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Processes for the Clarification of the Crude Oil of Baobab Seeds Extracted by Pressing on Activated Carbon Elaborated from the Capsules of the Fruit (*Adansonia digitata* L.)

Edouard Mbarick Ndiaye[1,2*], Alioune Sow[3], Kalidou Ba[1], Mouhamed Ndoye[1], Yousra El Idrissi[2], Seyni Ndiaye[1], Hamza El Moudden[4], Papa Guedel Faye[1], Hicham Harhar[2], Nicolas Ayessou[1], Mohamed Tabyaoui[2], Mady Cisse[1]

[1]Laboratory of Water Energy Environment and Industrial Processes (LE3PI), ESP-UCAD, ESP-UCAD, Cheikh Anta Diop University, Dakar, Senegal
[2]Laboratory of Materials, Nanotechnology and Environment, Faculty of Sciences-Rabat, Mohammed V University of Rabat, Rabat, Morocco
[3]Laboratory of Biological, Agronomic, Food Sciences and Modeling of Complex Systems (LABAAM), UFR of Agronomic Sciences, Aquaculture and Food Technologies (S2ATA), Gaston Berger University of Saint-Louis, Saint-Louis, Senegal
[4]Higher School of Technology of El Kelaa of The Sraghna, Cadi Ayyad University, Marrakech, Morocco
Email: *papaedou@gmail.com, alioune.sow@ugb.edu.sn, kalidouba228@gmail.com, ndoyeline@gmail.com, yousra.elidrissi93@gmail.com, seyni.dic.ia@gmail.com, hamzaelm802@gmail.com, papaguedel.faye@esp.sn, hichamoo79@yahoo.fr, nicolas.ayessou@ucad.edu.sn, tabyaouihamid@gmail.com, mady.cisse@ucad.edu.sn

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Abstract

The baobab, *Adansonia digitata* L. plays an important role in the economy of local populations. The oil from the seeds of the baobab fruit is nowadays highly prized because of its numerous cosmetic and therapeutic applications and its composition of unsaturated fatty acids, sterols and tocopherols. However, unlike refined oils, locally extracted baobab oil has not undergone purification operations to ensure its quality. Only a filtration on special cloths is carried out after decantation. Indeed, the oil obtained after pressing is cloudy because of the presence of various impurities. It therefore requires treatment operations to make it more attractive and of higher quality. Therefore, in order to provide innovative solutions to local companies to improve the quality of vegetable oils, a study of clarification (treatment) of crude oil is necessary. An experimental device has been developed in the laboratory. It includes a glass column and a filter bed of dune sand and activated carbon. This study has shown the efficiency of the experimental device. Indeed, the activated carbon, thanks to its adsorbing power, has allowed a significant decrease in turbidity at the 5% threshold, from 14.61 NTU for the raw oil to 0.08 NTU for the oil filtered on 3% carbon and 0.033 NTU for the oil filtered on 5% carbon. That is to say an abatement higher than 95%. This decrease in turbidity could be correlated with the decrease in brown index from 187.39^{a} for the initial crude oil to 128.53^{d} for the oil treated with 3% activated carbon versus 187.59^{a} for the oil filtered on cloths. The lowest brown index was observed with the filtration using 5% activated carbon (35.99^{b}). Thus, for the yellowness index, only the filtration on 5% charcoal allowed to obtain a significant decrease in yellowness. The yellowing index of the oil with 5% was 44.67^{b} against 79.04^{a} for the oil filtered with 3% activated carbon, 86.33^{a} for the crude oil and 86.46^{a} for the oil filtered on cloths. Finally, the oil sample treated with 5% activated carbon had the clearest clarity than the other samples with a clarity (L) equal to 97.98^{c} against 95.63^{d} for the oil treated with 3% carbon and 94.99^{b} for the oil filtered on filter cloths. According to the results obtained, the experimental device made it possible to obtain a clearer baobab oil with a low brown index, thus improving the sensory quality of the oil.

