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Research Article

Physicochemical Characterization of Non-Wood Forest Product Oils: Towards a Strategic Positioning in Agroforestry

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Abstract

NTFPs play a crucial role in local ecosystems and economies, especially in rural areas where they are an important source of income and food security. The main objective of the study is to characterize the physicochemical properties of oils from these NTFPs in order to better understand their economic, food and industrial potential. This includes the analysis of fatty acids, minor compounds, as well as functional properties such as acidity, saponification index and iodine. The kernels of the NTFPs studied are rich in proteins with contents of 18.9% for *Blighia sapida*, 21% for *chrysophyllum albidum*, 22.5% for *carapa procera* and 18.9% for *Tieghemella heckelii*. In addition, these almonds are rich in oil with a content of 47.7% *Tieghemella heckelii*, 52.2%, *Blighia sapida*, 52% *Chrysophyllum albidum* and 54% *carapa procera*. These plants are oilseeds. These lipids have low acidity levels varying between 1.2 ±0.2 to 2.6 ±0.3%. The iodine values of the oil are 73.1 ±0.4 for *Chrysophyllum albidum*, 70 ±0.3 for *Carapa procera*, 93.2±0.5, for *Blighia sapida* and 91.7 ±0.2 *Tieghemella heckelii*. Regarding the saponification indices the values found are 193.7±0.8 for *Blighia sapida*, 189.4±0.7 mgKOH/g for *Carapa procera*, 154.6±0.2 for *Chrysophyllum albidum* and 147.3 ±0.5 for *Tieghemella heckelii*. The saponification indices are between 147.3 ±0.5 to 193.7 ±0.8. The analysis of the composition of free fatty acids showed that *Tieghemella heckelii* oil is mainly composed of oleic acid at 53.6±0.1 and stearic acid at 38.5±0.3. *Blighia sapida* oil's major compounds are oleic acid (54.6±0.1%), palmitic acid (24.2±0.2%) and stearic acid (16.4±0.0 %). *Carapa procera* oil is mainly composed of oleic acid at 50.7±0.0%, palmitic acid at 23±0.1%, linoleic acid at 11±0.0% and stearic acid 10.4±0.1%. As for *Chrysophyllum albidum* oil, it is mainly composed of oleic acid at 47.6±0.3% and α-linolenic acid 17.8±0.1%. The results show that β-sitosterol and γ-tocopherol constitute the major compounds in all the oils studied. The results show that NTFP oils can be a sustainable alternative to conventional oils, making them attractive for growing sectors, particularly those linked to sustainable development. Thus, this study makes a significant contribution to the promotion of NTFPs with a view to economic and environmental sustainability, while highlighting their potential role in the development of modern agroforestry.

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1. Introduction

The Ivorian Forest cover, which was 16.5 million hectares in 1960, has increased to around 2 million hectares today. Côte d'Ivoire has therefore lost more than 87% of its forest cover in 60 years, which makes it today a non-forest country. Experts announce that the Ivory Coast risks completely losing its forests by 2050 if the rate of this loss continues [1-3]. This deforestation is due to bush fires, abusive logging and intensive slash-and-burn agriculture, particularly cocoa and coffee growing (Fordeco-ci).

Deforestation is also one of the causes of climate change, drought and therefore the advance of the desert. It is also these different factors which are at the origin of soil impoverishment. The combination of these factors is also generally the cause of a decline in soil fertility, the destruction of orchards by parasites and water stress suffered by plants.

As a result, despite the high production of cocoa beans (2 million tonnes, 2023) the yield of agricultural operations remains low. Indeed, the average yield of the Ivorian orchard according to the studies of Assiri et al., (2012), is between 260 and 600 kg/hectare/year [4] against an announced forecast potential of 3 to 5 tonnes/hectare for newer varieties of cocoa trees (NRAC).

To compensate for this insufficiency, the State of Côte d'Ivoire offers its support through agricultural support structures such as the National Agronomic Research Center (NRAC), the National Agency for Rural Development Support (NARDS), and the Interprofessional Fund for Agricultural Research and Advice (IFARA), through the supervision of planters in the use of approved chemical fertilizers and pesticides. The use of pesticides and fertilizers makes it possible to improve or maintain the yield and quality of these agricultural products, particularly cocoa and coffee. It also reduces the need for new land and thus reduces the destruction of the country's forest cover.

