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Impact of Extraction Method on Physicochemical Characteristics and Antioxidant Potential of *Adansonia digitata* Oil

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Abstract

In this study, the effect of extraction processes on the physicochemical characteristics and antioxidant potential of baobab (*Adansonia digitata* L.) seed oil was evaluated. The oils were extracted, on the one hand, by cold pressing, and on the other hand, with three types of organic solvents (acetone, chloroform, n-hexane). The recorded results indicated that the extraction yield of baobab oil was significantly impacted by both the extraction method and the polarity of the solvent used. In addition, chloroform provides the best extraction yield (40.12 ± 0.607). However, extraction by cold pressure preserves at best the physicochemical and bioactive properties of the extracted oils. Indeed, the pressing oil contains a content of phenolic compounds (0.047 ± 0.0024 mgEAG/g of oil) and a very high radical scavenging activity (DPPH) ($31.71\% \pm 0.61\%$). For the various oils extracted, the minimum and maximum values were 0.50 and 3.17 mEq·kg^{-1}; 56.26 and 99.113 mgI$_2$·100 g^{-1}; 1.457 and 1.465; 205.37 and 233.587 mgKOH/g respectively for the peroxide, iodine, refractive and saponification values. The color parameters (L*, a* and b*) of the oils also differ depending on the nature of the organic solvent used. Principal component analysis (PCA) and correlation analysis were performed on the physicochemical properties and the antioxidant potential of the extracted oils. Therefore, the results suggest the mixed use of acetone and hexane to obtain oil comparable to that extracted by cold pressing.

Keywords

Adansonia digitata L., Oil, Extraction, Biochemical Characteristics

1. Introduction

The baobab (*Adansonia digitata* L.) is an emblematic tree of African savanna [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 genus *Adansonia* belongs to the family Bombacaceae and the order Malvales [5]. In Africa, this baobab species is present only in the semi-arid and sub-humid regions south of the Sahara with the exception of Liberia, Uganda, Djibouti and Burundi [2] [6]. In Senegal, stands of *Adansonia digitata* L. are present throughout the country [3]. The different parts of the baobab (roots, bark, wood, gum, leaves, flowers, capsules, pulp, seeds) are used [6] [7] [8]. Buchmann *et al.* [7] reported about 300 traditional uses of baobab in Africa. The baobab fruit weighs between 150 and 350 g in Senegal, and can reach more than 496 g in Niger [9]. The total mass of the seeds represents between 43% and 60% of the total mass of the fruit [3] [10]. The seeds contain very high concentrations in terms of protein (18.4%), lipids (12.2%) and carbohydrates (45.1%) [11]. Baobab seed oil is used in the pharmaceutical and cosmetic industries because of its content of essential fatty acids and vitamins A, D, E and F [12] [13]. Indeed, the oil allows the rejuvenation and renewal of cells, thus improving the elasticity of the skin and reducing the appearance of stretch marks [14]. It is known for its high permeability, its nourishing properties, its emollient power and its softening properties on the skin and scalp [14] [15]. Used as a massage cream, baobab oil softens the skin and helps relieve pain and injury [14]. Also, they have been used in the treatment of various conditions such as hair dandruff, muscle spasm, varicose veins and wounds [12]. Vermaak *et al.* [13] indicate that baobab seed oil is used alone or in combination with other parts of the plant to treat various conditions such as fever, diarrhea, cough, dysentery, hemoptysis and worms. In traditional medicine, the oil has been used to treat inflammation of the gums and to relieve toothache [6]. After the treatment of the oil, the residual part is mixed with coconut oil for the manufacture of soap which helps to fight against skin diseases such as eczema, sunburn, acne and rashes [16]. In the literature, several studies have been devoted to the characterization of oil extracted with organic solvents [17] [18] [19] [20] [21]. However, studies on the antioxidant potential of baobab oils extracted by pressing are unknown as well as comparison of baobab oils extracted by organic solvent with that of cold pressure. In this context, our study aims to evaluate, the effect of different extraction methods on the extraction yield, the physicochemical properties and the antioxidant potential of the different baobab oils. Thus, this study should provide information likely to promote, in the industrial and pharmaceutical fields, a large-scale use of baobab oil.

2. Materialand Methods

2.1. Plant Material and Pretreatments

The fruits were collected in the locality of Bignona (12˚45'0'' North and 16˚30'0''

West), Senegal. A voucher specimen are stored and referenced under a specified identification number. The pulped seeds were washed and then dried at 65°C for 24 hours in an oven. After drying, the seeds were crushed with a pestle and a mortar and then crushed with a hammer mill (Moulinex, AR 11). The ground product thus obtained was also sieved using a 600 μm mesh sieve to obtain a finer particle size used for the extraction procedures. All analyses such as extraction and chemical parameters were made in duplicate during this work.