Keywords

Activated Carbon, Baobab Oil, Clarification, Filtration, Process

1. Introduction

The African baobab, scientific name *Adansonia digitata* L. belongs to the family Bombacaceae, order Malvales [1] [2]. It plays an important social, economic and environmental role [3] (Ndiaye, 2020). The baobab fruit contains black to brown seeds [4]. The seeds, which represent more than half of the dehusked fruit, are under-exploited compared to the pulp [2]. In Senegal, until now, only a few industrialists and women grouped in cooperatives are active in the processing of vegetable oils and with little means [5]. In addition, the authorization by the European Union Commission on June 27, 2008, to market dehydrated baobab pulp as a new food ingredient, has increased the economic value of the species on a national and international scale. Since 2009, annually, more than 100 tons of raw pulp and 50 tons of baobab seeds are processed into powder and oil, respectively, and exported by small and medium enterprises [6]. Today, the seeds of the baobab fruit are highly prized because of the lipids (12.2%) they contain [7] [8]. Indeed, baobab seed oil is highly sought after by the cosmetic and pharmaceutical industries because of its composition [7] [9]. According to Vermaak *et al.* 2011 [10], this oil is composed of saturated fatty acids (33%), monounsaturated fatty acids (36%) and polyunsaturated fatty acids (31%). They also state that baobab oil contains phytosterols such as β-sitosterol, campesterol and stigmasterol. Other authors, had indicated the presence of vitamins A, D, E and K in baobab oil [11] [12]. Cyclopropenic acids are also present. Finally, the seeds are also rich in sodium, phosphorus and magnesium [2] [4]. A liter of baobab oil can cost up to 30 USD.

However, like all unsaturated vegetable oils, baobab oil is sensitive and subject to several degradation reactions during the various stages of production, processing and storage [8]. Indeed, the crude baobab oil, after extraction in the press is very cloudy because of the presence of particles in suspension [5] [8]. In addition, the operating conditions of pressing, light, heat and oxygen in the air, are the triggers of alteration reactions that are sometimes irreversible. These reactions lead to the degradation of the oil. Thus, the objective of this study is to provide innovative and effective solutions to small and medium-sized local enterprises for the treatment of unflourised crude vegetable oils. Indeed, in these local processing units, the crude oil obtained is only filtered by means of special filter cloths after decantation. In addition, the sensory quality of the vegetable oils extracted by hand remains poor. Thus, trials were undertaken to clarify (treat) the crude baobab oil using activated charcoal made from the baobab fruit capsules, which are usually discarded in the forest [13]. An experimental device consisting of a glass column, a sand filter bed for the removal of visible particles in suspension and an activated carbon filter bed as well as a vacuum pump was developed for this purpose. After each test, physical analyses were performed to evaluate the effect of the treatment on the quality of the baobab oil.

2. Materials and Methods

2.1. Collection and Preparation of Plant Material

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

Baobab fruits are first, shelled and the different components separated (**Figure 1**). Initially, the seeds are covered with the whitish pulp. The seeds are separated from the pulp by the dry method. First, the seeds covered with pulp are dried in the sun and then pulped in a 316N stainless steel pulping machine equipped with a 150 μm sieve. Then, this step is followed by a coarse sieving to separate the pulp from the seeds. The latter are crushed in a millet mill with a capacity of 300 to 350 $kg \cdot h^{-1}$ with an electric motor power estimated at 7.5 CV, equipped with sieves with holes of 02 mm in diameter and a speed of 2800 rpm. The obtained grind is collected in a basin.

The shells (capsules) collected were washed thoroughly with water and then

Figure 1. Whole fruit (A), opened fruit (B), pulp-enveloped seeds (C), pulp-free seeds (D), crushed seeds (E), and crushed seed kernel (F) of baobab fruit (*Adansonia digitata* L.).

dried in the sun for 3 days. Then, they were crushed in a mortar before being dried in the study at 105˚C for 24 h. They are crushed using a blender type (HAEGER, Model No. HG-2801, made in P.R.C). Finally, the obtained crushed material is sieved through a 0.400 mm diameter sieve. The resulting biomass is used for the production of activated carbon. **Figure 2** shows the different stages of preparation of the baobab fruit capsules.