However, the use of these products (fertilizers and pesticides) can lead to health and food safety problems linked to their residues because of their disastrous effects on fauna and flora through water contamination, air and soil [5]. In addition, the high cost of these products on the market makes them less accessible to farmers, because they are too expensive for the majority of farmers.

The other alternative considered by the state of Côte d'Ivoire is the use of non-timber forest products (NTFPs) for the direct reforestation of the forest cover or the use of certain plants in agroforestry, in cocoa and coffee growing. The choice of these plants must take into account several factors, namely economic, nutritional, societal and environmental values, to increase their acceptability by producers.

From this perspective and taking into account current global issues relating to environmental protection, interest in new domestic species has been brought up to date. We are therefore considering developing an economic model with the following plants (*Tieghemella heckelii*, *blighia sapida*, *chrysophyllum albidum*, and *carapa procera*) whose advantages are notable and the potential is known [6-12]. They can therefore be used for reforestation, but also in agroforestry in coffee and cocoa farming. This model will thus reduce the need for new land, reduce the destruction of forest cover and thus reconstitute the Ivorian forest.

In addition to these qualities listed above, the almonds of these plants are highly prized and used by certain African populations as culinary thickeners and for body maintenance. The consequences of deforestation and climate change, on the soil, on the quality of agricultural products (cocoa, coffee) and their socio-economic impact on Ivorian farmers raise the following question: how to involve populations in a project while offering solutions adapted to their development problems while respecting their eating and growing habits through a new income producing with high added value, these plants?

The motivation of our team is to provide its assistance and expertise in order to facilitate the creation of an innovative economic model around these plants and to deepen the reflection on the valorization of the co-products of these plants, to the effect to give them added value and promote their large-scale use in reforestation and agroforestry in Africa. The present study was undertaken to determine the properties of the constituents of the almonds of *Tieghemella heckelii*, *blighia sapida*, *chrysophyllum albidum*, and *carapa procera* in Côte d'Ivoire, the seeds of which are traditionally used by the local population. This study is to determine the chemical composition and physicochemical properties of the oils and kernels of these NTFPs, in order to justify and promote their use as agroforestry plants.

2. Material and Methods

2.1. Material

The plant seeds (NTFPs) used in this study come from the National Floristic Center (NFC) of Félix Houphouët-Boigny University. Located within the botanical garden, 82W7+JP7, C 55, Abidjan in Ivory Coast, West Africa. The fruits were collected during August 2018. The seeds were extracted and stored in bulk freezer bags at +4 ℃ until transported to the agro-industrial chemistry laboratory in Toulouse, France. They were subsequently stored in a cold room at + 4 ℃.

2.2. Seed Extraction Methods

2.2.1. Tieghemella Heckelii (Makoré) and Chrysophyllum Albidum Seeds Treatment

Figure 1 shows the seeds of *Tieghemella heckelii* and the ripe fruits of *Chrysophyllum albidum*. The seeds of these fruits are inside a berry. The same traditional mechanical processing technique is used to separate the seeds from the berry. The fruits are fermented in a container for at least a week under regular control. The seeds are then released from the fermented berry by hand and washed with water.

Extracting the almonds from the seeds required a method to crack the hard outer shell to access the almond inside. Before breaking the shell, the seeds are dried by exposure under a ventilated shelter for a week to facilitate the extraction of the almonds. A nutcracker is then used to break the shell to avoid breaking the almond inside.

Figure 1. *Seeds of Tiegbemela heckelii (Makoré) (A) and Chrysophyllum albidum (B).*

The almonds obtained are stored in a cool, dry place, away from light and humidity, to avoid deterioration.

2.2.2. Blighia Sapida Seeds Treatment

Blighia sapida fruits were harvested fully ripe. The seeds were harvested after natural opening of the fruits. The seeds are black in color, surrounded by light yellow arils (Figure 2). This fleshy part (aril) of the seed is edible. After harvest, the aril is separated from the black seeds by hand and dried by exposure under a ventilated shelter for a week.