2.2. Extraction of Oil by Pressing

The extraction of the oil was carried out using a mechanical press (DD85G, IBG MonfortsOekotec GmbH, Mönchenglabach, Germany). The 10 mm die was used throughout the extraction and the rotational speed of 25 rpm was maintained. The outlet head temperature was also maintained at 105°C throughout the operation. Beforehand, the exit head was brought to this temperature for about 25 minutes before the start of the extraction operation. At the end of the extraction, the obtained crude baobab oil is a mixture of oil with gummy impurities. This crude oil was immediately packaged in bottles for two days for decantation. The oil was transferred to new bottles and centrifuged (centrifuge Hettich, Zentrifugen, Germany) at 4500 rpm for 10 minutes. The obtained oil was stored at 4°C for later analyzes.

2.3. Extraction of Oil by Solvent

In this part, the baobab oil was extracted with Soxhlet on particles with particle sizes of less than 600 μm using acetone, chloroform or n-hexane. These solvents were purchased from Prolabo (VWR Chemicals, USA). During extraction of the oil, the temperature of 70°C ± 2°C, the extraction time of six (6) hours and the ratio of 1:8 (g/mL) were used based on the optimum parameters obtained on different seeds [22] [23] [24] [25]. In order to remove traces of solvents, the extracted oil was evaporated by means of a rotary evaporator (Heidolph, Germany) at 45°C and then put in an oven for 24 hours at 40°C.

2.4. Analytical Methods

The physicochemical characteristics of extraction oils such as density, acidity, peroxide value, acid value, refractive index, iodine value, saponification value and color index of the extracted oils were determined. The saponification value was determined according to the French standard NF T60-206; The acid value according to standard NF T60-204. The acidity which corresponds to the percentage expression of oleic acid was calculated from the acid value. The iodine value is determined 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 standard soxhlet extraction method (NF V03-905). The density was measured by the NF T60-214 method at 25°C. The polyphenols were assayed according to the method of Georgé *et al.* [26]. 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 L*, a*, b*, Y1, c* and h color parameters of the various oils. The component L* indicating the clarity or luminance varies from black to white. The component a* corresponds to the green-red antagonist couple. The component b* corresponds to the blue-yellow antagonistic couple; Y1, c* and h correspond respectively to the yellowingindex, chromaticity and chromatic tone.

2.5. Antioxidant Activity

The antioxidant activity was evaluated with 2.2-diphenyl-1-pyridyrazyl (DPPH) according to the method described by Adaramola *et al.* [27]. In addition, some adjustments were made to its protocol. Thus, 2 mL of DPPH (0.1 mM) prepared in methanol was introduced into a test tube containing 0.5 mL of baobab oil. The mixture was stirred for five (5) minutes and then incubated in the dark and at room temperature for 30 minutes. After this incubation period, the absorbance was read at 517 nm against a blank (0.5 mL of baobab oil and 2 mL of methanol) using a UV spectrophotometer (SPECORD 200 PLUS). The absorbance of the control (0.5 mL of DPPH and 2 mL of methanol) is determined at this wavelength. This activity is compared to a control antioxidant (quercetin). The antiradical activity is expressed as a percentage of DPPH reduced according to this relation:

$$\text{Inhibition of DPPH}(\%) = \frac{\text{Absorbance}_{\text{control}} - \text{Absorbance}_{\text{sample}}}{\text{Absorbance}_{\text{control}}} \times 100$$

2.6. Statistical Analysis

A principal component analysis (PCA) and a hierarchical classification were carried out on the physicochemical data of the oils in order to find the best correlations between the random variables. The results obtained have been studied by correlation analyzes (Pearson correlation coefficients) between the physicochemical properties and the antioxidant potential of the extracted oils. To compare the averages, this analyzes of variance with the Fisher LSD test at the significance level of 5% were also performed. Thus, all analyzes were carried out with software R (version 3.2.4, 2016).

3. Results and Discussion

3.1. Physical Properties

The physical parameters studied on the various oils of baobab include the extraction yield, the density, the refractive index, the extinction coefficients and the color indices. The results obtained are listed in Table 1.

Table 1. Physicochemical characteristics of baobab oils extracted by cold pressing and organic solvents.