2.2. Obtaining Baobab Oil

The baobab seed kernel powder is pressed with a press type KOMET, DD85G (IBG Monforts Ockotec GmbH, Germany). This press is equipped with a 10 mm die with a rotation speed of 25 rpm. The outlet head was heated to 105˚C for 25 min at the beginning of the extraction. Thus, the crude oil obtained is very cloudy and mixed with impurities. It is therefore left to decant for several days. One part will be filtered under pressure with special cloth filters and the other part will be used for treatment tests on activated carbon.

2.3. Preparation and Activation of the Sand

The sand used was a dune sand from the region of Dakar, Senegal (latitude: 14˚41'31" North; longitude: 17˚26'51" West). 10 kg mass of dune sand was collected, cleaned to remove impurities and sieved on a 0.4 mm sieve, to homogenize the particle size. Activation with sulfuric acid was performed according to, the method of written by Abdelkader Ouakouak, 2017 [14].

Then, 2 Kg of dune sand were mixed with 2 Kg of 0.1 M sulfuric acid. The mixture was stirred for 1 h. The excess acid is neutralized with 0.2 M sodium hydroxide. The sand is then rinsed several times with distilled water to bring the pH between 6.5 and 7.5 then dried in an oven at 105˚C for 24 h. Thus, the prepared sand is then, put in a sealed jar until the tests of treatment of crude oil of baobab (**Figure 3(B)**).

Figure 2. Whole fruit (A), opened fruit (B), crushed hulls (C) and crushed 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 the Activated Carbon

The biomass thus obtained was chemically pre-treated with orthophosphoric acid H_3PO_3 (85%) before being carbonized in a furnace according to the method described by [13].

Therefore, after steaming at 105˚C, 150 g of the raw material is put in contact under stirring (1 h) with 300 g of the acid. The resulting mixture was oven dried at 120˚C for 6 h [15] and then stored in hermetically sealed flasks in the dark until the carbonization tests.

Pyrolysis was performed in a tube furnace (Eraly) preheated to 530˚C before the beginning of the experiment to obtain a steady state temperature [16]. Indeed, after impregnation, the mixture was oven-fired heated for 2 h. The resulting chars were first cooled in the oven and then in a desiccator.

Then, in order to eliminate possible carbonization residues, the activated carbons are washed in 0.1 M hydrochloric acid and/or soda solutions and rinsed thoroughly with distilled water to obtain a pH between 6.5 and 7. The washed and rinsed carbons are then dried in an oven at 105˚C for 24 h then cooled and stored in hermetically sealed jars until the filtration tests (**Figure 3(A)**).

2.5. Analytical Methods

The brown index, yellowness index, clarity and turbidity were determined to evaluate the impact of activated carbon filtration on some quality markers of baobab seed oil (*Adansonia digitata* L.). Thus, brown index, clarity and yellowness index were determined with a colorimeter type CM-5, Konica Milnota Sensing Americas Inc, US. Turbidity was determined with the Eutech TN-100 turbidimeter, Thermo scientific, according to the method written by the Centre d'expertise en analyse environnementale du Québec [17].

2.5.1. Color Index (Ic)

Colorimetry is a process by which it is possible to find the degree of absorbance of light by the liquid [8]. The darker the color, the greater the absorbance. The color or yellowness index allows us to assess the quality of the color of the oil. The measurement of this index noted Y1 is well suited to assess the state of degradation of an oil, exposed to heat, light or other environment. It is determined according to the method adopted by [8]. The liquid oil sample is poured into the cell with a sufficient optical path length for the defined ranges and then the cell is placed in the light box near the observation tube. Then, the cover of the box is closed and the color of the sample is determined thanks to a model of representation of the colors. The colorimeter used is of type MINOLTA CR-5.