This operation reduces humidity to prevent decomposition of this part of the seed. The almonds obtained are stored in a cool, dry place, away from light and humidity, to avoid deterioration.

Figure 2. *Blighia sapida Seed.*

2.2.3. Carapa Procera Seed Treatment

As shown in Figure 3, *Carapa procera* seeds are surrounded by a very hard shell that protects the kernel. The manual method (small hammer) is used to break the shell and recover the almonds.

Figure 3. *Carapa procera seeds.*

Like other almonds, they are stored in a cool, dry place, away from light and humidity, to avoid deterioration.

2.3. Extraction of Oil from NTFPs Almonds

Depending on the quantity and quality of oil required for analysis, we extracted the oils from these kernels using two oil extraction methods. We extracted total lipids in the solvent with a Soxhlet extractor for oil content measurements. The oil used for chemical and physicochemical characterization was cold extracted from cyclohexane. The various lipid extractions obtained by solvent were carried out at least three times.

2.4. Solvent Extraction of Lipids by Soxhlet

A mass of 15 grams of almonds of each species is crushed and placed in a cartridge and placed in the soxhlet extractor. Using 150 ml of cyclohexane contained in a 200 ml flask, the fat contained in the ground material is exhausted by heating the solvent (approximately 85 ℃). The heating is stopped after six (6) hours. The oil is obtained after evaporation of the solvent on a rotary evaporator at 40 ℃ under vacuum at 200 mbars.

2.5. Cold Extraction in Cyclohexane

A 5 g mass of kernels of each species ground in a blade mill was placed respectively in a 30 ml centrifuge tube with 25 ml cyclohexane. The tubes were swirled for 30 s and then centrifuged for 15 min at 10,000 × g. The supernatant was decanted and the phase (lipid material) was recovered. This process was repeated three times. All of the collected organic phases were combined and filtered through a funnel containing fiberglass filter paper on which a few grams of anhydrous sodium sulfate was placed. The oil is obtained after evaporation of the solvent on a rotary evaporator at 50 ℃ under vacuum at 200 mbars.

2.6. Determination of Protein Content of Meal

The method used is an indirect method which consists of determining the percentage of nitrogen (% N) by the Kjeldahl method according to standard NF V 18-100 revised 2014. The Kjeldahl method consists of mineralizing the organic nitrogen contained in the sample in the form of ammonia and then dosing it with an acid [13].

For mineralization, 0.8 g of dried and defatted oilcake is placed in a glass tube to which 12.5 ml of 95% concentrated sulfuric acid has been added. The mixture is put under a host for 16 hours. After 16 hours, two catalyst tablets are introduced into the tube. The mixture is then mineralized at 400 ℃ for 1 hour. Finally, the analysis is carried out by a KjeltecTM 8400-type analyzer.

2.7. Determination of Oil Indices

The determination of the acid and iodine indices and the acidity was done by volumetric dosage methods following the standard protocols: NF EN ISO 3961 for the iodine index, NF EN ISO 660 for the acid index and acidity, and NF EN ISO 3657 revised in 2020 and 2023 for the saponification index. The determination of acidity was carried out by the theoretical method based on the fatty acid profile of the oil of each species.

2.8. Determination of Moisture and Fiber Content

The humidity level was determined according to the AOAC method (2005). 2g of ground material of each species obtained after grinding the almonds is placed in a previously tared watch glass [14]. The samples are placed in an oven (Memmert) at 103±3 ℃ until a constant mass is obtained. The determination of the fibers was carried out by difference calculation.

2.9. Determination of Tocopherol Content by HPLC

The tocopherol content of the oil was determined by HPLC-fluorimetry, according to the analytical method described in the AFNOR NFISO 9936 standard. We used a liquid-phase chromatograph coupled to a Dionex fluorescence detector (λex290 nm; λem 317 nm) and an oven heated to a fixed temperature of 22 °C. We injected 20 µl of a 10 mg/ml solution of oil in cyclohexane into the HPLC apparatus. The mobile phase was a mixture of isooctane and isopropanol (99.5/0.5 v/v), at a flow rate of 1.1 ml/minute. Quantification was based on external calibration with standards (α-tocopherol, γ-tocopherol, and δ-tocopherol) from Sigma.

