Scientific Research Publishing

Journal of Materials Science and Chemical Engineering, 2024, 12, 69-83
https://www.scirp.org/journal/msce
ISSN Online: 2327-6053
ISSN Print: 2327-6045

Improving the Quality of Baobab Oil by Filtration on Activated Carbon from the Fruit Capsules

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How to cite this paper: Ndiaye, E.M., Sow, A., Faye, P.G., Ba, K., Ndoye, M., Cisse, O.I.K., Ayessou, N.C. and Cisse, M. (2024) Improving the Quality of Baobab Oil by Filtration on Activated Carbon from the Fruit Capsules. *Journal of Materials Science and Chemical Engineering*, **12**, 69-83.
https://doi.org/10.4236/msce.2024.121006

Received: December 17, 2023
Accepted: January 27, 2024
Published: January 30, 2024

Abstract

The baobab, *Adansonia digitata* L., plays an important role in the economy of local populations. Nowadays, baobab seed oil is highly prized for its many cosmetic and therapeutic applications, and for its composition of unsaturated fatty acids, sterols, and tocopherols. However, it undergoes numerous reactions during production, processing, transport, and storage, leading to undesirable products that make it unstable. The aim of this study was to provide local processors with innovative solutions for the treatment of unrefined vegetable oils. To this end, an experimental device for filtering crude oil on activated carbon made from fruit capsules was designed. The results obtained after the treatment show a significant decrease at ($p < 5\%$) in acid value (1.62 to 0.58 mg KOH/g), peroxide value (4.40a to 0.50c $mEqO_2/Kg$), chlorophyll concentration (1.81 to 0.50 mg/Kg) and primary and secondary oxidation products. According to these results, activated carbon's adsorptive power eliminates oxidation products and certain pro-oxidants such as chlorophyll, resulting in a cleaner, more stable and better storable oil.

Keywords

Activated Carbon, *Adansonia digitata* L., Baobab Fruit, Baobab Oil, Stability

1. Introduction

The baobab (*Adansonia digitata* L.) is a massive tree that is widespread in Se-

negal and Africa. It belongs to the Bombacaceae family, order Malvales [1] [2] and plays an important social, economic and environmental role [3]. The leaves and pulp of the baobab fruit are used as food, while the roots, stems and bark are used in traditional medicine [4] [5]. The seeds, which represent more than half of the dehusked fruit, are underexploited compared with the pulp [1]. Today, the baobab is of particular economic interest due to its rare and precious seed oil [6] [7]. Indeed, baobab seed oil is highly sought after by the cosmetics and pharmaceutical industries because of its composition [6] [8]. According to Vermaak *et al.* 2011, [9] this oil is composed of saturated fatty acids (33%), monounsaturated fatty acids (36%) and polyunsaturated fatty acids (31%). They also point out that baobab oil contains phytosterols such as β-sitosterol, campesterol and stigmasterol. Other authors have reported the presence of vitamins A, D, E and K in baobab oil [10] [11]. Cyclopropenic acids are also present. Finally, the seeds are also rich in sodium, phosphorus, and magnesium [5] [12].

However, like all unsaturated vegetable oils, baobab oil is sensitive and subject to various degradation reactions during the various stages of production, processing, and storage [7]. Indeed, crude baobab oil, after press extraction, is very cloudy due to the presence of impurities and suspended particles [13]. In addition, the operating conditions of pressing, light, heat and oxygen in the air, trigger alteration reactions that are sometimes irreversible [13]. These reactions lead to oil degradation.

The aim of this study is to provide small and medium-sized local businesses with innovative and effective solutions for processing unfloured crude vegetable oils. In fact, in these local processing units, the crude oil obtained is only filtered using special filter cloths after decantation. The oxidation products formed by the oil's initial alteration and degradation reactions are not eliminated, thereby accelerating the oil's deterioration. In addition, the sensory quality of artisanally extracted vegetable oils remains poor. This is why we have undertaken laboratory trials to treat raw baobab oil using activated carbon made from baobab fruit capsules, which are generally discarded in the forest [14]. An experimental device consisting of a glass column, an activated carbon filter bed, a sand bed to remove suspended particles, and a vacuum pump was designed for this purpose. After filtration on the activated carbon, chemical analyses were carried out to assess its effect on the stability and quality of the treated baobab oil.

2. Materials and Methods

2.1. Collection and Preparation of Plant Material

The plant material consists of capsules and seeds from the fruit of baobab (*Adansonia digitata* L.), dehusked and pulped. Fruits were collected at random in the commune of Sindian, Bignona Department, Ziguinchor region, Senegal (latitude: 12˚57'47" North; longitude: 16˚10'55" West).