2.5.2. Brown Index (Ib)

The brown index represents the proportion of the yellow color to the red color while the violet index represents the proportion of blue to red. The color is determined by a device called a MINOLTA CR-5 type colorimeter using the method adopted by Sow, 2019. This device measures the transmission and gives the values of L^*, a^*, b^* which allow us to calculate the brown index according to Equation (1):

$$IB = \frac{100(x-0.31)}{0.172} \tag{1}$$

$$\text{with}: x = \frac{(a+1.75L)}{(5.645L+a-3.012b)}$$

with: a^*: represents the chromatic component of the Red (a^+) to the Green (a^-); b^*: represents the chromatic component of the yellow (b^+) to the blue (b^-); L^*: represents the brightness, $L = 0$ (Black), $L = 100$ (White).

2.5.3. Turbidity

Turbidity is an index of the presence of suspended particles in the product (20 Centre of Expertise). Turbidity was determined by adapting the method written by the Centre d'expertise en analyse environnementale du Québec [17]. It is determined using a nephelometer. This device measures the light scattered by the suspended particles at an angle of 90˚ to the incident light beam. The microprocessor converts the amount of light received into NTU (Nephelometric Turbidimeter Unit) values. The oil to be analyzed is poured into a measuring cuvette and sealed. Then the cuvette is placed in the measuring base of the turbidimeter, making sure that the pin is positioned opposite the arrow. The turbidity value read is shown on the display. The turbidity result is the average of three measurements taken. The turbidimeter was a EUTCH TN-100, waterproof turbidimeter.

2.5.4. Presentation of the Experimental Device

The experimental device consists of: a glass column of length 80 cm and internal diameter 2.5 cm, hung on a gallows. The column is closed by a stopper with a minimum of holes. The column is connected to a 1 L Büchner Erlenmeyer flask connected to a vacuum pump, Vacuum MZ 2 NT, 7.0 mbar. In order to avoid the passage of particles in the filtrate, a cotton layer was introduced in the lower part of the column (**Figure 4**).

The filtration is facilitated by the action of the vacuum pump. Thus, during the experiments, a 15 cm thick sand bed was used. Indeed, according to studies conducted by Thiam lira, 2018 [18], the optimal thickness that allows effective treatment of crude peanut oil was between 15 cm and 20 cm.

Thus, during this study, the effectiveness of filtration by activated carbon or filter cloths on the chemical composition of baobab oil will be studied. For that, in a first step, the role of sand on the experimental device will be evaluated. Secondly, the physicochemical characteristics such as: the yellowing index, the brown index, the peroxide index, the composition of the oil in carotenoids, chlorophyll, primary and secondary oxidation products and the turbidity will be determined for each treated oil. The comparison of the results obtained will make it possible to propose to the processing units alternative solutions for the improvement of the conditions of production of vegetable oils in Senegal in general and baobab oil in particular.

2.5.5. Statistical Analysis

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

3. Results and Discussion

To evaluate the impact of the treatment process on the oil quality, analyses are performed after each filtration.

3.1. Initial Characteristics of the Baobab Crude Oil

Immediate analysis of the crude baobab oil was performed after extraction and decantation. The results of this analysis are recorded in **Table 1**.

The yellowing index, brown index, clarity and turbidity are among the characteristic parameters of the quality of vegetable oils [8] [19]. The crude oil of baobab initially analyzed presents a yellowing index and a high brown index respectively equal to 86.33 and 187.39. These high values could be correlated to the content of unsaponifiable matter such as carotenoids, but also to the presence of compounds from the first reactions of degradation of the oil since the beginning

Figure 4. Experimental filtration device for baobab (*Adansonia digitata* L) crude oil.

Table 1. Physical characteristics of crude baobab oil determined after extraction.

Characteristics	Raw baobab oil (*Adansonia digitata* L.)
Indice de jaunissement	86.33 ± 0.0067
Indice brun	187.39 ± 0.77
Clarity	95.25 ± 0.045
Turbidity (NTU)	14.61 ± 0.24

of the process [5]. The clarity (L) of the crude oil obtained was 95.25. The high turbidity (14.61) could reflect the presence of solid impurities and colloidal materials in suspension in the crude baobab oil [18].

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

Thus, to evaluate the role of sand on the experimental setup, filtration of oil over activated sand was performed. The filtrate obtained is analyzed and the results are reported in **Table 2**. These results are compared with those of the raw oil initially analyzed.