2.10. GC Analysis

2.10.1. Determination of Sterol Content by GC

The determination of sterol content began with the preparation of a 2 mg/ml solution of cholestanol (internal standard). We added precisely 50 µl of this solution (corresponding to 100 µg of cholestanol) to a 15 ml screw-top tube. After chloroform evaporation, 100 mg of oil was added.

Saponification was carried out through addition of 2 ml of 1 M KOH in ethanol. The mixture was vortexed and heated for 20 min in a water bath at 75 ℃. The reaction mixture was allowed to cool, 1 ml of demineralized water plus 6 ml of cyclohexane were added and the contents of the tube were mixed by vortexing. We allowed the mixture to separate and recovered the organic phase containing the unsaponifiable matter. We mixed 160 µl of this solution with 40 µl of silylation reagent (99% N, O-bis [trimethylsilyl trifluoroacetamide] plus 1% trimethylchlorosilane: BSTFA/TMCS, 99/1). Sterol determinations were performed by GPC with a Perkin Elmer Auto System XL, equipped with a CPSil 8CB (Varian) 30 m x0.25 mm column, with a film thickness of 0.25 µm. The carrier gas was helium, at a column head pressure of 100 kPa. We injected 1 µl of solution in the on-column mode. The oven temperature was maintained at 160 ℃ for 0.5 min and was then increased gradually to 260 ℃ at a rate of 20 ℃/minute. Oven temperature was then increased to 300 ℃ at a rate of 2 ℃/minute, and finally to 350 ℃ at a rate of 45 ℃/minute. The total analysis time was 50 min.

The temperature of the flame ionisation detector (FID) was set at 360 ℃ [15].

2.10.2. Fatty Acid Profile by GC

The fatty acid profile of the oils was carried out following the Schulte method [16]. The oil (15 mg) was solubilized in 1 ml of TBME (Tert-Butyl Methyl Ester), after methylation using TMSH, the fatty acid methyl esters obtained are analyzed by GC. The gas chromatograph used is of the Varian 3900 type; 1 µl of the previous solution is injected into this chromatograph with the following parameters: Injector in split mode, a ratio of 1/100, 250 ℃ (55 min). CP-Select CB for FAME fused silica WOCT type column, 50 m, 0.25 mm, film thickness 0.25 µm. Carrier gas: helium with a flow rate of 1.2 ml/min. Oven temperature: initial 185 ℃ for 40 minutes, then increased by 15 ℃/min to 250 ℃ and maintained at 250 ℃ for 10.68 min. The identification of fatty acid methyl esters was based on the retention times obtained for a mixture of methyl esters using commercial standards Mix 37 (Sigma Aldrich).

3. Results and Discussion

3.1. Exploitation of NTFPs in Côte d'Ivoire

Until now, the plants *Tieghemella heckelii, blighia sapida, chrysophyllum albidum*, and *carapa procera* are unimproved subspecies, there is no actual cultivation of these trees. Despite attempts to domesticate these plants, they remain primitive plants. The trees are not planted, but preserved during the clearing of the initial forest. The multiplication of these plants is done from unselected seeds, they grow naturally in favorable conditions [11, 17-20]. However, these studies found germination rates between 30% and 60% of unselected seeds. They are fast-growing species. This species is suitable for domestication, extensively in rural areas and especially in agroforestry. The creation of farms of these NTFPs is therefore a long-term operation of around 5 years.

Future studies must be carried out (NCAR and Swiss Research Center) to improve the cultivation of natural or improved species in order to reduce the age of fruiting, the size of these trees and their productivity.

Several obstacles exist for the harmonious development of new cultures. These are essentially linked to the existence of insect pests during the growth of the plant, to the collection and fermentation of the fruits, to the isolation of the almond and the crushing of these to extract them. oil. Work must be carried out on these subjects in the laboratory and in the field, which will allow us to acquire the expertise necessary to remove all these obstacles.

