

Stability Monitoring of Baobab's Oil According to Physicochemical Parameters

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Abstract The objective of the study is to investigate the impact of baobab seed pretreatment operations, origin and type of packaging on the stability of baobab oils after fourteen (14) months of storage at room temperature. Thus, the acid, iodine, peroxide, saponification, refraction and color values of the oils extracted by cold pressing were evaluated. The results obtained reveal that the initial acid values (0.49 to 2.36 mgKOH.g⁻¹) significantly changed following packaging in amber (0.72 to 2.90 mgKOH.g⁻¹) and transparent (0.78 to 2.63 mgKOH.g⁻¹) bottles, at the end of the storage period. The results indicate a significant decrease in the iodine values of oils packaged in amber bottles (82.04 to 87.32 mgI₂.100g⁻¹) and transparent bottles (81.29 to 85.45 mgI₂.100g⁻¹). However, after storage at room temperature, the peroxide and saponification values significantly increased ($p < 0.05$) in all baobab oils. A correlation analysis between the physicochemical properties of the extracted oils was carried out. Also, a principal component analysis on the composition of the oils at the end of storage was also carried out. These results suggest the extraction of the oil from unwashed baobab seeds from the locality of Ziguinchor and packaging in amber bottles.

Keywords: *Adansonia digitata* L., seeds, extraction, pressure, oil, storage, stability

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1. Introduction

The baobab (*Adansonia digitata* L.) is an emblematic tree of the African savannah [1]. It is one of the most striking and recognizable woody species in Africa due to its large size [2] and can reach more than 25 m in height [3,4]. The baobab occurs naturally in the Sahelian, Sudano-Sahelian, Sudanian, Sudano-Guinean, and Guinean zones, where average annual rainfall is 300, 700, 800, 1100, and 1200 mm, respectively [2,5,6]. This tree can reach over 1000 years of age [7,8] and can produce approximately 200 kg of fruit each season [9]. The various parts of the baobab tree have always been used for food, medicinal, cultural, and economic purposes [10,11,12]. Furthermore, fruit production is attributed to genetic traits, physiological phenomena, and pedoclimatic conditions [13].

The fruit is the most exploited and utilized part of the baobab. The seeds, which represent more than half of the

mass of the shelled fruit, are underutilized compared to the pulp [3,14]. Baobab seeds contain very high levels of protein (18.4%), lipids (12.2%) and carbohydrates (45.1%) [15]. Baobab oils are very rich in palmitic, stearic, oleic and arachidic acids and in tyrosol, hydroxytyrosol and caffeic acid [16]. Currently, the oil from these seeds is highly sought after by the pharmaceutical and cosmetic industries because of its composition [7,17,18,19,20]. Indeed, baobab oil is known for its high permeability, nourishing properties, emollient power and softening abilities on the skin and scalp [7,17]. In the industrial sector, cold-pressed extraction of baobab oil is widely applied [21]. However, studies on the oxidative stability of baobab oil extracted by cold pressing are almost non-existent. After the implementation of the new process to improve the extraction yield and reduce the production cost, the evaluation of the quality of the extracted oils during storage remains essential. In this context, our study aims to investigate the influence of baobab seed pretreatment operations, origin and type of packaging on the stability of baobab oils after 14 months of storage at

room temperature. For this purpose, principal component analyses (PCA) and correlation analyses are carried out to assess the impact of extraction processes and storage conditions on the physicochemical characteristics and the fatty acid and phenolic compound contents of the oils extracted by pressing. Thus, in the industrial and pharmaceutical fields, this study could provide information likely to increase the shelf life of baobab oils while preserving the bioactive compounds.

2. Material and Methods

2.1. Plant Material and Pre-treatments

The plant material consisted of baobab (*Adansonia digitata* L.) seeds from fruits collected at three locations: seeds from Kougheul (13°58'60" N and 14°48'0" W), Ziguinchor (12°33'50" N and 16°15'50" W) and Bignona (12°48'18" N and 16°14'4" W), Senegal. Three (3) batches of 50 kg of seeds from each source were used for oil extraction. Each batch was divided into two equal parts: 25 kg unwashed seeds and 25 kg washed seeds. Approximately 150 litres of water at room temperature (25°C) were used to wash the 75 kg of seeds, which were soaked and mixed for a total of two (2) hours. After washing, the seeds were dried in an oven at 65°C ± 1 °C for 24 hours. Six (6) samples of 25 kg of seed were then taken. The seeds from the different lots were ground separately in a mill and passed through a 1 mm mesh sieve.