The analysis of the results obtained allowed us to evaluate the influence of the use of sand on our experimental device. It appears from the results presented in **Table 2** that the filtration on the sand has no significant effect on the browning, yellowing and even less on the clarity of the oil analyzed. This is confirmed by the visual analysis, which did not allow for any difference in terms of yellowing between the crude oil (86.33^a) and that filtered on the dune sand (86.12^a). However, the turbidity of the sand-filtered oil showed a significant reduction from 14.61 NTU to 0.99 NTU. Thus, 93.22% of the solid and or colloidal impurities were retained by the sand bed. Indeed, during the passage of the oil sample on the sand bed, the larger particles (>0.4 mm) could be retained between the interstices. The attachment of particles to the surface of the filtering material is favored by a low flow velocity [18]. The results obtained show that filtration on sand has no major effect on the final composition of the treated oil. The sand in our device, simply allowed the retention of particles in suspension.

3.3. Evaluation of the Effect of Treatment on the Quality of Baobab Oil (*Adansonia digitata* L.)

Table 3 presents the results of the physical analyses carried out after the filtration of baobab crude oil on filter cloths and activated carbon. Thus to have an idea of the effect of the mass of activated carbon on the efficiency of the oil treatment, two ratios, 3 and 5% were used (mass of carbon on mass of crude oil treated). The analysis of variance at the 5% threshold allowed us to compare the different oil 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 device on activated carbon of baobab shells in the presence of treated dune sand. The results of the

Table 2. Physico-chemical characteristics of sand-filtered baobab crude oil.

Characteristics	Crude oil	Sand filtered oil
Yellowing index	$86.33^a \pm 0.0067$	$86.12^a \pm 0.26$
Brown index	$187.39^a \pm 0.77$	$183.51^a \pm 3.0067$
Clarity	$95.25^a \pm 0.045$	$95.15^a \pm 0.043$
Turbidity (NTU)	$14.61^a \pm 0.24$	$0.99^{b,c} \pm 0.43$

Table 3. Physico-chemical characteristics of raw baobab oil filtered on activated carbon and on filter cloths.

Characteristics	Crude oil	Filtered oil on canvas	Filtered oil on activated activated carbon (3%)	Filtered oil on activated carbon (5%)
Yellowing index	$86.33^{a} \pm 0.0067$	$86.46^{a} \pm 0.26$	$79.04^{a} \pm 0.0063$	$44.67^{b} \pm 0.0067$
Brown index	$187.39^{a} \pm 0.77$	$187.59^{a} \pm 1.024$	$128.53^{d} \pm 0.160$	$35.99^{b} \pm 0.084$
Clarity	$95.25^{a} \pm 0.045$	$94.99^{b} \pm 0.083$	$95.66^{d} \pm 0.063$	$97.98^{c} \pm 0.0033$
Turbidity (NTU)	$14.61^{a} \pm 0.24$	$0.99^{bc} \pm 0.43$	$0.08^{d} \pm 0.013$	$0.033^{d} \pm 0.0044$

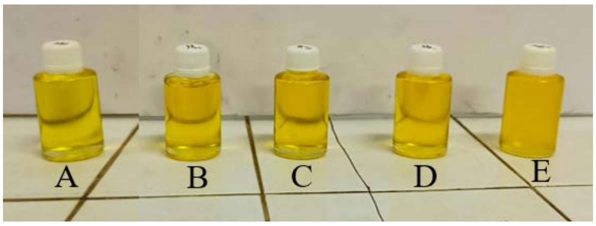

Figure 5. (A) Oil filtered on 5% activated carbon; (B) oil filtered with 3% activated carbon; (C) oil filtered on filter cloths; (D) oil filtered on dune sand; (E) crude oil from the seeds of the baobab fruit (*Adansonia digitata* L.).

analyses carried out after the treatments are recorded in Table III. Figure 5 shows the different treated oils.