Building on the interest of both urban and rural populations in these almonds, research teams, particularly in Africa, have been committed, for more than a decade, to their development. The bibliographic analysis carried out on the subject shows that these studies focused on the characterization of lipid extracts and cakes, the search for biologically active molecules in the leaves, roots and bark of trees. [17, 11, 21]

3.2. Physicochemical Characterization of NTFPs Seeds

The distribution of the constituent elements of the almonds of the four species of NWFPs obtained by the traditional mechanical processing method of shelling is presented in Table 1. This method is commonly used to extract almonds from hard-shelled seeds in some rural areas where the we find these plants.

Table 1. *Contents of almond constituents of the NTFPs.*

Content of constituents %	Tieghemella heckelii	Blighia sapida	Carapa procera	Chrysophyllum albidum
Humidity level	8.2±0.2	5.4±0.1	4.1±0.2	3.5±0.3
Dry matter	91.8±0.0	94.6±0.2	95.9±0.5	96.5±0.1
ash	2.1±0.1	3.2±0.2	2.5±0.1	2.8±0.3
Fiber	23.1±0.3	20.9±0.1	16.9±0.0	20.7±0.2
Protein	18.9±0.3	18.3±0.0	22.5±0.1	21±0.0
Oil (soxhlet)	47.7±0.2	52.2±0.1	54±0.2	52±0.3
Oil aspect	Butter	Fluid	Fluid	Fluid

Moisture content: the results show that the water and dry matter contents of almonds vary between 3.5±0.3 % to 8.2±0.2 % and between 91.8±0.0 to 96.5±0.1%. However, we note that *Tieghemella heckelii* almonds have the highest value, 8.2±0.2 %. These contents respect the reference standards, they are less than 10%, which guarantees their good conservation and avoids the development of mold in these almonds [14]. Apart from *Tieghemella heckelii*, the drying of other seeds (*blighia sapida*, *chrysophyllum albidum*, and *carapa procera*) was easily done under optimal conditions. This could be explained by the size of this almond see Figure 1. The almonds of *Tieghemella heckelii* measure approximately 5 cm long with a width of around 3 cm and a thickness of 1.5 cm. The almonds obtained after drying are therefore of good quality and can be stored for a long time before use. Fat content: all the fatty substances obtained are liquid except Makoré oil which is in the form of butter. The results clearly show without ambiguity that these four NTFPs are oilseeds with a fat content of 47.7% *Tieghemella heckelii*, 52.2±0.1%, *Blighia sapida*, 52±0.3% *Chrysophyllum albidum* and 54±0.2% *carapa procera*. We note that these high vegetable fat contents are in agreement with the work of Ouattara and al., (2010) with an oil extraction rate in the aril of *Blighia sapida* of 45.32% [21]. According to studies by Kone and al., (2022) *Tieghemella heckelii* almonds are rich in oil with a content of 64.7% [11]. Some studies report a fat content of dried Makoré almonds of between 40 and 50% [22]. Regarding the fat content of *carapa procera* almonds, similar results were reported on the work of Djenontin and al., (2012) [23]. The oil content of the kernels of these four NTFPs is comparable to the oil content of the kernels of *Ricinodendron heudelotii*, 47.4 ± 0.2% and of *Irvingia gabonensis* 63.8 ± 0.2% of other well-known NTFPs [24, 25]. Protein content: the results in Table 1 indicate that the almonds of these fruits are rich in fiber, intake in the diet would be beneficial, promoting intestinal and digestive transit. These contents vary between 18 to 22% (*Blighia sapida* 18.3±0.0%, *chrysophyllum albidum* 21±0.0%, and carapa procera 22.5±0.1%, *Tieghemella heckelii* 18.9±0.3%). Compared to the percentage recommended for Food by the Food and Agriculture Organization of the United Nations (FAO, 2003) [26] which varies from 12-15%, the values reported in this work are higher. These protein-rich almonds can be used in various industrial formulations, in particular to improve the nutritional quality of certain products or their functional properties. These results can provide additional arguments for the use of *Blighia sapida* and *Tieghemella heckelii* kernels (edible) in food formulations. The proteins from these almonds can be added to food products (biscuits, pasta, cereals) to enrich their nutritional content, particularly for specific audiences such as children or vegetarians.

3.3. Physicochemical Characterization of Oils

The results of acid value, acidity, iodine and saponification index of oils extracted from almonds obtained from the seeds are summarized in Table 2.

