentonite/iron oxide nanocomposites. *Journal of Physical Science, 29*(2). https://doi.org/10.21315/jps2018.29.2.7

Hardyanti, I. S., Nurani, I., Hardjono HP, D. S., Apriliani, E., & Wibowo, E. A. P. (2017). Pemanfaatan Silika (SiO2) dan Bentonit sebagai Adsorben Logam Berat Fe pada Limbah Batik. *JST (Jurnal Sains Terapan), 3*(2). https://doi.org/10.32487/jst.v3i2.257

Hasanudin, H., Putri, Q. U., Agustina, T. E., & Hadiah, F. (2022). Esterification of Free Fatty Acid in Palm Oil Mill Effluent usSulfated Carbon-Zeolite Composite Catalyst. *Pertanika Journal of Science and Technology, 30*(1), 377–395. https://doi.org/10.47836/pjst.30.1.21

Hasibuan, H. A. (2018). Deterioration Of Bleachability Index Pada Crude Palm Oil: Bahan Review Dan Usulan Untuk SNI 01-2901-2006. *Jurnal Standardisasi*, *18*(1), 25–34. https://doi.org/10.31153/js.v18i1.694

Lengke, G., Lembang, T. O., Saleh, M., Pasae, Y., & Djonny, M. (2024). Evaluasi Kualitas Minyak Sawit Mentah (CPO) PT Suryaraya Lestari I Berdasarkan Parameter FFA, Kadar Air, DOBI, dan Kadar Pengotor *Paulus Chemical Engineering Journal. 2*(1).

Maged, A., Kharbish, S., Ismael, I. S., & Bhatnagar, A. (2020). Characterization of activated bentonite clay mineral and the mechanisms underlying its sorption for ciprofloxacin from aqueous solution. *Environmental Science and Pollution Research, 27*(26). https://doi.org/10.1007/s11356-020-09267-1

Md Sarip, M. S., Morad, N. A., Mohd Nawi, M. A. H., Tun Abdul Aziz, M. K., & Syed Jaapar, S. Z. imah. (2023). β-carotene enrichment in crude palm oil using subcritical water extraction and its relationship with the solubility. *Food Chemistry Advances, 2*. https://doi.org/10.1016/j.focha.2023.100245

Moussout, H., Ahlafi, H., Aazza, M., & Amechrouq, A. (2018). Bentonite/chitosan nanocomposite: Preparation, characterization and kinetic study of its thermal degradation. *Thermochimica Acta, 659*. https://doi.org/10.1016/j.tca.2017.11.015

Musie, W., & Gonfa, G. (2023). Thermal activation, characterization and performance evaluation of Ethiopian bentonite for sodium removal. *Water Science and Technology, 87*(4). https://doi.org/10.2166/wst.2023.031

Novelena, T. A., & Komari, N. (2022). Analisis Hubungan Antar Parameter Kualitas Crude Palm Oil di PT. Laguna Mandiri Rantau Factory. *Jurnal Natural Scientiae, 2*(1). https://doi.org/10.20527/jns.v2i1.4864

Nurmalasari, E., Kusworo, T. D., & Khairati, M. (2022). Rubber Industry Wastewater Treatment using A Combination of Ozonation and Modified PES-Nano ZnO Membranes. *Chemica*, *9*(3), 134–141.

Nurmalasari, E., Ulia, H., Aini, P., Kurnia Yahya, A., & Fahni, Y. (2023). Metode Modifikasi Membran Polietersulfon (PES) untuk Meningkatkan Anti-fouling −Mini Review Modified Polyethersulfone (PES) Membran Methods to Improve Anti-fouling −Mini

Review. In *Jurnal Ilmiah Teknik Kimia* (Vol. 20, Issue 2).

PASPI-Monitor. (2022). Spent Bleaching Earth (Sbe), the Hidden Treasure From Waste of the Palm Oil Refinery Plant. *Palm Oil Agribusiness Strategic Policy Institute*, *II*(28).