The baobab fruits are first shelled, and the various components separated (**Figure 1**). Initially, the seeds are covered by a whitish pulp. The seeds are

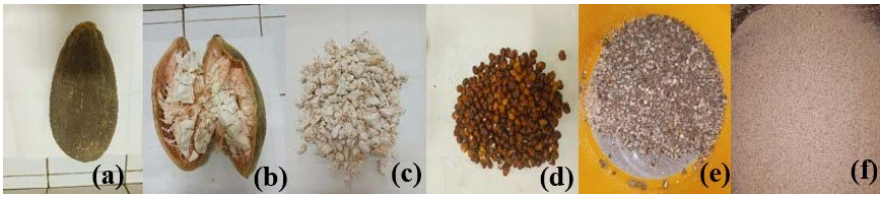

Figure 1. Whole fruit (b), open fruit (b), pulp-enveloped seeds (c), pulp-free seeds (d), crushed seeds (e) and crushed seed kernel (f) of baobab fruit (*Adansonia digitata* L.).

separated from the pulp using the dry method. First, the pulp-coated seeds are sun-dried and then pulped using a 316 N stainless steel pulping machine fitted with a 150 µm sieve. This is followed by coarse sieving to separate the pulp from the seeds. The latter are ground in a millet mill with a capacity of 300 to 350 $kg{\cdot}h^{-1}$ and an estimated electric motor power of 7.5 HP, fitted with sieves with 02 mm diameter holes and a speed of 2800 rpm. The ground material is collected in a recipient.

The shells collected were washed thoroughly with water, then sun-dried for 3 days. They were then crushed in a mortar and dried under study at 105˚C for 24 hours. They were ground using a HAEGER-type blender, Model No. HG-2801, made in P.R.C. Finally, the crushed material was sieved through a 0.400 mm diameter sieve. The biomass thus obtained is used to produce activated carbon. **Figure 2** shows the various stages in the preparation of baobab fruit capsules.

2.2. Production of Baobab Oil

The baobab seed kernel powder is pressed using a KOMET type DD85G press (IBG Monforts Ockotec GmbH, Germany). This press is fitted with a 10 mm die at a rotation speed of 25 rpm. The outlet head was heated to 105˚C for 25 min at the start of extraction. As a result, the crude oil obtained is very cloudy and mixed with impurities. It was therefore left to settle for several days. Part of the oil is pressure-filtered using filters fitted with special cloths, while the remainder is used for activated carbon treatment tests.

2.3. Preparing and Activating Sand

The sand used was dune sand from the region of Dakar, Senegal (latitude: 14˚41'31" North; longitude: 17˚26'51" West). A 10 kg mass of dune sand was taken, cleaned to remove impurities and sieved on a 0.400 mm sieve, to homogenise particle size. Activation with sulphuric acid was performed according to, the method written by Abdelkader Ouakouak, (2017) [15].

Next, 2 Kg of dune sand was mixed with 2 Kg of 0.1 M sulphuric acid. The mixture was stirred for 1 h. Excess acid was neutralised with 0.2 M sodium hydroxide. The sand is then rinsed several times with distilled water to bring the pH down to between 6.5 and 7.5, and oven-dried at 105˚C for 24 h. The prepared sand is then placed in a hermetically sealed jar until the baobab crude oil processing trials (**Figure 3(b)**).

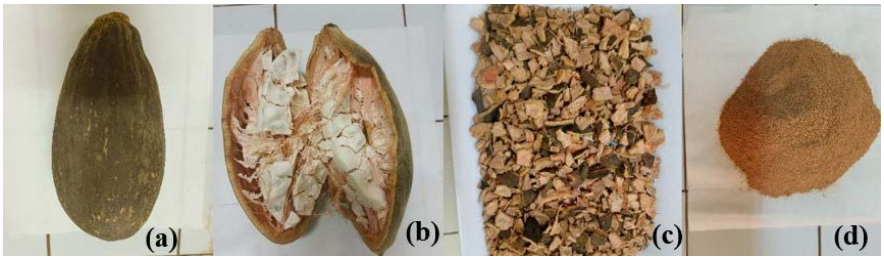

Figure 2. Whole fruit (a), open fruit (b), crushed hulls (c) and ground hulls (d) of baobab fruit (*Adansonia digitata* L.).