Table 2. *Physicochemical characteristics of oils from NTFPs.*

Physical characterization of oils	Tieghemella heckelii	Blighia sapida	Carapa procera	Chrysophyllum albidum
Acid number	2.9 ±0.4	4.9±0.6	5.4 ±0.5	2.5±0.2
Acidity (%)	1.4±0.5	2.4±0.1	2. 6±0.3	1.2±0.2
Iodine index	91.7 ±0.2	93.2±0.5	70 ±0.3	73. 1 ±0.4
Saponification index (mgKOH/g)	147.3 ±0. 5	193.7±0.8	189.4 ±0.7	154.6 ±0.2

The results show that the acidity of the oil sample varies greatly from one oil to another and is from 1.2 ±0.2 to 2.6 ± 0.3% in terms of free fatty acids. These low values of the acidity of the oils of the seeds studied show, in short, that the oils of these NTFPs are fresh with well-controlled production and of superior quality. The iodine value, which provides information on the degree of unsaturation of fatty acids in vegetable oils, was determined for the seed oil of the four plants. According to our study, the iodine value of seed oil was found to be 73.1±0.4 for *Chrysophyllum albidum*, 70±0.3 for *Carapa procera*, 93.2±0.5, for *Blighia sapida* and 91.7 ±0.2 *Tieghemella heckelii*. The value obtained is lower than 102.9 ±4.4 reported by Kone and al., (2022) on Makoré oil [11]. Our result in *Chrysophyllum albidum* oil is similar to that of Lawal et al., (1998) who showed that the iodine index value varies between 65.30 and 78 depending on the type of oil [27]. Studies by Esuoso and al., (2021) reported an iodine index value of 64.3 for Blighia sapida oil [28]. All iodine number values in this study, compared to the dryness scale, indicate that these oils are non-drying oils (iodine number values are less than 100 (g iodine/100 g d 'oil)).

These non-drying oils can be very useful in areas where stability and fluidity are important (Lubrication, Cosmetics, Skin Care and Food Industry). Their main characteristic is that they do not harden, making them suitable for applications where rapid oxidation or drying is undesirable. According to studies by Aloko et al., *Blighia sapida* seed oil can be a useful and inexpensive tablet lubricant [29]. The saponification index of the almond oils of *Blighia sapida* (193.7±0.8 mgKOH/g) and *Carapa procer*a (189.4±0.7 mgKOH/g) is higher than that of Chrysophyllum albidum (154.6 ±0.2 mgKOH/g) and Tieghemella heckelii (147.3 ±0.5 mgKOH/g). Similar results have been reported in the literature [11, 27, 28, 30, 31]. The saponification value obtained in this study (Table 2) projects these oils as well in the areas of soap making.

3.4. Fatty Acid Composition of Oils

The free fatty acid profile present in the almond oils of the NTFPs studied is presented in Table 3. Three groups of fatty acids were detected, saturated fatty acids, monounsaturated fatty acids and polyunsaturated acids. *Tieghemella heckelii* oil is mainly composed of oleic acid at 53.6±0.1 and stearic acid at 38.5±0.3. This oil is composed of approximately 44% saturated fatty acids. The high steric acid content explains the solid texture at room temperature (butter) of *Tieghemella* *heckelii* almond oil.

This oil has a composition similar to Shea butter [32]. The results reveal that the major compounds of *Blighia sapida* almond oil are oleic acid (54.6±0.1%), palmitic acid (24.2±0.2%) and stearic acid. (16.4±0.0%). Linoleic acid is also found in small quantities (2.5±0.2%). Our results agree with those of Esuoso and al., (1998) [28]. However, they differ from those of Djenontin and al., (2009) of which eicosenoic acid (C20:1) is the majority compound with a value of 48.4±1.0 [33].