Parameters	Pressure	Acetone	Chloroform	n-Hexane
Oilyield (%)	6.280 ± 0.432^a	23.05 ± 0.614^b	40.12 ± 0.607^d	30.29 ± 0.521^c
Density	0.911 ± 0.04^b	0.882 ± 0.016^a	0.945 ± 0.013^c	0.902 ± 0.020^{ab}
Refractive index	$1.464 \pm 2.8.10^{-4\,b}$	$1.459 \pm 3.10^{-4\,a}$	1.457 ± 3.10^{-4a}	1.465 ± 3.10^{-4b}
Iodine value ($mgI_2 \cdot 100g^{-1}$)	99.113 ± 0.528^d	83.296 ± 0.558^b	56.266 ± 1.092^a	90.775 ± 0.842^c
Saponification value ($mgKOH \cdot g^{-1}$)	233.587 ± 0.478^d	205.371 ± 0.808^a	205.494 ± 0.809^c	209.198 ± 0.791^b
Acid value ($mgKOH \cdot g^{-1}$)	18.827 ± 0.309^d	13.701 ± 0.235^c	5.568 ± 0.107^a	12.442 ± 0.089^b
Free fatty acid (%)	9.463 ± 0.155^d	6.915 ± 0.09^c	$2,80 \pm 0.054^a$	6.254 ± 0.045^b
Peroxyde value ($mEq \cdot kg^{-1}$)	2.091 ± 0.579^a	0.498 ± 0.01^b	2.365 ± 0.079^a	3.176 ± 0.244^a
k_{232} nm	1.492 ± 0.177^{ab}	0.862 ± 0.162^c	1.284 ± 0.029^a	1.737 ± 0.292^b
k_{270} nm	1.192 ± 0.204^{ab}	0.883 ± 0.281^b	1.571 ± 0.048^a	1.479 ± 0.471^a
L*	85.42 ± 0.391^a	85.15 ± 0.13^a	89.30 ± 0.02^b	96.16 ± 0.01^c
a*	-7.74 ± 0.367^b	-4.27 ± 0.10^d	-6.96 ± 0.05^c	-12.22 ± 0.01^a
b*	92.77 ± 0.121^a	95.68 ± 0.04^c	92.78 ± 0.07^a	87.08 ± 0.02^b
Y1	89.64 ± 0.177^c	90.79 ± 0.03^d	88.29 ± 0.02^b	84.10 ± 0.01^a
c*	93.09 ± 0.101^a	95.77 ± 0.04^c	93.05 ± 0.06^a	87.93 ± 0.01^b
h	94.77 ± 0.229^c	92.55 ± 0.03^a	94.29 ± 0.03^b	97.99 ± 0.01^d

On the same line, averages with the same letter are not significantly different from the 5% threshold.

The extraction yield was higher with chloroform than with hexane or acetone. Indeed, these yields were 6.28%; 23.05%; 30.29% and 40.12% respectively with pressing, acetone, n-hexane and chloroform. Therefore, the lower polar solvents (n-hexane and chloroform) exhibited the highest oil extraction efficiencies. This difference noted between the hot extraction yields can be explained reasonably by the physicochemical properties of the solvents used [22] [28]. However, n-hexane is mentioned in the literature as the most appropriate solvent for lipid extraction [29]. It is known that, n-hexane usually extracts only non-polar lipids and very little polar lipids. Acetone, a renewable organic solvent with a very low boiling point, would be miscible with all oils except palm [30]. Moreover, the results obtained are in agreement with those reported by Mani *et al.* [23] when optimizing the extraction of oil from *Moringa oleifera* seeds which were 33.47% and 30.33%, respectively with hexane and acetone. On the other hand, Tir *et al.* [28] obtained sesame oil extraction yields of 43.75% and 37.23% respectively with hexane and acetone. The differences in extraction yields would be due to the operating parameters used such as temperature, particle size, extraction time

and the ratio (solvent/particle size) [22] [23] [24] [25] [31]. In addition, we find that the extraction yield was 6.28% and 40.12% with pressing and chloroform, respectively. This notorious difference in performance indicates the large amount of residual oil still contained in the cakes after extraction by pressing.

With regard to density, a significant difference was noted on the extracted oils. Density is an important physical feature in the classification of oils. It depends on the fatty acid composition, the minor compounds and the temperature [32]. For the pressing oil, the density is 0.911. Also, it is 0.882 ± 0.016; 0.902 ± 0.020 and 0.945 ± 0.013 respectively for acetone, hexane and chloroform. Indeed, the density of the extracted oils varied with the evolution of the molar mass of the solvents used. These results also suggest a difference in the composition of the extracted oils. However, the results obtained are consistent with those of 0.880 and 0.943 reported on baobab seed oils by Buhari *et al.* [33] and Chindo *et al.* [18], respectively. These values are close to those of the oils of *Moringa oleifera* (0.9032 ± 0.03) and argan (0.9158 - 0.9170) widely used in the cosmetic and pharmaceutical fields [34] [35].