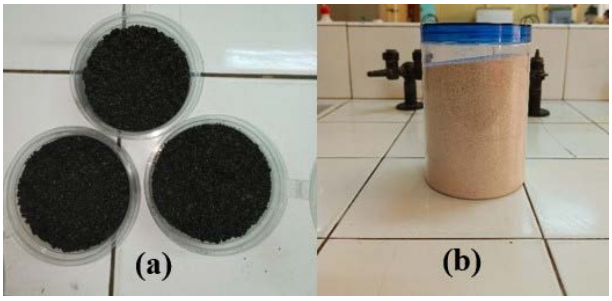

Figure 3. Activated charcoal from baobab fruit shells (a), activated dune sand (b).

2.4. Preparation of Activated Charcoal

The biomass thus obtained was chemically pre-treated with H_3PO_3 orthophosphoric acid (85%) before being carbonised in the furnace according to, the method described by Maazou *et al.*, (2017) [16].

After steaming at 105˚C, 150 g of the raw material is brought into contact with 300 g of the acid under stirring (1 h). The resulting mixture is oven-dried at 120˚C for 6 h [17], and then stored in hermetically sealed bottles in the dark until the carbonization tests.

Pyrolysis was carried out in a tube furnace (Eraly) which was preheated to 530˚C before the start of the experiment, to achieve a steady state temperature. After impregnation, the mixture was fired for 2 hours. The resulting coals were first cooled in the furnace and then in a desiccator.

Next, to remove any carbonization residues, the activated carbons are washed in 0.1 M hydrochloric acid and/or sodium hydroxide solutions, then rinsed thoroughly with distilled water to achieve a pH of between 6.5 and 7. The washed and rinsed carbons are oven-dried at 105˚C for 24 hours, then cooled and stored in hermetically sealed jars until the filtration tests (**Figure 3(a)**).

2.5. Analytical Methods

Acid and peroxide values, carotenoid and chlorophyll composition and extinction coefficients (K_{232} and K_{270}) were determined in order to assess the impact of activated carbon filtration on the stability of treated baobab oil. French standards [18] were used to determine peroxide and acid values respectively. The chlorophyll and carotenoid contents of baobab oil were determined by UV spectrophotometer measurement using the method described by [19]. Absorbances

were measured using a spectrophotometer (UV/VIS type LLG-uniSPEC 2) at wavelengths of 232 and 270 nm.

2.5.1. Acid Value (AV)

It consists in neutralising the free fatty acids present in an oil with an alcoholic solution of potassium hydroxide [18].

To the nearest 0.01 g, 5 g of oil is weighed into a 250 mL flask, into which 50 mL of ethanol (95%) is added. The mixture is then heated gently to near boiling point. In the presence of phenolphthalein, titrate with ethanolic potassium hydroxide solution (KOH 0.1 N) until the color indicator turns pink (a persistent pink color lasting at least 10 seconds, marking the end of the determination).

Taking into account that 1 mL of normal potassium hydroxide solution corresponds to 56.1 mg potassium, the acid value (mg KOH/g oil) is equal to:

$$\mathbf{Av} = \frac{V \times N \times 56.1}{E} \tag{1}$$

V, is the volume (ml) of the ethanolic potassium hydroxide solution (0.1 N) used and *E*, the mass in grams (g) of the test sample.

2.5.2. Peroxide Value (PV)

The test sample, dissolved in acetic acid and chloroform, is treated with a potassium iodide solution [18]. The iodine released is titrated with a solution of sodium thiosulfate (0.01 N).

In a 500 mL flask, 2.0 g of baobab oil is weighed, dissolved in 10 mL of chloroform, 15 mL of acetic acid and 1 mL of saturated potassium iodide solution. The flask is then stoppered, the mixture stirred for one (01) minute and placed in a dark place for five (05) minutes. After this time, 75 mL of distilled water is added and titrated in the presence of starch employments by shaking vigorously. At the same time, the fat-free blank test is carried out.

The peroxide value, expressed in micrograms of active oxygen per gram ($mEqO_2 \cdot Kg^{-1}$), is calibrated at:

$$\mathbf{Pv} = 1000 \times \frac{(V - Vb) \times 0.01}{E} \tag{2}$$

where *V*, is the volume of sodium thiosulfate solution used for the test. *Vb*, blank volume and *E*, test sample mass in grams.

2.5.3. Determination of Chlorophylls and Carotenoids

The chlorophyll and carotenoid contents of baobab oil were determined by UV spectrophotometer measurement using the method described by Gharby *et al.*, (2018) [19].