2.2. Oil Extraction by Pressing

The baobab oil was extracted using a mechanical press (DD85G, IBG Monforts Oekotec GmbH, Mönchengladbach, Germany). The 10 mm spinner was used throughout the extraction, and the rotation speed of 25 rpm was maintained. The outlet head temperature was also maintained at 105 °C throughout the procedure. The outlet head was previously heated to this temperature for approximately 25 minutes at the start of the extraction process. At the end of the extraction, the product obtained was a mixture of oil with rubbery impurities. The crude oil was immediately bottled in amber bottles for two days. After decanting, the oil was transferred to new bottles and centrifuged using a centrifuge (Hettich, Zentrifugen, Germany) at 4500 rpm for ten (10) minutes. The baobab oil obtained was stored at 4°C before analysis.

2.3. Physicochemical Analysis

The physicochemical characteristics (extraction yield, density, acidity, peroxide value, acid value, refractive index, iodine value, saponification value and color index) of the extracted oils were determined in order to obtain information to promote its exploitation in pharmaceutical and/or industrial fields. The saponification value was determined according to the French standard NF T60-206; the acid value according to the standard NF T60-204; the iodine value according to the French standard NF T60-203; the peroxide value according to the French standard NF T60-220; the extraction yield according to the standardized Soxhlet extraction method (NF V03-905).

The extinction coefficients at 232 nm and 270 nm (k_{232} and k_{270}) were determined according to the French standard NF T60-223 with a UV spectrophotometer (SPECORD 200 PLUS). The refractive index was measured with a refractometer (EXACTA-OPTECH, Mod-RMT, München, Germany). A colorimeter (CM-5, Konica Minolta Sensing Americas Inc., US) was used to determine the color parameters L^* , a^* , b^* , $Y1$, c^* and h of the different oils. The L^* component indicating lightness or luminance varies from black to white; the a^* component corresponds to the green-red antagonistic couple; the b^* component corresponds to the blue-yellow antagonistic couple; $Y1$, c^* and h correspond respectively to the yellowness index, chromaticity and chromatic tone. The acidity, which corresponds to the expression in percentage of oleic acid, was calculated from the acid index. The density was measured by the NF T60-214 method at a temperature of 25°C. The dosage of polyphenols was carried out according to the method of Georgé et al. [22].

2.4. Statistical Analysis

A principal component analysis (PCA) and a numerical classification were performed on the physicochemical data of the oils to search for the best correlations between the random variables. Also, the results obtained were studied by correlation analyses (Pearson correlation coefficients) between the acid, iodine, refractive, peroxide, saponification and color index. To compare the means, variance analyses with the Fisher LSD test at the 5% significance level were also performed. Thus, all analyses were carried out with R software (version 4.4.3, 2025).

3. Results and Discussion

3.1. Physical Properties

Table 2 shows the refractive index at the beginning and end of storage of baobab oils extracted by cold pressing. After fourteen months of storage at room temperature, the refractive index has undergone a significant variation in practically all the oils. Indeed, the analysis of variances indicates that there is a significant difference at the 5% threshold of the refractive indices. At the end of storage of the oil from washed seeds, the initial values of the refractive indices which were between 1.4640 and 1.4642 varied between 1.4647 and 1.4648 regardless of the type of packaging. On the other hand, for oils from unwashed seeds, the initial values (1.4650 and 1.4660) varied between 1.4647 and 1.4653 and between 1.4647 and 1.4663 respectively for those stored in amber bottles and transparent bottles. The increase in the refractive index illustrates the rancidity of the oils. According to Nkafamiya et al. [23], the rancid odor was perceptible when the refractive index increased by 0.001. These different results suggest that the origin of the fruits, the seed washing operation and the light have an influence on the refractive indices. Also, the oils extracted from washed seeds then stored in amber bottles displayed the lowest refractive index. Therefore, these oils would contain, after this shelf life, more long-chain fatty acids than those