The refractive index for assessing the purity of the oils is between 1.457 and 1.465. The analysis of the variance indicates that there is a significant difference at the 5% threshold for the measured refractive indexes. The refractive index is also affected by the polarity of the extraction solvents. In fact, the oils extracted with the two most polar solvents (chloroform and acetone) had the lowest refractive index. As a result, these two oils would have more long chain fatty acids than other oils. According to Shahidi [32], the lipid refractive index varies according to the molecular weight, the chain length of the fatty acids, the degree of unsaturation and the degree of conjugation. The determined values are in agreement with those obtained by Chadare *et al.* [36] and Nkafamiya *et al.* [17]. These refractive index obtained are comparable with those of *Nigella* spseed oil (1.46 - 1.47), *Jatropha curcus* (1.468 - 1.469), olive (*Olea europaea* L.) (1.468) and argan (*Argania spinosa* L.) (1.468 - 1.471) [37] [38] [39] [40]. In addition, the refractive index is an important property that can detect adulteration of vegetable oils. Based on the iodine and refractive indices, we can say that baobab oil is non-drying.

The specific absorption at 232 nm for oils extracted by pressing and solvents (n-hexane, acetone and chloroform) are below the limit values set by the International Oleic Council (IOC) [41] and the Codex Alimentarius [42] for oils from virgin olives which are respectively 2.60 and 3.5. Indeed, it allows, at 232 nm, to evaluate the presence of the primary products of oxidation of fatty acids (linoleic hydroperoxides, oxidized fatty acids) while at 270 nm are detected the secondary oxidation products (alcohols, ketones…) [43]. The specific extinction at 232 nm of the oil extracted with hexane is consistent with the value of 1.73 reported by Gharby *et al.* [44] for sesame oil. Also, the extinction coefficient at 232 nm of oil extracted with acetone (0.862 ± 0.162) is lower than those extracted with chloroform (1.284 ± 0.029), n-hexane (1.737 ± 0.292) and

pressing (1.492 ± 0.177). These results indicate that the extinction coefficient k_{232} increases with the polarity of the solvents. In addition, the primary oxidation products are lower for the oil extracted with acetone than with those extracted with chloroform, n-hexane or pressing. The oil obtained with acetone is less oxidized than those obtained with chloroform, n-hexane and pressing. This trend was also reflected by the lower peroxide value with the oil extracted with acetone. Ultimately, baobab oil extracted with acetone would be more resistant to oxidation compared to other oils. On the other hand, the specific extinction at 270 nm between 0.883 and 1.571 remains above the limit value allowed for virgin olive oils [42]. The results obtained show that the oil extracted with the most polar solvent (acetone) had the lowest extinction coefficient k_{270}. Therefore, the secondary oxidation products would be less important in the oil extracted with acetone than in the other oils. Also, the extinction coefficients k_{270} nm measured have significantly varied with the polarity of the solvents used and the boiling temperature of the extraction solvents. The results recorded also suggest that these secondary oxidation products would be lower in the pressed oil than in those derived from n-hexane or chloroform. However, the specific extinction at 270 nm of the oil extracted with chloroform remains similar to that of 1.54 ± 0.07 reported by Azhari *et al.* [45] for breast milk oil (*Cucumis melo vartibis*).

The color parameters (L*, a*, b*, Y1, c* and h) of the extracted oils are given in Table 1. The lowest and highest luminosity L* were respectively noted on the acetone (85.15 ± 0.13) and hexane (96.16 ± 0.01). This parameter L* characterizing the ability of a sample to reflect light more or less shows that the oil extracted with n-hexane is brighter than those extracted with pressing, acetone and chloroform. However, the brightness L* of oils extracted by pressing and acetone are similar. Similarly, the color parameter a* indicating the color hue between green and red is −12.22 ± 0.01; −7.74 ± 0.367; −6.96 ± 0.05 and −4.27 ± 0.10 respectively for the oils obtained with n-hexane, pressing, chloroform and acetone. Indeed, the oil extracted with hexane draws more towards the red coloring than those extracted with chloroform, acetone and pressing. Also, the parameter b* corresponding to the color shade between blue and yellow varies according to the different oils extracted. The highest value of b* was obtained with acetone which is 95.68 ± 0.04. This value indicates that the oil extracted with acetone is more yellow than those obtained with chloroform, hexane and pressing.

This value indicates that the oil extracted with acetone is more yellow than those obtained with chloroform, n-hexane and pressing. The b* parameter of the oil obtained by pressing is also similar to that obtained with chloroform. The yellowness index Y1 of the oil extracted with acetone (90.79 ± 0.03) confirms the accentuated coloration of the yolk. On the other hand, Y1 yellowing index values of the oil extracted by pressing and acetone are very close. As a result, the latter two would contain a larger amount of carotenoids [46] [47]. The difference in color observed between the oils obtained at high temperature could be attributed

to the polarity of the solvents. Thus, the physicochemical characteristics of the oils extracted differ according to the properties of the solvents used. In addition, Al-farga *et al.* [48] reported with the oil of alhydwan seeds (*Boerhawia elegana Choisy*) the values 65.44 (L*), 1.11 (a*) and 28.33 (b*). In contrast, Shao *et al.* [47] had obtained 39.26 (L*), 30.56 (a*) and 50.40 (b*) values with tomato seed oil. Data processing by variance analysis shows that there are significant differences at the 5% level.