The oil sample to be analysed was prepared at 1% in cyclohexane. Next, 1 cm quartz cuvettes are filled with the prepared solution. The blank contains only cyclohexane. Absorbances are measured using a spectrophotometer at wavelengths of 670 nm for chlorophylls and 470 nm for carotenoids. The specific extinction coefficients are 613 and 2000 respectively for pheophytin (the main

component of the chlorophyll fraction) and lutein (the main component of the carotenoid fraction). The pigment content is determined as follows:

$$\text{Chlorophille}\left(\frac{\text{mg}}{\text{kg}}\right) = \text{Abs}670 * (106/613) * 100 * d \quad (3)$$

$$\text{Carotenoides}\left(\frac{\text{mg}}{\text{Kg}}\right) = \text{Abs}470 * (106/2000) * 100 * d \quad (4)$$

where Abs, is the absorbance; *d*, is the spectrophotometer cell thickness (1 cm). Results are expressed in milligrams of pheophytin and lutein per kilogram of oil, respectively.

2.5.4. Determination of Absorbance

Oxidation products of unsaturated fatty acids, when they have a conjugated diene structure for example (linoleic hydroperoxide), absorb at around 232 nm. Secondary oxidation products absorb at around 270 nm. Consequently, the determination of the absorbance in the vicinity of 232 and 270 nm enables the detection and evaluation of primary and secondary oxidation products [20]. To this end, 0.10 g to the nearest 0.0001 of baobab oil is weighed into a 25 mL flask and dissolved with cyclohexane, topping up to the mark. Next, 1 cm quartz cuvettes are filled with the prepared solution. The blank contains only cyclohexane. Absorbances are measured using a spectrophotometer at wavelengths 232 and 270 nm.

2.6. Presentation of the Experimental Set-Up

The experimental set-up consists of a glass column, 80 cm long and with an internal diameter of 2.5 cm, suspended from a gallows. The column is sealed with a stopper fitted with a small number of holes. The column is connected to a 1 L Büchner Erlenmeyer flask and a Vacuum MZ 2 NT, 7.0 mbar vacuum pump. To prevent the passage of particles into the filtrate, a layer of cotton was inserted in the lower part of the column (**Figure 4**).

Filtration is facilitated by the action of the vacuum pump. Thus, during the experiments, a sand bed with a thickness of 15 cm was used. In fact, according to studies carried out by Thiam lira, (2018) [21], the optimal thickness for effective treatment of crude groundnut oil was between 15 cm and 20 cm.

In the course of this study, the effectiveness of filtration with activated carbon or filter cloths on the chemical composition of baobab oil will be evaluated. Firstly, the role of sand in the experimental set-up will be assessed. Secondly, chemical characteristics such as acid value, peroxide value, carotenoid, chlorophyll, primary and secondary oxidation product composition will be determined for each treated oil. The comparison of the results obtained will enable alternative solutions to be proposed to the processing units, in order to improve the production conditions for vegetable oils in Senegal in general, and baobab oil in particular.

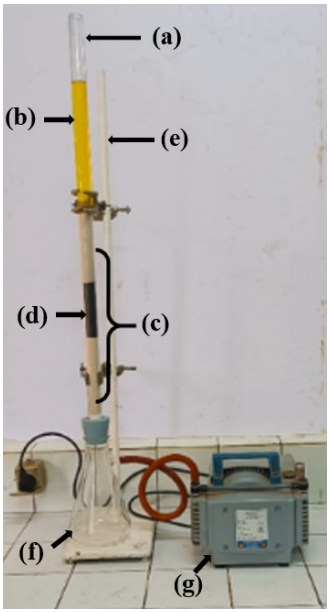

Figure 4. Experimental filtration system for baobab (*Adansonia digitata* L.) crude oil. Glass column (a); baobab oil (b), activated sand (c), activated charcoal (d), stem (e), Büchner Erlenmeyer (f), vacuum pump (g).

2.7. Statistical Analysis

One-way analysis of variance and Fischer's LSD test at the 5% significance level were used to compare means. The results obtained represent the average of three analyses, using STATISTICA (version 16.2.04) and RStudio (version 4.4.2) software.

3. Results and Discussion

To assess the impact of the treatment process on the oil stability, analyses were carried out after each filtration.

3.1. Initial Characteristics of Baobab Crude Oil

Immediate analysis of the crude baobab oil was carried out after extraction and decantation. The results are shown in Table 1.

Acid and peroxide values, chlorophyll and carotenoid composition, and oxidation product composition are parameters that characterise the stability and quality of vegetable oils [7] [22] [23]. The acid and peroxide values obtained were 1.62 mg KOH g^{-1} and 4.40 $mEqO_2 \cdot Kg^{-1}$ respectively. These acid and peroxide values are considerably higher than those found by Ndiaye *et al.* (2022). Indeed, the authors had found values for baobab oil corresponding to 0.5 mg KOH g^{-1} for the acid and 0.5 $mEqO_2 \cdot Kg^{-1}$ for the peroxide value. This difference would be reflected in a slight oxidation of the oil and low hydrolysis of triglycerides [23]. Carotenoid composition was 0.68 $mg \cdot kg^{-1}$ versus 1.81 $mg \cdot kg^{-1}$ for chlorophyll. Finally, primary oxidation products (K_{232} nm; 1.09) of crude baobab seed oil were higher than secondary oxidation products (K_{270} nm; 0.08).