Firstly, it appears from this analysis that the yellowing of the oil decreased slightly from 86.33^{a} for the crude oil to 79.04^{a} for the oil filtered with 3% activated carbon. Filtration on specific cloths did not modify the coloration of the oil. However, there was a significant difference in the yellowing index between the crude oil and that filtered with 5% activated carbon (44.67^{b}). This decrease could be the consequence of a reduction of carotenoids present in baobab oil. Indeed, according to Ndiaye *et al*, (2022), it is the carotenoids that are responsible for the yellow color of baobab oil. Then, for the browning, we note that the decrease was significant for the treatment using activated carbon. The browning went from 187.39^{a} to 128.53^{d} for the oil filtered on 3% activated carbon and to 35.99^{b} for the one treated with 5% carbon. In addition, the clarity (L) of the analyzed samples (95.25^{a}) increased significantly for the oil filtered on activated carbon (95.66^{d} at 3% and 97.98^{c} at 5%. While turbidity decreased significantly regardless of the filtration technique used. The turbidity of the raw oil was 14.61^{a} NTU and decreased to 0.99^{bc} NTU for the oil treated on filter cloths. The decrease was more significant with activated carbon filtration (0.08^{d} NTU at 3% versus 0.033^{d} NTU at 5%).

Visual analysis of the different oil samples (Figure 5) confirmed these obtained results. Samples A, B, C, D and E correspond respectively to oil filtered on 5% activated carbon, oil filtered on 3% activated carbon, oil filtered on filter cloths, oil filtered on activated dune sand and finally the raw oil. Thus, bottle E was more turbid than bottle D which was more turbid than bottle C which was more turbid than bottle B which was more turbid than bottle A. In addition, the oil treated with activated carbon was clearer and its browning was less accentuated.

These results are in agreement with those found by Lira Thiam, (2018). Indeed, the author had noted a clear improvement in the organoleptic quality of peanut oil treated on activated carbon. In addition, Lacoste *et al.* (2004) [20] report that when activated carbon was added to the bleaching earth, most of the impurities including polycyclic aromatic hydrocarbons (PAH) were removed.

3.4. Statistical Analysis

3.4.1. Correlation of Studied Physicochemical Parameters of Baobab Oil

The correlation study between the different physical quality characteristics of baobab seed oil is presented in Table 4. It shows a very strong positive correlation ($R^2 = 0.97$) between the yellowing index and the brown index. On the other hand, the relationship between yellowing index and lightness reported a strong negative correlation ($R^2 = -0.99$). Finally, lightness was negatively correlated with the brown index ($R^2 = -0.97$).

3.4.2. Principal Component Analysis

A principal component analysis (PCA) was performed to evaluate the impact of the filtration method on the quality of baobab oil. The first two dimensions (Dim1 and Dim2) express 99.5% of the total inertia (Table 5). Therefor, the first

Table 4. Pearson correlation coefficients between physical parameters of baobab oil (*Adansonia digitata* L.).

Variables	Yellowing index	Brown index	Clarity	Turbidity (NTU)
Yellowing index	1			
Brown index	0.97	1		
Clarity	−0.99	−0.97	1	
Turbidity (NTU)	0.45	0.53	−0.39	1

Table 5. Correlation between components and variables.

Variables	Components	
	Dim1	Dim2
Yellowing index	0.98	−0.18
Brown index	0.99	−0.073
Clarity	−0.97	0.24
Turbidity	0.59	−0.80
Eigen value	3.24	0.73
Variance (%)	81.08	18.38
Cumulative variance (%)	81.08	99.46

dimension (Dim1) alone contributes 81.1% and the second (Dim2) 18.4%. The variables yellowing index (0.98), brown index (0.99) are positively correlated with the first dimension, which is negatively correlated with lightness (−0.97). The second dimension is characterized by the variable turbidity (0.80) and is positively correlated (Figure 6).