packaged in transparent bottles. This difference would be due to light which would cause direct photo-oxidation and photosensitized oxidation [24,25,26]. During this direct photo-oxidation, light accelerates the kinetics of the oxidation reactions [26]. Also, the increase in the refractive index of the oils, after fourteen months of storage, would come from a variation in the molecular mass of the fatty acids, the degree of conjugation and the degree of unsaturation [27]. The color variation of the extracted oils at the beginning and end of storage was determined and the recorded results are listed in Table 1. This color change at the end of the storage period is a visual indication of the oxidation of the oils. The results reveal a significant evolution ($p < 0.05$) of the color parameters on all the oils extracted by cold pressing. The baobab oils obtained with unwashed seeds and packaged in amber bottles appear lighter than the other oils. Indeed, the brightness L^* at the beginning of storage of the oils from washed seeds which was between 95.44 and 95.98 oscillated between 95.35 and 98.04 for those from amber bottles and between 95.15 and 95.33 for those from transparent bottles. Regarding unwashed seeds, the luminescence at the beginning of storage, which was between 94.87 and 96.37, increased to between 95.39 and 98.70 for those in transparent bottles and between 94.62 and 96.67 for those in amber bottles. In other words, the increase in brightness L^* is more noticeable with oils from unwashed seeds packaged in transparent bottles. Therefore, these very light oils reflect more light than other oils. At

the end of storage, the color of lighter baobab oils is also accompanied by an increase and a decrease in the color parameters a^* and b^* , respectively. These a^* and b^* parameters significantly varied with seed pretreatment, light exposure and storage time of the oils ($p < 0.05$).

Indeed, UKS oil packaged in amber bottles tends towards green color (-13.24) and less towards yellow color (67.16) than the other oils. At the same time, those from UBS and UKS and packaged in transparent bottles appear respectively redder (-9.43) and less yellow (64.16). Moreover, the values of the Y1 yellowing indices confirm the weak yellow color of these oils. These yellowing indices indicate that UKS oils packaged in amber as well as transparent bottles would contain lower carotenoid contents [28,29]. Given the antioxidant properties of carotenoids, UKS oils remain the most oxidized at the end of storage. Generally speaking, the significant decrease in the yellowing index ($p < 0.05$) observed for all baobab oils is more pronounced with transparent bottles. Indeed, carotenoids are a family of terpenoid pigments, whose color varies from yellow to orange-red [30]. According to Laguerre et al. [31], carotenoids can be pure hydrocarbons called carotenes (lycopene, β -carotene, etc.) or possess an oxygenated functional group and are called xanthophylls (astaxanthin, lutein, etc.). These carotenoids act as photon scavengers and trap highly reactive singlet oxygen [25, 30]. Also, carotenoid pigments degrade rapidly under the effect of light and increased temperature [32,33].

Table 1. Variation of physicochemical properties of baobab oils extracted by pressing at the beginning and end of storage at room temperature in amber and transparent bottles