Table 1. Physico-chemical characteristics of baobab oil.

Characteristics	Crude oil	Oil filtered on sand
Acid value (mg KOH g^{-1})	$1.62^{a} \pm 0.16$	$1.33^{c} \pm 0.10$
Peroxide value ($mEqO_2 \cdot Kg^{-1}$)	$4.40^{a} \pm 0.33$	$3.46^{b} \pm 0.24$
Chlorophyll ($mg \cdot kg^{-1}$)	$1.81^{a} \pm 0.26$	$1.62^{ab} \pm 0.09$
Carotenoids ($mg \cdot kg^{-1}$)	$0.68^{a} \pm 0.09$	$0.62^{a} \pm 0.01$
k_{232} nm	$1.09^{a} \pm 0.02$	$0.84^{b} \pm 0.01$
k_{270} nm	$0.08^{a} \pm 0.01$	$0.74^{ab} \pm 0.01$

Results are expressed as average ± standard deviation (n = 3); values with same superscript letters within the rows do not differ significantly ($p < 0.05$).

3.2. Evaluation of the Effect of Sand on the Efficiency of the Filtration Process

To assess the effect of sand on the chemical composition of processed baobab oil, the crude oil was filtered over activated sand. The filtrate obtained was analysed and the results reported in Table 1.

Analysis of the results obtained enabled us to assess the influence of sand use on our experimental set-up. The results presented in Table 1 show that sand filtration has no major effect on the composition of carotenoids, chlorophyll and primary and secondary oxidation compounds. Indeed, we noted a decrease in the pigment content of the filtered oil. However, no significant difference at the 5% threshold was observed. This was confirmed by visual analysis, which showed no difference in color between the crude oil and that filtered on activated sand. However, there was a slight decrease in the free acidity and peroxides present in the oil. As the oil sample passed over the sand bed, larger particles (>0.4 mm) were retained between the interstices. Particle adhesion to the surface of the filter material is favored by the low flow velocity [13] [21]. According to the results obtained, sand filtration has no major effect on the stability of the treated oil. The use of sand in our system was to retain particles in suspension.

3.3. Evaluation of the Effect of Processing on the Chemical Characteristics of Baobab (*Adansonia digitata* L.) Oil

Table 2 shows the results of the parameters analysed after filtration of baobab crude oil on filter cloths and activated carbon. To get an idea of the effect of the activated carbon mass on the oil treatment efficiency, two ratios, 3% and 5% (carbon mass to treated crude oil mass) were used. Analysis of variance at the 5% level enabled us to compare the different filtration techniques used.

The crude oil obtained after extraction was filtered at the production unit on filter cloths and in the laboratory using the experimental set-up (Figure 4) on activated carbon from baobab shells in the presence of treated dune sand. The results of the post-treatment analyses are given in Table 2.

Table 2. Chemical characteristics of baobab crude oil filtered on activated carbon and filter cloths.

Caractéristiques	Crude oil	Oil filtered		
		On canvas	On activated carbon (3%)	On activated carbon (5%)
Acid value (mg KOH g^{-1})	$1.62^{a} \pm 0.16$	$3.05^{b} \pm 0.03$	$0.71^{de} \pm 0.06$	$0.58^{e} \pm 0.03$
Peroxide value ($mEqO_2 \cdot Kg^{-1}$)	$4.40^{a} \pm 0.33$	$3.98^{ab} \pm 0.21$	$0.74^{c} \pm 0.00$	$0.50^{c} \pm 0.25$
Chlorophyll ($mg \cdot kg^{-1}$)	$1.81^{ab} \pm 0.26$	$1.62^{ab} \pm 0.09$	$0.63^{cd} \pm 0.01$	$0.50^{e} \pm 0.18$
Carotenoids ($mg \cdot kg^{-1}$)	$0.68^{a} \pm 0.09$	$0.62^{a} \pm 0.01$	$0.62^{a} \pm 0.12$	$0.43^{ab} \pm 0.09$
k_{232} nm	$1.09^{a} \pm 0.02$	$0.84^{b} \pm 0.01$	$0.078^{c} \pm 0.01$	$0.29^{d} \pm 0.03$
k_{270} nm	$0.08^{a} \pm 0.01$	$0.74^{ab} \pm 0.01$	$0.48^{d} \pm 0.01$	$0.32^{c} \pm 0.01$

Results are expressed as average ± standard deviation (n = 3); values with same superscript letters within the rows do not differ significantly ($p < 0.05$).