The processed and analyzed baobab oil samples were grouped into three classes (Figure 6 and Figure 7). Class 1 consists of crude oil characterized by a high brown index and turbidity. The second class is represented by the oils filtered on cloths and on 3% activated carbon. It is characterized by a high yellowing index. The third class is represented by oil filtered on 5% activated carbon, characterized by a very clear and a very low yellowing and browning index. In

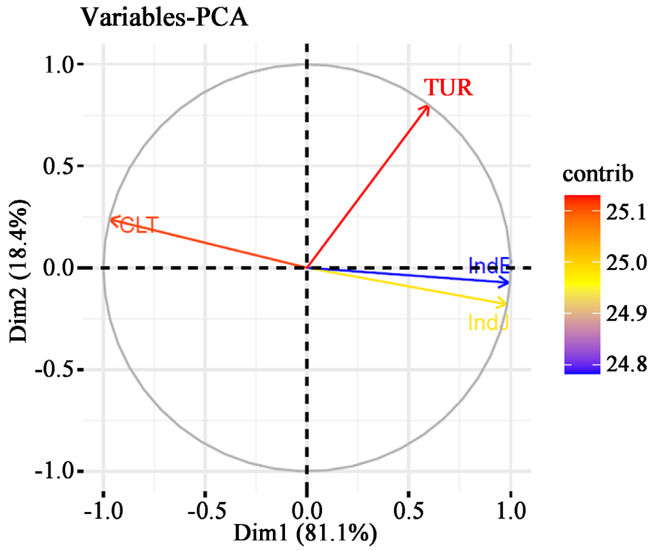

Figure 6. Correlation between the physical characteristics of baobab oil and the first two dimensions of the PCA.

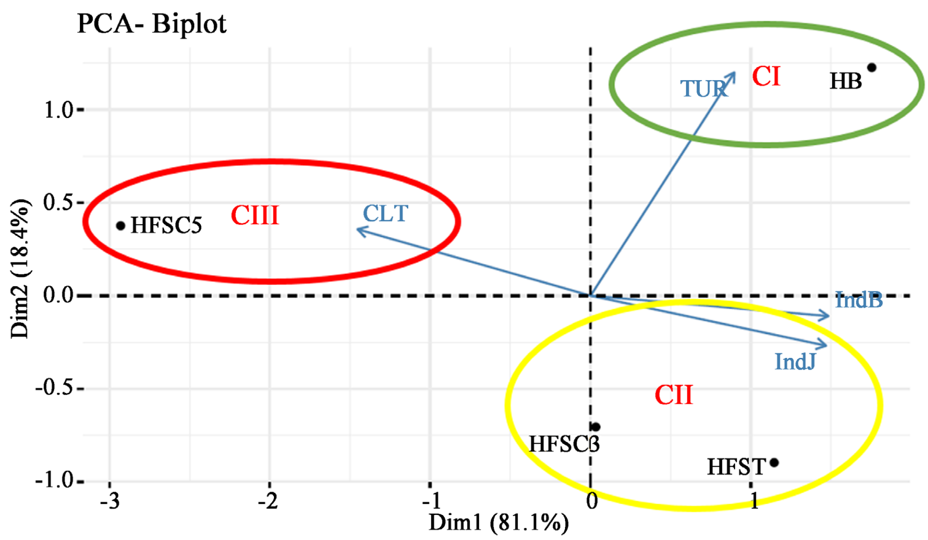

Figure 7. Projection of individuals on the factorial diagram (Dim1, Dim 2): Dimension (Dim), Class 1(CI), Class 2 (CII), Class 3 (CIII).

summary, it appears from these analyses that the oils filtered on activated charcoal allowed to obtain a clearer oil, of better physical quality.

4. Conclusion

The objective of this study was to provide innovative and efficient solutions to local companies in the treatment of unrefined vegetable oils. The results obtained show that filtration on activated carbon preserves the quality of the oil at best. Indeed, activated carbon, because of its adsorbing power [18], has reduced almost all the impurities present in the oil. On the other hand, unlike filtration on special cloths, filtration on activated carbon considerably reduces the carotenoids. Indeed, at 5% activated carbon, there is a strong decrease in carotene pigments which can be natural antioxidants for vegetable oils. Therefore, further studies will be necessary to determine the optimal conditions (ratios: activated carbon and filtering sand/oil mass) for the treatment of this oil. In addition, when filtration on filter cloths must be carried out, it is advisable to do so in a closed circuit to protect the product from pro-oxidants. Therefore, the control of certain parameters of the working environment remains crucial.

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Conflicts of Interest

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

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