3.2. Chemical Properties

Table 2 contains the chemical properties of cold-pressed baobab oils and organic solvents. The acid value reports the degradation state of oil by evaluating the amount of free fatty acids formed during extraction or storage. The acid values were between 5.568 and 18.827 mgKOH·g^{-1} respectively with chloroform and pressing method. The acid value noted varies significantly with the polarity of the solvents. In fact, the oils extracted with organic solvents revealed the weakest acid level. Consequently, the hydrolysis of the ester bonds of the triglycerides is greater in the oil resulting from pressing than in those resulting from solvents. At the same time, the increase in the acid value causes a change in the content of glycerol and of free fatty acids in the oil [49]. From these results, we can say that the quality of hot-extracted baobab oils is less altered than that of cold pressure. The latter is therefore less sensitive to rancidity during extraction. In addition, these values are very high compared to those reported by Nkafamiya *et al.* [17] (0.33 mgKOH·g^{-1}) and Birnin-Yauri and Garba [19] (3.14 mgKOH·g^{-1}). However, the acid value of the oil extracted with chloroform is close to those obtained by Ajayi [50] (5.19 mgKOH·g^{-1}) and Oyeleke *et al.* [51] (6.52 mgKOH·g^{-1}). The acid values obtained are also higher than the limit value recommended by the European Pharmacopoeia [52]. These recorded results could be reasonably explained by the pretreatment applied to baobab seeds and/or the presence of a highly active lipase which would lead to rapid acidification of baobab oil during extractions [53]. Also, these important values can be attributed to the heating temperature of the screw head or boiling solvents. According to Tchiégang *et al.* [54], the temperature would cause the hydrolysis of one or two of the ester bonds of triglycerides favoring the formation of free fatty acids. In contrast, Brevedan *et al.* [55] reported a higher acid value for sunflower with n-hexane than with pressing.

Table 2. The polyphenols content and the antioxidant activity of the oils extracted by pressing and organic solvents.

Parameters	Pressure	Acetone	Chloroform	n-Hexane
Polyphenols (mgEAG/g)	0.047 ± 0.0024[b]	0.026 ± 0.003[a]	0.025 ± 0.002[a]	0.028 ± 0.004[a]
DPPH (%)	31.71 ± 0.610[d]	26.38 ± 0.600[c]	9.23 ± 0.670[a]	15 27 ± 0.150[b]

On the same line, averages with the same letter are not significantly different from the 5%.

The iodine value is used to determine the degree of unsaturation of a vegetable oil and to assess stability during storage [56]. The registered iodine value varies significantly with the extraction process. Indeed, this index was between 56.266 and 99.113 $mgI_2 \cdot 100g^{-1}$ and seems to be affected by the polarity of the extraction solvents. Also, the oil extracted with chloroform showed the lowest iodine value (56.266 ± 1.092 $mgI_2 \cdot 100g^{-1}$). Therefore, this high quality oil would be more resistant to oxidation and have a longer shelf life. This iodine valueindicates the low percentage of acidity (2.80% ± 0.054%) of this oil. In other words, the oil extracted with chloroform would contain the lowest amounts of oleic and linoleic acids. The iodine values below 100 $mgI_2 \cdot 100g^{-1}$ make it possible to classify baobab oil as non-drying oils [57]. The oils extracted by pressing, n-hexane and acetone showed the highest iodine values. These high iodine levels suggest the high unsaturated fatty acid content of these oils. Ultimately, baobab oil is comparable to olive oil (75 - 94 $mgI_2 \cdot 100g^{-1}$) widely used by the cosmetics and pharmaceutical industries [38]. The results obtained are in agreement with those indicated by Nkafamiya *et al.* [17] and Danbature *et al.* [21]. The iodine value seems to decrease with the polarity of the solvents.

The peroxide value permit to understand the degree of oxidation of the unsaturated fatty acids. Indeed, the oxidation of the oils leads to the formation of hydroperoxides, primary products of oxidation. Thus, the peroxide value corresponding to the hydroproxide content represents a very useful and very sensitive criterion for assessing the first stages of the oxidative deterioration of a fatty substance and an oil during production and storage [58] [59]. This standard method is included in the specifications for "fatty substances" with a threshold value of 10 meq O_2 per kg of material for a refined oil [58] [60]. In other words, all the peroxide values of the baobab oils obtained are lower than this limit value of 10 $mEq \cdot kg^{-1}$ fixed by the Codex Alimentarius [52]. The quality of the oil extracted with acetone is better than other oils. Indeed, the combination of the peroxide value with the extinction coefficients (k_{232} and k_{270}) shows that the oxidative stability of the oil extracted with acetone is relatively better, which could be explained by the presence of natural antioxidants such as tocopherols, sterols, carotenoids and phenolic compounds [30] [44] [61]. Moreover, these results suggest that the oil extracted with acetone would be less oxidized and less sensitive to deterioration than those extracted by pressing or with chloroform and n-hexane. Also, the peroxide value of the pressing oil could be explained by the temperature reached during the extraction. The results obtained are close to those reported by Adebayo *et al.* [62] with kariya seed oil (*Hildergadia berteri*). However, the peroxide values obtained are lower than those of palm oils (16.08 $mEq \cdot kg^{-1}$) and sorrel (*Hibicus sabdariffa*) (5.00 ± 0.01 $mEq \cdot kg^{-1}$) respectively reported by Birnin-Yauri and Garba [19] and Betiku and Adepoju [63]. The variance analysis indicates that there are significant differences at the 5% threshold of the peroxide values. The oxidative deterioration of oils during extraction and storage operations has been extensively studied and the titration method has been the most widely used [17] [19] [27] [40] [43] [44] [46] [55].