Table 3. *Fatty acid profile of oil extracted from NTFPs.*

Fatty acid profit	Tieghemella heckelii	Blighia sapida	Carapa procera	Chrysophyllum albidum
C14:0 lauric acid	ND	ND	ND	6.3±0.1
C14:0 myristic acid	0.1±0.1	ND	0.1±0.2	2.4±0.2
C15:0 pentadecylic acid	ND	ND	0.3±0.0	ND
C16:0 palmitic acid	4.9±0.2	24.2±0.2	23±0.1	7.1±0.1
C20:0 arachidic acid	ND	0.9±0.0	1.6±0.2	ND
C22:0 behenic acid	0.3±0.2	DN	0.6±0.3	ND
C18: 0 stearic acid	38.5±0.3	16.4±0.0	10.4±0.1	9.7±0.2
Saturated fatty acid	43.8±0.1	41.5±0.0	36.0±0.2	25.5±0.0
C16:1n 7 palmitoleic acid	ND	ND	0.4±0.0	ND
C18:1n9c oleic acid	53.6±0.1	54.6±0.1	50.7±0.0	47.6±0.3
C18:1n7c cis-vaccenic acid	ND	0.8±0.2	0.6±0.2	0.5±0.1
C20:1n9 gondoic acid	1.3±0.1	ND	0.1±0.2	ND
Monounsaturated fatty acid	54.9±0.2	55.4±0.1	51.8±0.0	48.1±0.1
C18:2n6t linolelaidic acid	ND	ND	ND	ND
C18:2n6c linoleic acid	1.2±0.5	2.5±0.2	11±0.0	8.6±0.1
C18:3n6 γ-linolenic acid	ND	ND	1.0±0.1	ND
C18:3n3 α-linolenic acid	0.1±0.1	0.6±0.1	0.2±0.1	17.8±0.1
Polyunsaturated fatty acid	1.3±0.1	3.1±0.1	12.2±0.1	26.4±0.2

Like *Blighia sapida* oil, *Carapa procera* oil is mainly composed of oleic acid at 50.7±0.0%, palmitic acid at 23±0.1%, linoleic acid at 11±0.0% and stearic acid 10.4±0.1%. Regarding the almond oil from the seeds of *Chrysophyllum albidum*, the majority constituents are oleic acid at 47.6±0.3% and α-linolenic acid at 17.8±0.1%. We also note the presence of stearic acid at 9.7±0.2%, linoleic acid at 8.6±0.1% and lauric acid at 6.3±0.1%. Similar results are reported in the literature [23, 34]. The fatty acid profile of all the oils studied shows that they are mainly composed of a saturated fatty acid and monounsaturated fatty acid. The presence of saturated fatty acids in these oils can therefore be appreciated for their stability and their ability to provide a solid texture, skin protection, as well as effective hydration in care products. In addition, the presence of monounsaturated fatty acids in these oils, thanks to their moisturizing properties can be used in skin and hair care, as well as their stability in cooking and in food products.

3.5. Minor Constituents of Oils

Table 4 groups together the unsaponifiable fraction of oils, it is composed of tocopherols and sterols. These are functionally important non-fatty molecules of the different oils studied.

Table 4. *Minor compounds profile of oil extracted from NTFPs.*

Minor compounds	Different types of almond oils from PFNLs			
	Tieghemella heckelii	**Blighia sapida**	**Carapa procera**	**Chrysophyllum albidum**
tocopherols (%)				
α-tocopherol	31.0 ± 0.01	24.7 ±0.0	36.4 ± 0.01	25.4 ± 0.0
γ- tocopherol	10.9 ± 0.02	11.3 ±0.5	13.2 ±0.1	9.8 ± 0.1
δ- tocopherol	43.1 ± 0.2	33.6 ±0.1	55.1 ±0.5	42.1 ± 0.6
Total (mg/100g)	98.4	92.2	118.4	97.1
sterols %				
campesterol (%)	3.9 ±0.5	16.9 ±0.3	6.5 ±0.1	5.5 ±0.1
stigmasterol (%)	19.5 ±0.2	42.6 ±0.2	21.1 ± 0.01	18.1 ±0.2
β sitosterol (%)	54.6 ±0.3	79.1 ±0.5	73.2 ±0.3	63.4 ±0.3
Stigmastanol (%)	6.7 ±0.01	1.1 ±0.1	0.5 ±0.1	2.3 ±0.5
d5 Avenastérol (%)	6.3 ±0.1	0.6 ±0.2	4.6 ±0.5	3.3 ±0.4
total sterols (mg/100g)	183.6	245.2	290.1	202.5