Parameters		Amber Bottles					Transparent Bottles				
Oils	Storage	R.I.	A.V. mgKOH.g ⁻¹	P.V. mEq.kg ⁻¹	I.V. mgI ₂ .100g ⁻¹	S.V. mgKOH.g ⁻¹	R.I.	A.V. mgKOH.g ⁻¹	P.V. mEq.kg ⁻¹	I.V. mgI ₂ .100g ⁻¹	S.V. mgKOH.g ⁻¹
WZS	Start	1.4642 ^c (0.0003)	1.02 ^b (0.01)	3.31 ^{ab} (0.01)	87.20 ^{ef} (2.78)	202.43 ^a (0.66)	1.4642 ^b (0.0003)	1.02 ^{ab} (0.01)	3.31 ^a (0.01)	87.20 ^{ef} (2.78)	202.43 ^a (0.66)
	End	1.4648 ^a (0.0003)	1.73 ^e (0.06)	11.28 ^d (0.99)	83.80 ^{ab} (0.57)	222.77 ^b (1.07)	1.4647 ^a (0.0003)	1.62 ^f (0.06)	14.60 ^b (0.23)	85.19 ^{bd} (0.90)	218.18 ^c (1.03)
UZS	Start	1.4650 ^{ab} (0.0006)	0.92 ^{ab} (0.09)	2.94 ^a (0.01)	86.23 ^{cde} (0.87)	201.49 ^a (0.66)	1.4650 ^a (0.0006)	0.92 ^{ad} (0.09)	2.94 ^a (0.01)	86.23 ^{be} (0.87)	201.49 ^a (0.66)
	End	1.4647 ^a (0.0003)	0.95 ^{ab} (0.05)	16.22 ^c (0.59)	84.11 ^{abc} (0.45)	224.86 ^b (0.71)	1.4647 ^a (0.0003)	1.06 ^b (0.05)	25.63 ^e (0.72)	83.14 ^{ac} (0.91)	213.69 ^b (0.99)
WBS	Start	1.4640 ^c (0.0001)	0.49 ^d (0.07)	2.99 ^{ab} (0.03)	85.44 ^{bcd} (1.80)	199.62 ^c (0.27)	1.4640 ^b (0.0001)	0.49 ^e (0.07)	2.99 ^a (0.03)	85.44 ^{bcd} (1.80)	199.62 ^d (0.27)
	End	1.4648 ^a (0.0003)	0.72 ^c (0.06)	9.20 ^e (0.79)	82.04 ^a (1.02)	221.25 ^b (0.98)	1.4648 ^a (0.0003)	0.78 ^{cd} (0.11)	4.73 ^d (0.77)	81.84 ^b (0.52)	215.83 ^f (0.93)
UBS	Start	1.4650 ^{ab} (0.0003)	0.72 ^c (0.08)	3.45 ^b (0.04)	89.14 ^f (0.30)	201.03 ^a (0.84)	1.4650 ^a (0.0003)	0.72 ^c (0.08)	3.45 ^a (0.30)	89.14 ^f (0.30)	201.03 ^a (0.84)
	End	1.4648 ^a (0.0003)	0.90 ^a (0.11)	14.96 ^f (0.52)	87.32 ^{def} (1.01)	215.80 ^e (0.56)	1.4648 ^a (0.0003)	1.01 ^{ab} (0.11)	7.95 ^b (0.48)	85.45 ^{be} (1.15)	219.73 ^c (0.81)
UKS	Start	1.4660 ^d (0.0001)	2.36 ^f (0.03)	1.49 ^c (0.01)	83.04 ^{ab} (0.28)	211.31 ^d (0.15)	1.4660 ^c (0.0001)	2.36 ^g (0.03)	1.49 ^c (0.28)	83.04 ^{acd} (0.28)	211.31 ^e (0.15)
	End	1.4653 ^b (0.0006)	2.90 ^g (0.10)	25.22 ^g (0.68)	83.26 ^{ab} (0.65)	217.86 ^f (1.00)	1.4663 ^c (0.0003)	2.63 ^h (0.17)	33.32 ^f (0.44)	81.29 ^a (0.74)	213.21 ^b (0.83)

Mean values and standard deviations in parentheses are obtained from three repetitions. Within a column, means with the same letter are not significantly different at the 5% level. WZS: Washed Ziguinchor Seeds; UZS: Unwashed Ziguinchor Seeds; WBS: Washed Bignona Seeds; UBS: Unwashed Bignona Seeds; UKS: Unwashed Kounghoul Seeds; R.I.: Refractive index; A.V.: Acid value; P.V.: Peroxide value; I.V.: Iodine value; S.V.: Saponification value.

Table 2. Evolution of color parameters of baobab oils extracted by pressing at the beginning and end of storage at room temperature in amber and transparent bottles

Parameters		Amber Bottles					
Oils	Storage	L*	a*	b*	Y1	c*	h
WZS	Start	95.44 ^a ± 0.02	-10.73 ^h ± 0.10	94.93 ^g ± 0.10	87.03 ^g ± 0.01	95.53 ^g ± 0.11	96.45 ^a ± 0.10
	End	97.35 ^g ± 0.04	-12.01 ^b ± 0.02	61.91 ^a ± 0.01	68.08 ^a ± 0.01	63.07 ^a ± 0.02	100.98 ^f ± 0.02
UZS	Start	94.98 ^c ± 0.02	-11.49 ^g ± 0.00	101.49 ^j ± 0.10	89.63 ^j ± 0.04	102.14 ⁱ ± 0.01	96.46 ^a ± 0.10