However, this method is complex and long [59] [64]. Also, Sahhidi and Zhong [59] pointed out the possible interference in the determination of light, oxygen and iodine uptake by unsaturated fatty acids. In addition, the peroxide value is a measure that can be used only for samples whose autoxidation is not too advanced [65].

The saponification values measured are 233.587; 205.494; 205.371 and 209.198 mgKOH·g^{-1} respectively for oils extracted with pressing, chloroform, acetone and n-hexane. This significant difference noted between the extracted oils can be attributed to the extraction time and/or the physicochemical properties of the solvents. The baobab seed-oil obtained by pressure reveals the highest saponification value. Therefore, this baling oil would contain more short-chain fatty acids for stability during storage. The baobab oils extracted with organic solvents showed the lowest saponification values. These indicate a predominance of long chain fatty acids in these oils [66]. Very important for the food and cosmetics industries, oils with high saponification values would be less sensitive to deterioration [67]. The results also indicate that the saponification values are higher than those of *Persea americana* oil (35.76 mgKOH/g) [27], argan oil (190.88 mgKOH/g) [68] and olive oil (97.94 mgKOH/g) [46]. Thus, the high saponification value of baobab seed oil indicates the high potential for its use in the manufacture of soaps.

3.3. Antioxidant Potential of Extracted Oils

In order to estimate the quality of the oils extracted, the polyphenol content and the radical scavenging activitywere measured. The results obtained are listed in Table 2. These results indicate that the oil extracted by cold pressing was the richest sample of polyphenols with 0.047 ± 0.0024 mgEAG/g of oil followed by the oils extracted with the hexane (0.028 ± 0.004 mgEAG/g oil), acetone (0.026 ± 0.003 mgEAG/g oil) and chloroform (0.025 ± 0.002 mgEAG/g oil). In fact, according to Salih and Yahia [69], baobab seeds (*Adansonia digitata* L.) contain a polyphenol content of 6.689 ± 0.086 mgEAG/g of seed. With the latter, we can also say that the amount of polyphenols found in oils remains very low. The oil resulting from pressing contains higher polyphenol content. Thus, the application of this oil on the dermatological level would be more beneficial. In addition, this difference in terms of phenolic compounds between the pressing oil and those obtained with solvents results from the extraction method [70], the extraction time achieved and/or the physicochemical properties of the solvents used. Indeed, natural antioxidants (tocopherols, carotenoids, etc.) influence the lipid oxidation [71]. Therefore, oils extracted by pressing and with acetone will be less susceptible to oxidation during storage. However, the polyphenol contents of the various oils extracted are lower than that of *Persea americana* oil (8.27 ± 0.06 mgEAG/g of oil) reported by Adaramola *et al.* [27]. The treatment of the data by analysis of the variances shows that there is a significant difference at the threshold of 5%. The antioxidant activity of the extracted oils varied according to the extraction process.

The results obtained reveal that oils have variableradical scavenging activities. In other words, our results reveal that the pressing oil has the highest polyphenol content and radical scavenging activity. This antioxidant activity of the pressing oil could be explained by its high content of phenolic compounds. Indeed, some studies have reported a positive correlation between antioxidant activity and phenol content [72] [73]. For hot extraction, oil extracted with acetone was rated as the most active with antioxidant activity estimated at 26.38% ± 0.60%. This value remains comparable to that of olive oil (25.38% ± 0.64%) reported by Merouane *et al.* [74].