Firstly, this analysis showed that the acid value of the oil had increased significantly from 1.62^{a} to 3.05^{b} after filtration on cloths. This increase could be explained by the operating conditions in the processing unit. During filtration, the settled crude oil is placed in barrels exposed to light and oxygen from the air. The latter are pro-oxidants and could trigger or accelerate oil degradation reactions. In the case of activated carbon-filtered oil, statistical analysis revealed a significant reduction in acid number, regardless of the percentage of activated carbon used (0.71^{e} mg KOH g^{-1} with 3% vs. 0.58^{e} mg KOH g^{-1} with 5%). The peroxide value of the crude oil was 4.40^{a} $mEqO_2 \cdot Kg^{-1}$. After filtration on filter cloths, it remained almost the same (3.98^{ab} $mEqO_2 \cdot Kg^{-1}$). On the other hand, that filtered on activated carbon had decreased significantly from 4.40^{a} to 0.74^{c} $mEqO_2 \cdot Kg^{-1}$ with 3% activated carbon and to 0.50^{a} $mEqO_2 \cdot Kg^{-1}$ with 5% activated carbon.

Next, UV spectrophotometer analysis in cyclohexane at 670 and 470 nm determined the chlorophyll and carotenoid composition of the treated oil. Chlorophyll composition decreased significantly with charcoal mass. The crude oil had an initial chlorophyll concentration of 1.81 $mg \cdot kg^{-1}$. After filtration on activated carbon, this concentration fell to 0.63 $mg \cdot kg^{-1}$ with 3% activated carbon and to 0.50 $mg \cdot kg^{-1}$ with 5% activated carbon. On the other hand, although carotenoid concentration decreased from 0.68^{a} $mg \cdot kg^{-1}$ to 0.62^{a} and 0.43^{a} for oil samples treated with filter cloths and activated carbon, the analysis of variance revealed no significant difference at the 5% threshold. These minor compounds confer organoleptic and nutritional qualities to vegetable oils [13]. In addition, these compounds have a significant effect on the stability of this product during storage. Indeed, carotenoids, in particular the carotene pigment, are known to deactivate singlet oxygen produced by chlorophyll derivatives under the effect of radiation [24]. Carotene pigments are therefore considered to be among the most effective inhibitors of photo-oxidation [24]. Thus, a considerable decrease in carotenoid levels could be accompanied by an increase in oxidation by-products.

However, the considerable reduction in chlorophyll levels in our treated samples is beneficial for baobab oil, as chlorophylls are pigments that must be eliminated, or at least their concentration controlled, due to their negative effect on the stability of vegetable oils, particularly on oxidation. Several studies have demonstrated the peroxidizing power of these chlorophyll pigments when the oil is exposed to light, and their antioxidant action in the dark [24]. Chlorophylls *a* and *b* and their immediate degradation products, pheophytins *a* and *b*, are photosensitizers. In the presence of light, they change from their fundamental singlet state to an excited singlet state and then to a triple excited (metastable) state. These pigments tend to return to their singlet ground state by transforming atmospheric oxygen ($^3O_2$) into highly reactive singlet oxygen ($^1O_2$) [24].

Lastly, extinction coefficients at 232 and 270 nm give us an idea of the oxidation state of fats. The higher the extinction, the richer the oil is in oxidation products, and the less stable it is. Measurement of these specific extinction coefficients is suitable for determining oil quality [25]. The extinction coefficients K_{232} and K_{270} nm decreased significantly for the activated carbon process. On the other hand, there was a slight decrease with cloth filtration. This reduction in the concentration of primary and secondary oxidation products could be correlated with the reduction in oxidation and hydrolysis products in the oil.

Activated carbons are adsorbents, unlike cloth filters. The significant reduction in oxidation and rancidity products (free acids, hydroperoxides and toxic peroxides) in the oil can be explained by the fact that activated carbon adsorbs the various particles responsible for this phenomenon. Activated carbons have a porous structure made up of macropores, meso-pores and micropores, enabling them to adsorb certain particles [14] [26].