The value of the total tocopherol content is 98.4 mg/100g, 92.2 mg/100g, 118.4 mg/100g and 97.1 mg/100g, respectively for the oils of the almonds of *Tieghemella heckelii*, *Blighia sapida*, *Carapa procera* and *Chrysophyllum albidum*. These results show that the oils studied are moderately rich in tocopherols. Whatever the oil, the major constituent is γ-tocopherol with a content which varies between 33.6 ±0.1 mg/100g and 55.1±0.5 mg/100g. This molecule (γ-tocopherol) is a form of vitamin E with unique antioxidant and anti-inflammatory properties, particularly in neutralizing nitrogen free radicals. The sterol composition of these oils varies between 183.6 mg/100g and 290.1 mg/100g, it is 183.6 mg/100g for *Tieghemella heckelii*, 245.2 mg/100g *Blighia sapida*, 290.1 mg/100g *Carapa procera* and 202.5 mg/100g *Chrysophyllum albidum*. These results show that β-sitosterol constitutes the major compound in all the oils studied with a content of 54.6 ±0.3 *Tieghemella heckelii*, 79.1 ±0.5 *Blighia sapida*, 73.2 ±0.3 *Carapa procera* and 63.4 ±0.3 *Chrysophyllum albidum.*

3.6. Positioning of These Plants (NTFPs)

The work carried out on plant seed oils will provide information, arguments and indications on the possible valorization of these plants. These plants can be used for the reforestation of the Ivorian forest and in agroforestry, in orchards (cocoa and coffee growing) which will promote the creation of the sector for these almonds. The results of this work will make it possible to position these plants as a crop resulting from sustainable (cash) agriculture, a multi-service crop for the benefit of shaded crops. This work therefore opens the way to unprecedented diversification. In terms of benefits, the design of recoverable active lipid ingredients, obtained from the products of these crops, is a unique model of replicable Agroforestry. An agri-food industry and a non-food industry could also be added to this project.

These elements constitute an important asset for the creation and development of the almond sector of these plants. This sector will ultimately be a major element in the fight against poverty in Ivory Coast. In particular, it will represent a sustainable and very important source of income for women who are the primary actors in almond production.

In addition, the cultivation of these oilseed plants in agroforestry crops such as cocoa and coffee will make it possible to improve the productivity of these products and therefore, contribute to the economic development of Côte d'Ivoire. This association will make a strong contribution to the fight against desertification, global warming and drought.

4. Conclusion

The results of this study revealed that the amount of oil obtainable from the seeds of Tiegbemela heckelii, blighia sapida, chrysophyllum albidum, and carapa procera is high compared to other oilseeds. The fat content of *Tieghemella heckelii* seeds is 47.7%, that of *Blighia sapida* 52.2%, *Chrysophyllum albidum* 52% and *carapa procera* 54%. In addition, these almonds are rich in protein with contents varying between 18 to 22% (*Blighia sapida* 18.9%, *chrysophyllum albidum* 21%, and *carapa procera* 22.5%, *Tieghemella* *heckelii* 18.9%). These include oil-protein plants which have unlimited applicability in the industrial field. The study of physicochemical parameters shows that these almonds store well and easily, which is explained by a low humidity level of between 3 to 8%. The results relating to iodine indices suggest that the oils obtained are non-drying and therefore do not oxidize, they are stable and keep well. From the values of saponification indies, it can be concluded that these oils can be used for soap making. Due to their composition of oleic acid, α-linolenic acid also stearic acid, linoleic acid, lauric acid and minor compounds (γ-tocopherol and β-sitosterol) these oils can be used in various fields.

Abbreviations

Fordeco	Forest Development Corporation Cote d'Ivoire
NARC	National Agronomic Research Center
GC	Gas Chromatography
ND	Not Determined
TBME	Tert-Butyl Methyl Ester
NARDS	National Agency for Rural Development Support
IFARA	Interprofessional Fund for Agricultural Research and Advice
NTFPs	Non-timber Forest Products
HPLC	High Performance Liquid Chromatography
AFNOR	French Association for Standardization

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Conflicts of Interest

The authors declare no conflicts of interest.

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