3.4. Statisticalanalysis

3.4.1. Correlations between Physicochemical Characteristics and Antioxidant Potential of Baobab Oils

The correlation analysis between the physicochemical characteristics of the extracted oils and the antioxidant potential shows a very strong negative correlation of the extraction yield with the radical scavenging activity, the polyphenol content, the acid value, the iodine value and saponification value (Table 3). This table shows that the polyphenol content was negatively correlated with the extraction yield, and positively correlated with theradical scavenging activity. This positive correlation between polyphenol content and radical scavenging activityis consistent with the results obtained through several studies [72] [73]. On the other hand, the acid and iodine values are very negatively correlated with the extraction yield, and inversely correlated with the anti-radical activity, the polyphenol content and the refractive index. Similarly, saponification value was positively correlated with yield, and negatively correlated with polyphenol content and acid value. Also, we also find that the peroxide value was positively correlated with the specific extinction coefficients (k_{232} and k_{270}), the luminescence L* and the chromatic tone h, and inversely correlated with the parameters a* and b*. The very strong correlations between the extinction coefficients and the peroxide value attest to the spectrophotometric approach for evaluating the oxidation state of a fatty substance. Our results are also in agreement with those reported by Guzmán *et al.* [75]. According to them, there was no correlation between the variables peroxide and acid values. On the other hand, the color parameters (a*, b* and Y1) were negatively correlated with the peroxide value, the specific extinction k_{232} and the luminescence L*. The h color tone has a positive correlation with the peroxide value, the specific extinction k_{232} and the L* luminescence, and a negative correlation with the parameters a*, b* and Y1.

3.4.2. Principal Component Analysis

Principal component analysis (PCA) was carried out to evaluate the effect of pressing and/or solvents (acetone, chloroform and n-hexane) on the physicochemical characteristics and antioxidant potential of the extracted oils (Figure 1 and Figure 2). The first two dimensions (Dim 1 and Dim 2) express

Table 3. Pearson correlation coefficients between physicochemical characteristics and antioxidant potential of baobab oils (*Adansonia digitata* L.).

Variables	O. yield	Density	DPPH	Polyph.	R.I.	A.V.	I.V.	P.V.	S.V.	k_{232} nm	k_{270} nm	L*	a*	b*	Y1
Density	0.170														
DPPH	**−0.970**	−0.322													
Polyph.	**−0.832**	0.404	**0.729**												
R.I.	−0.632	0.085	0.463	0.606											
A.V.	**−0.984**	−0.185	**0.932**	**0.802**	**0.752**										
I.V.	**−0.872**	−0.196	**0.778**	0.681	**0.907**	**0.946**									
P.V.	0.319	**0.730**	−0.525	0.091	0.423	−0.209	0.008								
S.V.	**−0.807**	0.444	0.696	**0.999**	0.608	**0.779**	0.664	0.133							
k_{232} nm	−0.002	0.654	−0.224	0.342	0.692	0.124	0.334	**0.944**	0.377						
k_{270} nm	0.658	**0.783**	**−0.801**	−0.182	−0.041	−0.602	−0.449	**0.888**	−0.137	0.692					
L*	0.575	0.267	**−0.717**	−0.413	0.270	−0.426	−0.119	**0.824**	−0.381	**0.711**	**0.753**				
a*	−0.139	−0.433	0.346	−0.082	−0.668	−0.017	−0.298	**−0.917**	−0.113	**−0.948**	−0.664	**−0.870**			
b*	−0.230	−0.378	0.426	0.034	−0.605	0.070	−0.227	**−0.905**	0.003	**−0.909**	−0.679	**−0.919**	0.993		
Y1	−0.407	−0.303	0.577	0.239	−0.451	0.247	−0.064	**−0.869**	0.208	**−0.816**	−0.714	**−0.980**	0.948	0.978	
h	0.148	0.405	−0.353	0.057	0.665	0.010	0.297	**0.907**	0.087	**0.936**	0.653	**0.880**	−0.999	−0.996	−0.955