These results are consistent with those obtained by Thiam (2018), Lacoste *et al.* (2005) [27] and Sidani *et al.* (2012) [26]. Indeed, Thiam (2018) had reported a decrease in acid and peroxide values from 4.72 mg KOH g^{-1} and 14.26 meqO_2·kg^{-1} respectively for crude oil to 2.56 mg KOH g^{-1} and 13.08 meqO_2·kg^{-1} after treatment on 3% activated carbon. Lacoste et al (2005) reported that when activated carbon was added to bleaching earths, most of the polycyclic aromatic hydrocarbons (PAHs) were removed. Finally, Sidani *et al.* (2012) had worked on the filtration of an oil doped with four polycyclic aromatic hydrocarbons. They used activated carbon-lined plates to lower PAH levels. As a result, they noticed that PAH levels dropped considerably.

3.4. Statistical Analysis

3.4.1. Correlation of Baobab Oil Chemical Parameters

The correlation study between the various chemical quality characteristics of baobab seed oil is presented in **Table 3**. It shows a very strong positive correlation (r^2 = 0.99) between peroxide value and chlorophyll. The peroxide value is also positively correlated (r^2 = 0.96) with the K_{232} constant, which is positively correlated (r^2 = 0.96) with chlorophyll. On the other hand, the relationship between constant K_{270} and the peroxide value, chlorophyll, showed a negative cor-

relation.

3.4.2. Principal Component Analysis

A principal component analysis (PCA) was carried out to assess the impact of the filtration method on baobab oil stability. The first two dimensions (Dim1 and Dim2) express 91.26% of the total inertia (Table 4). Thus, the first dimension (Dim1) alone contributes 68.86% and the second (Dim2) 22.4%. The variables peroxide index (0.99), chlorophyll (0.99) and specific extinction coefficient K_{232} (0.93) are positively correlated with the first dimension. The second dimension is characterised by the variable K_{270} (0.99) (Figure 5).

The baobab oil samples processed and analysed were grouped into three classes (Figure 5 and Figure 6). Class 1 is the crude oil obtained after pressing, characterized by a low acid number and a high level of primary oxidation products and chlorophyll. The second class is represented by oil filtered on special cloths in the production unit. This second class is characterised by a high acid and peroxide value, and high levels of oxidation products and chlorophyll. Finally, the third class is represented by oils filtered on 3% and 5% activated carbon. It is characterised by a low presence of oxidation products and low acid and peroxide values. In short, these analyses show that oils filtered on activated charcoal give a more stable, cleaner oil with better physico-chemical qualities.

Table 3. Pearson correlation coefficients between physical parameters of baobab oil (*Adansonia digitata* L.).

Variables	Acid value	Peroxide value	Chlorophyll	Carotenoids	k_{232}	K_{270}
Acid value	1					
Peroxide value	0.81	1				
Chlorophyll	0.79	0.99	1			
Carotenoids	0.52	0.66	0.68	1		
k_{232}	0.70	0.96	0.96	0.47	1	
k_{270}	0.53	−0.04	−0.07	0.11	−0.23	1

Table 4. Correlation between components and variables.

Variables	Components	
	Dim1	Dim2
Acid value	0.84	0.52
Peroxide value	0.99	−0.07
Chlorophyll	0.99	−0.09
Carotenoids	0.76	0.10
k_{232}	0.93	−0.24
k_{270}	0.03	0.99
Own value	4.13	1.34
Variance (%)	68.87	22.41
Cumulative variance (%)	68.86	91.26