Parameters		Amber Bottles					
	End	95.39 ^a ± 0.01	-12.41 ^f ± 0.01	88.13 ^e ± 0.02	84.14 ^e ± 0.01	89.00 ^e ± 0.01	98.02 ^c ± 0.01
WBS	Start	95.98 ^d ± 0.20	-11.83 ^c ± 0.10	93.56 ^f ± 0.12	86.32 ^f ± 0.10	94.30 ^f ± 0.10	97.21 ^b ± 0.10
	End	98.04 ^h ± 0.01	-13.40 ^d ± 0.04	80.73 ^d ± 0.01	79.50 ^d ± 0.01	81.84 ^d ± 0.01	99.42 ^d ± 0.01
UBS	Start	94.87 ^b ± 0.03	-11.20 ^{bc} ± 0.10	99.27 ⁱ ± 0.06	88.88 ⁱ ± 0.10	99.90 ⁱ ± 0.06	96.44 ^a ± 0.06
	End	96.86 ^f ± 0.08	-12.24 ^a ± 0.12	96.55 ^h ± 0.12	87.19 ^h ± 0.07	97.33 ^h ± 0.11	97.23 ^b ± 0.08
UKS	Start	96.37 ^e ± 0.02	-12.13 ^a ± 0.10	69.42 ^c ± 0.11	73.54 ^c ± 0.06	70.49 ^c ± 0.06	99.91 ^e ± 0.05
	End	98.70 ⁱ ± 0.01	-13.24 ^e ± 0.01	67.6 ^b ± 0.01	71.16 ^b ± 0.01	68.45 ^b ± 0.06	101.15 ^g ± 0.01
		Transparent Bottles					
WZS	Start	95.44 ^d ± 0.02	-10.73 ^f ± 0.10	94.93 ^h ± 0.10	87.03 ^h ± 0.01	95.53 ^h ± 0.11	96.45 ^a ± 0.10
	End	95.15 ^{bc} ± 0.00	-12.02 ^a ± 0.02	92.27 ^f ± 0.01	86.04 ^f ± 0.00	93.05 ^f ± 0.06	97.42 ^d ± 0.00
UZS	Start	94.98 ^{ab} ± 0.02	-11.49 ^d ± 0.00	101.49 ^j ± 0.10	89.63 ^j ± 0.04	102.14 ^j ± 0.01	96.46 ^a ± 0.10
	End	96.62 ^e ± 0.01	-11.96 ^{ab} ± 0.01	86.59 ^d ± 0.02	83.70 ^d ± 0.01	87.41 ^d ± 0.02	97.86 ^e ± 0.01
WBS	Start	95.98 ^f ± 0.20	-11.83 ^c ± 0.10	93.56 ^f ± 0.12	86.32 ^f ± 0.10	94.30 ^f ± 0.10	97.21 ^b ± 0.10
	End	95.33 ^{cd} ± 0.02	-11.55 ^d ± 0.06	91.51 ^e ± 0.08	85.51 ^e ± 0.28	92.23 ^e ± 0.07	97.19 ^b ± 0.05
UBS	Start	94.87 ^a ± 0.03	-11.20 ^{bc} ± 0.10	99.27 ⁱ ± 0.06	88.88 ⁱ ± 0.10	99.90 ⁱ ± 0.06	96.44 ^a ± 0.06
	End	94.85 ^a ± 0.01	-9.43 ^g ± 0.01	76.44 ^c ± 0.02	78.39 ^c ± 0.03	77.02 ^c ± 0.02	97.03 ^c ± 0.01
UKS	Start	96.37 ^g ± 0.02	-12.13 ^e ± 0.10	69.42 ^b ± 0.11	73.54 ^b ± 0.06	70.49 ^b ± 0.06	99.91 ^f ± 0.05
	End	96.67 ^h ± 0.40	-11.91 ^{abc} ± 0.01	64.16 ^a ± 0.03	69.82 ^a ± 0.02	65.25 ^a ± 0.03	100.52 ^g ± 0.01

Mean values and standard deviations in parentheses are obtained from three repetitions. Within a column, means with the same letter are not significantly different at the 5% level. WZS: Washed Ziguinchor Seeds; UZS: Unwashed Ziguinchor Seeds; WBS: Washed Bignona Seeds; UBS: Unwashed Bignona Seeds; UKS: Unwashed Koungheul Seeds.

3.2. Chemical Properties

The chemical properties at the start and end of storage of cold-pressed baobab oils are presented in Table 2. Analysis of variance indicates significant differences at the 5% threshold of acid values. This value, based on a back-dosage, corresponds to the number of milligrams of potassium hydroxide (KOH) required to neutralize the free acidity of one gram of a fatty substance. Indeed, the quantification of the free fatty acids present in an oil makes it possible to determine its degree of alteration. Generally, the initial acid values [(0.49 to 2.36) mgKOH.g⁻¹] changed significantly following packaging in amber bottles [(0.72 to 2.90) mgKOH.g⁻¹] and transparent bottles [(0.78 to 2.63) mgKOH.g⁻¹], at the end of the storage period. These results show a slight increase in the acid value in all oils. However, the variations in acid values indicating the alteration of baobab oils are difficult to attribute separately to the seed washing operation and to light.