Pratiwi, J., Putri, S. E., Pratiwi, D. E., & Ramadani, A. I. W. S. (2022). Synthesis And Characterization Of Bentonite-Zno Composites. *Jambura Physics Journal*, *4*(1). https://doi.org/10.34312/jpj.v4i1.13499

Sharma, P., Kumari, S., Ghosh, D., Kumar, J., Vij, A., Brajpuriya, R. K., Rawat, P., Srivastava, C. M., Saini, S., Sharma, V., Hassan, M. I., & Majumder, S. (2023). Structural morphological, and thermal properties of nano bentonite and α-Fe2O3/bentonite nanocomposite. *Zeitschrift Fur Physikalische Chemie*, *237*(4–5). https://doi.org/10.1515/zpch-2022-0073

Soylu, T. M., Özel, C., Karakuzu Ikizler, B., Özarslan, A. C., Terzioğlu, P., Elalmis, Y. B., & Yücel, S. (2024). Mesoporous silica aerogels for sunflower oil refining and investigation of their adsorption performance. *Journal of Sol-Gel Science and Technology*. https://doi.org/10.1007/s10971-024-06395-9

Suhadi, J. A., Goncalves, E. F., Foe, K., & Soetaredjo, F. E. (2018). Bentonite-Biochar composite for bleaching of crude coconut oil. *ARPN Journal of Engineering and Applied Sciences*, *13*(8).

Syafira, R. Z., Anwar, S. H., & Rozali, Z. F. (2022). Pengendalian Mutu Crude Palm Oil (CPO) Dengan Metode Control Chart dan Failure Mode and Effect Analysis (FMEA) Pada Pabrik Kelapa Sawit PT.XYZ. *Jurnal Teknologi Dan Industri Pertanian Indonesia*, *14*(2). https://doi.org/10.17969/jtipi.v14i2.23056

Torkashvand, H., & Bagheri-Mohagheghi, M. M. (2021). Purification, Synthesis and Structural, Optical Characterizations of Silicon (Si) Nano-Particles from Bentonite Mineral: the Effect of Magnesium-Thermic Chemical Reduction. *Silicon*, *13*(5). https://doi.org/10.1007/s12633-020-00533-y

Wang, Y., Jiang, Q., Cheng, J., Pan, Y., Yang, G., Liu, Y., Wang, L., Leng, Y., & Tuo, X. (2021). Synthesis and characterization of CTAB-modified bentonite composites for the removal of Cs+. *Journal of Radioanalytical and Nuclear Chemistry*, *329*(1). https://doi.org/10.1007/s10967-021-07797-7

Wong, F. H., Lim, M. S. W., Tiong, T. J., Chan, Y. J., Asli, U. A., & Yap, Y. H. (2023). Relationship between the deterioration of bleachability index (DOBI) value and hydrogenation performance for the hydrogenation of split-crude palm oil (s-CPO) in the oleochemical industry. *Asia-Pacific Journal of Chemical Engineering*, *18*(6). https://doi.org/10.1002/apj.2973

Yahya, A. K., Nurmalasari, E., Aini, A. P., & Ulya, H. N. (2024). Performance Evaluation of Bentonite/Nano-SiO2 Composite as Bleaching Earth in Crude Palm Oil Processing. *Jurnal Kimia Sains Dan Aplikasi*, *27*(4), 167–173. https://doi.org/10.14710/jksa.27.4.167-173

Yahya, A. K., Rahayu, P., Ulia, H., & Maulana, A. Y. (2022). Analisa Head Loss Dan Kerja Pompa Dengan Variasi Perubahan Diameter Pada Sistem Pemipaan. *SAINTI: Majalah Ilmiah Teknologi Industri*, *19*(2).

Yuliana, M., Sutrisno, R. J., Hermanto, S., Ismadji, S., Wijaya, C. J., Santoso, S. P., Soetaredjo, F. E., & Ju, Y. H. (2020). Hydrophobic Cetyltrimethylammonium Bromide-Pillared Bentonite as an Effective Palm Oil Bleaching Agent. *ACS Omega*, *5*(44). https://doi.org/10.1021/acsomega.0c04238