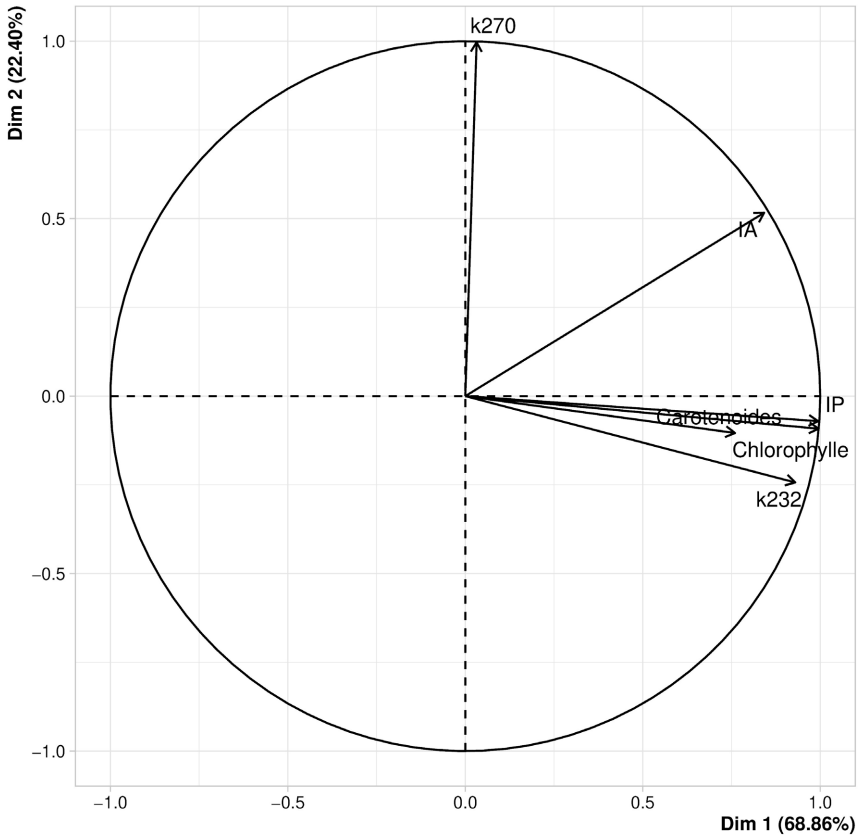

Figure 5. Correlation between the chemical characteristics of baobab oil and the first two dimensions of the PCA.

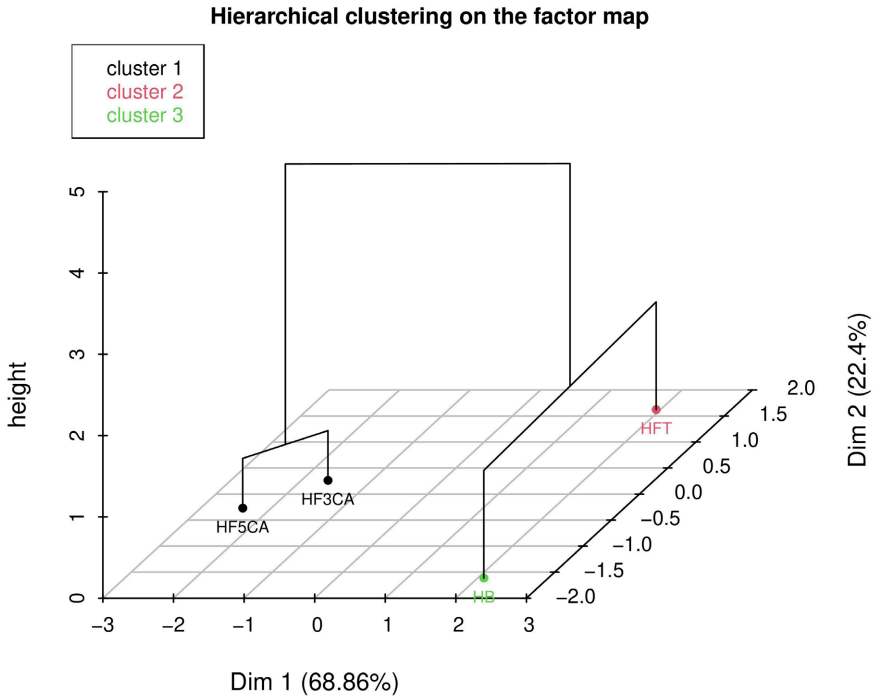

Figure 6. Dendrogram of baobab oil samples studied after cluster analysis: class 1 (CI), class 2 (CII), class 3 (CIII).

4. Conclusion

The aim of this study was to provide local companies with innovative and effective solutions for processing unrefined vegetable oils. To assess the effect of processing on stability, certain parameters characteristic of oil quality (acid and peroxide values, chlorophyll and carotenoid content, and extinction coefficients K_{232} and K_{270}) were determined after each filtration. The results show that filtration of crude oil on filter cloths was effective in retaining suspended particles. However, the working conditions in the processing unit favored oil oxidation, with the acid number rising from 1.62^{a} for the initial crude oil to 3.05^{b} mg KOH g^{-1}. In addition, these results show that activated carbon filtration preserves oil quality at its best. Indeed, thanks to its adsorbent capacity, activated carbon reduced the concentration of free fatty acids, oxidation products and certain pro-oxidants such as chlorophyll, making the oil more stable, clearer and of better physico-chemical quality. These results suggest the coupling of these two treatment methods (that's to say a filtration on filter cloths packed with activated carbon) within the processing unit to optimise process efficiency and thus obtain more stable, higher quality oil. The filter cloths retain suspended particles, while the activated carbon adsorbs the oxidation products formed, as well as certain pigments and pro-oxidant elements. However, when filter cloths are used, we recommend that they are used in a closed circuit to protect the product from pro-oxidants. For this reason, the control of certain parameters in the working environment remains crucial.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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