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Oenocarpus bataua Mart. (Arecaceae): Rediscovering a Source of High Oleic Vegetable Oil from Amazonia

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Abstract The fatty acid (FA) composition of *Oenocarpus bataua* oil from 38 samples collected over a large geographical range (i.e. French Guiana and Peru) was analyzed. Fifteen fatty acids were obtained from the mesocarp of this palm species. Oleic (72.7%) and palmitic (18.1%) acids were the predominant FAs. Minor FAs were *cis*-vaccenic acid (2.3%), linoleic acid (1.9%), stearic acid (1.7%), palmitoleic (0.9%) and alpha-linolenic acid (0.8%). The mean lipid content of the dry mesocarp was 51.6%. The *O. bataua* oil samples analyzed were remarkably rich in α-tocopherol. By contrast, the other fractions of the unsaponifiable matter (sterols, carotenoids) did not show any noteworthy specificity in comparison with common vegetable oils. However, the particularly high percentage in Δ5-avenasterol of *O. bataua* oil could serve as a marker for its authentication. Results are discussed in terms of the potential nutritional value of *O. bataua* oil.

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Introduction

The search for new sources of vegetable oils has been a topic of keen interest over the last 20 years. It is of particular interest for developing countries where edible oil consumption is mainly based on oils that can be detrimental to human health (saturated oils), such as African palm oil and coconut oil [1, 2]. Palm fruits are one of the main sources of oils and fats, but few palm species have been exploited. The Amazonian region holds more than 150 palm species, some of which (e.g. *Oenocarpus bataua*, *O. bacaba*, *Mauritia flexuosa*, *Attalea maripa*, *A. speciosa*, *Bactris gasipaes*) represent a great potential source of edible oils. The genus *Oenocarpus*, and particularly the species *O. bataua* (formerly *Jessenia bataua*, *J. polycarpa*, or *J. oligocarpa*), has been described as a promising palm for the Amazonian region due to the oil content of its fruits [3–5].

O. bataua (locally known as ungurahui, seje, patawa, coroba) is a canopy or subcanopy palm (up to 35 m in height) whose distribution range includes the northern half of South America, including Panama and Trinidad [6]. It is a monoecious species that is fairly abundant in the Amazonian forests and sometimes forming oligarchic populations on waterlogged soils.

O. bataua is one of the most useful plants for indigenous communities in Amazonia. An abundant ethnobotanic literature describes its uses in the Amazon region [3, 4, 7]. The fruits are mainly used as a source of oil for medicinal, cosmetic or culinary purpose, and

for preparing a milk-like beverage. Oil is extracted by boiling the fruits and collecting the lipidic supernatant [4]. The milk-like beverage, also called "*chicha*" in Ecuador or "*vino de seje*" in Venezuela, is an important source of calories and protein in the indigenous diet [3]. The fruits of *O. bataua* and their derivatives (pulp, beverages, oil) are sold in regional Amazonian markets. In Cayenne (French Guiana) and Iquitos (Peru), small local industries produce ice-cream with the mesocarp of this palm. *O. bataua* oil is sold for medical purposes (hair tonic) throughout the Ecuadorean Amazonian region, and even in phytotherapy shops in major cities like Quito and Guayaquil.

Few studies have focused on the composition of *O. bataua* oil despite its potential as an edible vegetable oil. Balick and Gershoff [4] reported the first fatty acid (FA) composition of *O. bataua* oil. Complementary FA analyses were provided by Lubrano and Robin [8], Alemán et al. [9], Mambrim and Barrera-Arellano [10] and Rios et al. [11]. However, these few studies were based on a small number of samples, and consequently they were not representative of the overall geographical variation of this species. In addition, a very low number of fatty acids (six or seven) were detected in these studies, suggesting that the sensitivity of the methods used was not optimal. Finally, conflicting results were reported on percentages of FAs (e.g. oleic acid ranged from 40 to 82% and palmitic acid varied from 11 to 29%). Besides, data regarding the minor constituents of *O. bataua* oil are very scarce [8, 11] and its tocopherol content has never been measured. The sterol composition found by Lubrano and Robin [8] was not very consistent with that provided by Rios et al. [11]. In addition, the sterol content reported by Mambrim and Barrera-Arellano [10] (7,000 mg/kg) and Rios et al. [11] (2.5 mg/kg) are out of the range of values generally found in edible oils (100–1,000 mg/kg) [12].