However, the increase in free fatty acids after 14 months of storage at room temperature would result from the hydrolysis of ester bonds of the larger triglycerides in UKS oils. For the latter, the values noted after 14 months of storage could reasonably be explained by their already high initial values. These results could reasonably be explained by the enzymatic action of lipase leading to acidification of baobab oils during storage [34,35]. Furthermore, all the measured acid values are below the limit value of 4 mgKOH.g⁻¹ set by Codex [36]. The results obtained show that the iodine index measuring the degree of unsaturation and stability of the oils was significantly affected ($p < 0.05$) by the storage time. Indeed, the iodine indexes decreased in all baobab oils after storage at room temperature. The decrease was more pronounced for samples stored in transparent bottles. It appears from the table that the initial values [(83.04 to 89.14) mgI₂.100g⁻¹] decreased in the amber bottles [(82.04 to 87.32) mgI₂.100g⁻¹] and transparent bottles [(81.29 to 85.45) mgI₂.100g⁻¹]. These results show that the iodine index

decreases during exposure to light. This difference between the oils packaged in these bottles would reasonably be due to the degradation of unsaturated fatty acids by oxidation. Thus, the oils in transparent bottles would contain fewer unsaturated fatty acids. Furthermore, the iodine values of the oils from unwashed seeds (UZS, UBS, UKS) are higher than those from washed seeds (WZS, WBS). This lower sensitivity to oxidation of these oils can be attributed to a supply of natural antioxidants from the baobab pulp. Several studies have highlighted the presence, in this pulp, of antioxidants such as vitamin C (ascorbic acid), gallic acid, caffeic acid, tyrosol, hydroxytyrosol and carotenoids [3,19,37,38]. With its very high ascorbic acid content, baobab fruit is among the fruits richest in vitamin C. Ascorbic acid is widely used to preserve food from oxidation due to its antioxidant properties. As at the beginning of storage, oils from unwashed Bignona seeds (UBS) showed the highest iodine values. For these oils, the recorded values were 87.32 ± 1.01 mgI₂.100g⁻¹ and 85.45 ± 1.15 mgI₂.100g⁻¹, respectively, for those stored in amber and transparent bottles. These results suggest a higher unsaturated fatty acid content in these baobab oils after 14 months of storage. Furthermore, the region where the baobab fruits were harvested had a significant effect on the measured iodine value. The peroxide value is defined as the number of grams of active oxygen in the peroxide contained in one gram of fat capable of oxidizing potassium iodide with the release of iodine. This standardized method (AFNOR, AOCS, IUPAC) has reference values (*Codex alimentarius*, *Pharmacopoeia*), and appears almost systematically in the "fat" specifications with a threshold value classically set at 10 mEq.kg⁻¹ of matter for a refined oil [26,39]. After storage at room temperature, the peroxide index significantly increased ($p < 0.05$) in all baobab oils. Indeed, the initial values [(1.49 to 3.45) mEq.kg⁻¹] increased significantly in the amber bottles [(9.20 to 25.22) mEq.kg⁻¹] and the transparent bottles [(4.73 to 33.32) mEq.kg⁻¹]. The results obtained show a greater increase in oils from unwashed seeds (UZS, UBS, UKS) than those

from washed seeds (WZS, WBS). It is clear from the table that packaging in transparent bottles causes an increase in the peroxide value of the oils. This strong evolution could be explained by the influence of several factors such as the fatty acid composition, the number of unsaturations, the position of the unsaturations, peroxides, oxygen, oil treatment, the presence of pro-oxidants (metal ions, enzymes) or natural antioxidants (tocopherols, carotenoids, etc.), temperature, light and the type of packaging [24,25,27,40,41]. Furthermore, the results obtained are lower than those of Shao et al. [29]. They observed, after 120 days of storage of tomato oil in the dark, peroxide values of 54.42 mEq.kg⁻¹ and 106.25 mEq.kg⁻¹, respectively for samples stored in glass bottles at 25 and 35°C. Tchiégang et al. [42], on the other hand, recorded a peroxide value of 25 mEq.kg⁻¹ for *Ricinodendron heudelotti* (Bail.) oil extracted by pressing and stored for 4 months at room temperature in polyvinyl chloride bottles. The values obtained remain very close to those reported by Dandjouma et al. [43] for *C. schweinfurthii* oil stored for 10 months in 100 mL clear glass bottles at room temperature [(28.66 ± 0.61) mEq.kg⁻¹] and at 4 °C [(24.83 ± 0.33) mEq.kg⁻¹]. Furthermore, during the assay, the interference of light, oxygen and iodine absorption by unsaturated fatty acids was highlighted [44]. This titration assay method allows the measurement of the total amount of hydroperoxides, while chromatographic methods provide information on specific hydroperoxides [27]. Thus, high-performance liquid chromatography (HPLC) and gas chromatography (GC) coupled with mass spectroscopy (MS) are widely used methods in oil analysis [45,46,47,48]. Nuclear magnetic resonance (NMR) is also used in combination with chromatographic methods for the identification or quantification of molecules [47].