O. yield: oil yield; R.I.: refractive index; S.V.: saponification value; P.V.: peroxide value; A.V.: acid value; I.V.: iodine value; Polyph.: polyphenols.
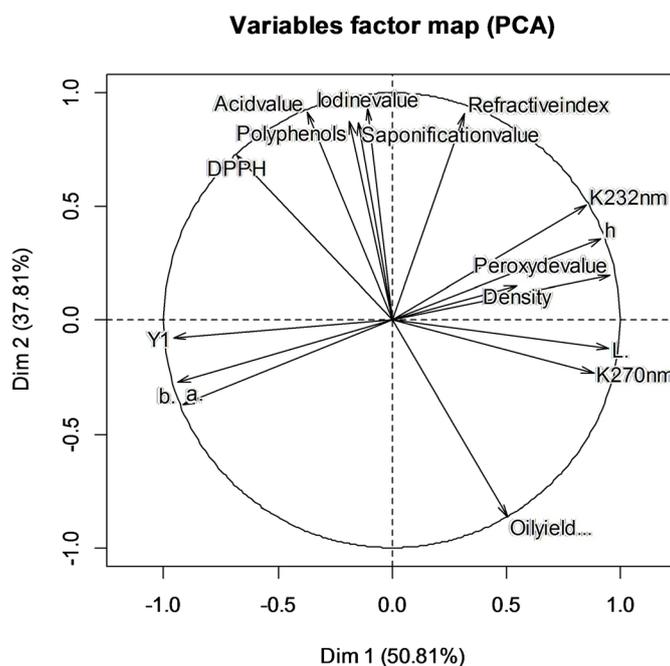
Figure 1. Correlation between physicochemical properties and the antioxidant potential of baobab oils and the first two dimensions of PCA.
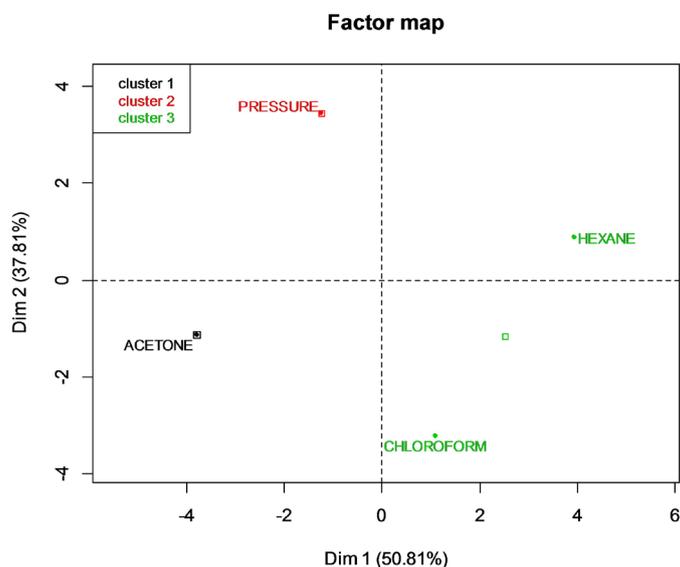
Factor map

88.62% of the total variance. Indeed, the first dimension (Dim 1) contributes to 50.81% and the second dimension (Dim 2) to 37.81%. The density variables, peroxide value, specific extinction coefficients (k_{232} and k_{270}), luminescence L* and chromatic tone h are positively correlated with the first axis, while variables a* (color shade between green and red), b* (shade of color between blue and yellow) and yellowness index Y1 are negative. The parameters for evaluating the oxidation state of the extracted oils are well aligned with this first dimension (Dim 1), which could be considered as an axis of quality. Moreover, the polyphenol variables, radical scavenging activity, refractive index, acid value and iodine value are positively correlated to the second dimension (Dim 2). On the other hand, the yield variable is negatively correlated with this dimension (Dim 2). Furthermore, the parameters representing the antioxidant potential, the state of conservation and the identification of the oils obtained are well aligned with this second dimension. The dimensional axes (Dim 1 and Dim 2) delimit the types of solvents and extraction used. The position on the axis Dim 1 differentiates the oil with the peroxide value, density, specific extinction coefficients (k_{232} and k_{270} nm), luminescence L* and h (n-hexane) color tone, to the other oils characterized by the color parameters (a* and b*) and yellowness index Y1 (acetone and chloroform). However, the position on the axis Dim 2 opposes the oils with a polyphenol content, an free radical scavenging activity, a refractive index, a saponification value and a high iodine value (oil extracted by pressing), oils (extracted with chloroform and acetone) in low yield. Thus, based on the physicochemical properties of the oils, it is clear that the oil extracted by pressing best retains its quality. Nevertheless, the solvents (acetone, chloroform and n-hexane) make it possible to obtain oils with a lower radical scavenging activity and Y1 yellowing index. The oil extraction methods have been grouped

into three classes. The first class is the oil extracted with acetone. The latter is characterized by a yellowness index and color parameters (a* and b*). Class 2 consists of oil extracted by cold pressing. Finally, class 3 consists of the less polar solvents (chloroform and n-hexane).

4. Conclusion

In this study, the impact of pressing and solvents on physicochemical characteristics, polyphenol content and radical scavenging activity of baobab oils extracted was determined. The results obtained reveal that the oil extracted by pressing retains at best its physicochemical properties and contains a very high content of phenolic compounds and radical scavenging activity. Also, this oil produced by pressing exhibits a more intense yellow coloration than that obtained from the solvents. However, chloroform provides the best extraction yield. The extraction with n-hexane makes it possible to obtain oils whose physicochemical characteristics are less attenuated. With organic solvents, the oil extracted with acetone, the most polar solvent, exhibits an acceptable radical scavenging activity. Taken together, these results provide fundamental element for decision making regarding the method of extraction to use for specific addressed use of baobab oil. These results suggest the mixed use of acetone and hexane for better conservation of the chemical and bioactive characteristics of baobab oil. Therefore, further studies will be needed to determine the optimal conditions for extracting oil comparable to cold pressed oil and for identifying bioactive compounds.

Conflicts of Interest

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

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