These chromatographic methods require small sample quantities and interferences from minor compounds other than hydroperoxides are easily excluded [27]. The saponification index, which corresponds to the mass (in milligrams) of potassium hydroxide (KOH) required to saponify one gram of fat, has evolved over storage. The initial values obtained [(199.62 to 211.31) mgKOH.g⁻¹] increased significantly in the amber bottles [(215.80 to 224.86) mgKOH.g⁻¹] and the transparent bottles [(213.21 to 219.21) mgKOH.g⁻¹]. In absolute terms, the increase in the saponification value of the oils suggests a decrease in the length of the fatty acid chains. This increase is more pronounced with the oils packaged in the amber bottles. Consequently, these oils would contain more short-chain fatty acids than those packaged in the transparent bottles. The significant difference noted between the oils contained in these two types of bottles can be attributed to oxygen and trace metals that would cause the breakage of the unsaturated fatty acid chains [42]. However, this increase is difficult to correlate with the seed washing operation. The work of Nkafamiya et al. [23] on the stability of baobab oil extracted with Soxhlet showed an increase [(180 to 200) mgKOH.g⁻¹] after 140 days of storage at room temperature (30 ± 2°C). The values obtained are comparable to those reported by Tchiégang et al. [42] for *Ricinodendron heudelotti* (Bail.) oil which had evolved between 195.02 and 219.26 mgKOH.g⁻¹ after 120 days of storage.

3.3. Principal Component Analysis

Principal component analysis (PCA) was performed to evaluate the effects of baobab seed washing, fruit collection area, and light on the stability of extracted oils at the end of storage. The first dimension (Dim 1) contributed 46.58% and the second (Dim 2) 21.27%. These first two dimensions (Dim 1 and Dim 2) presented the highest eigenvalues (4.65 and 2.12) (Table 3).

Table 3. Correlations between components and variables

Variables	Principal Component				
	Dim 1	Dim 2	Dim 3	Dim 4	Dim 5
R.I.	0.499	0.370	0.518	0.298	-0.478
S.V.	-0.009	-0.916	-0.207	0.052	-0.075
P.V.	-0.372	0.895	0.010	0.024	0.111
A.V.	-0.828	0.333	0.002	0.251	0.255
I.V.	0.536	-0.180	-0.072	0.767	0.273
L*	-0.700	-0.308	0.525	0.265	0.135
a*	0.386	0.299	-0.801	0.198	-0.258
b*	0.911	0.009	0.334	-0.103	0.204
Y1	0.934	0.032	0.276	-0.131	0.167
h	-0.979	-0.146	0.103	0.017	-0.006
Eigen value	4.659	2.127	1.431	0.883	0.542
Variance (%)	46.587	21.275	14.312	8.826	5.421
Cumulative variance (%)	46.587	67.861	82.173	90.999	96.420

R.I.: Refractive index; S.V.: Saponification value; P.V.: Peroxide value; A.V.: Acid value; I.V.: Iodine value.

However, the third dimension (Dim 3), the fourth dimension (Dim 4) and the fifth dimension (Dim 5) have contributions of 14.31, 8.82 and 5.42%, respectively, and eigenvalues of 1.43, 0.88 and 0.54. In order to simplify the initial matrix and reduce information loss, the principal components were chosen. Thus, the first two dimensions (Dim 1 and Dim 2) selected express 67.86% of the total variance. The variables iodine index (0.536), b* (0.911) and yellowness index (0.934) are positively well correlated with the first axis, while the variables acid index (-0.828), luminance L* (-0.700) and chromatic hue h (-0.979) are negatively correlated. The peroxide index variable (0.895) is positively correlated with the second dimension (Dim 2), while the saponification index variable (-0.916) is negatively correlated with it. After storage at room temperature, the cold-pressed baobab oils were grouped into three classes (Figure 1 and Figure 2). Class 1 (UKS-TB, UKS-AB) is characterized by a high acid value (V.test = 2.705; p = 0.006), peroxide value (V.test = 2.200; p = 0.0277) and chromatic hue h (V.test = 2.040; p = 0.0413). Baobab seed oils from fruits collected in Ziguinchor and Bignona, then packaged in amber bottles (WZS-AB, UZS-AB, WBS-AB) constitute class 2 characterized by a high saponification value (V.test = 2.495; p = 0.0125) and a low peroxide value (V.test = -2.139; p = 0.0324). Class 3, represented by baobab seed oils from fruits collected in Ziguinchor and Bignona and packaged in transparent bottles (WZS-TB, UZS-TB, WBS-TB, UBS-TB, UBS-AB), is characterized by a high yellowing index Y1 (V.test = 2.101; p = 0.0355), b* parameter (V.test = 2.046; p = 0.0407) and refractive index (V.test = 1.963; p = 0.0495), and low chromaticity h

(V.test = -2.059; $p = 0.0394$) and chromaticity h (V.test = -2.531; $p = 0.0113$). From these results, it is clear that Ziguinchor seed oils packaged in amber bottles are less altered after storage at room temperature. In addition, the choice of producing baobab oil from fruits collected in this locality would help preserve the quality and stability of the extracted oils.

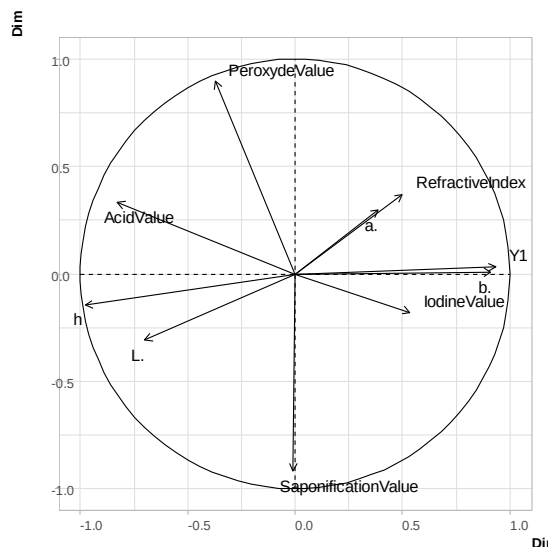


Figure 1. Correlation between the physicochemical properties of baobab oils and the first two dimensions of PCA

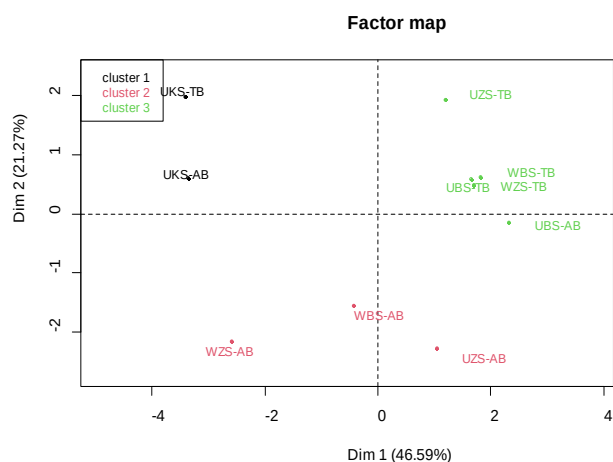


Figure 2. Projection of different oils after storage according to physicochemical properties in the factorial plane of the PCA

4. Conclusion

In this study, the influence of baobab seed pretreatment operations, fruit origin and packaging type on the stability of oils extracted by pressing after storage at room temperature was evaluated. According to the results noted, it appears that baobab oils obtained with unwashed seeds and packaged in amber bottles best preserve their physicochemical properties. These suggest the use of seeds from the locality of Ziguinchor. Also, unwashed seeds allow to obtain better quality oils and slightly higher extraction yields by pressing into oil. However, the clinical evaluation of the biological effects of these oils and their unsaponifiable fractions will allow to evaluate

the therapeutic and pharmaceutical potentials for the benefit of populations and consumers.

Conflicts of Interest

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

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