The aim of the present study was thus to gain further insight into the FA composition and lipid content of the *O. bataua* mesocarp. We surveyed a broad geographical area that includes several populations and environments in Peru and French Guiana, in order to highlight possible variations in fruit fatty acid composition and lipid content of this palm species. For comparison purposes, we include the FA composition and lipid content of two Amazonian palm species that are phylogenetically related to *O. bataua*, i.e. *O. bacaba* and *Euterpe precatoria* [13]. The FA composition is discussed in terms of human consumption and nutrition. In addition, considering the well-established nutritional importance of minor components present in the unsaponifiable fraction of edible oils [14], this study aimed at determining the sterol, tocopherol and carotenoid contents and composition of *O. bataua* oil.

Materials and Methods

Plant Material

Lipid content and fatty acid composition of the mesocarp were investigated using 22 and 16 wild *O. bataua* individuals selected from different localities in French Guiana and Peru (Loreto). The geographic distance among individuals varied between 1 and 20 km in French Guiana and 1–10 km in Peru. We harvested 10 ripe fruits (dark purple and soft to the touch) directly from the infructescence of each individual selected. The fruits were dried with silica gel and transported in plastic bags. Minor constituents of *O. bataua* oil were studied using fruits of three additional wild individuals from Loreto (Peru).

Lipid Extraction and Lipid Content Measurement

For each individual, the dry mesocarp was isolated mechanically from 5–8 fruits. The mesocarp was reduced to a fine powder using an analytical grinder (IKA A10, IKA® Staufen, Germany). This material was divided into three samples (replicates) of 0.3 g for fatty acid analyses, and 0.2 g for water content analyses. Total lipids were extracted from the 0.3 g samples using a modified Folch method with methylene chloride replacing chloroform as described previously [15]. Lipid content was determined gravimetrically after complete solvent evaporation under a nitrogen stream at 40 °C. The mesocarp lipid content was measured in triplicate for each individual of *O. bataua* ($n = 38$) using a completely randomized design. One sample of *O. bacaba* and *Euterpe oleracea* was included in this analysis. The lipid content was expressed on a dry weight basis after measurement of the powder water content. The water content of samples was estimated by desiccation of powders in an oven at 105 °C overnight.

Fatty Acid Composition Analysis

Fatty acid methyl esters (FAMEs) were prepared according to the ISO-5509 standard. Roughly, lipid extracts were first saponified with 4 ml of a 0.5 M methanolic solution of sodium hydroxide at 90 °C for 10 min and then methylated with 5 ml of 14% BF_3 methanolic solution at 90 °C for 3 min. GC analyses were performed using an HP 6890 system with flame ionisation detection (FID). A Famewax capillary column (RESTEK, France), 30 m × 0.25 mm × 0.25 μm was used. The analyses were carried out in program temperature mode from 185 °C to 225 °C at 4 °C/min and then in the isothermal mode for 10 min at 225 °C. Helium was used as carrier gas at a velocity of 40 cm s^{-1}. Both injector and detector were at 230 °C. FAMEs were identified by comparing their retention times with those of

the fatty acid methyl ester standards (Sigma) and were quantified as percentages of fatty acids over total fatty acids (w/w). The fatty acid composition was analyzed in triplicate for each individual of *O. bataua* ($n = 38$), *O. bacaba* ($n = 1$) and *Euterpe oleracea* ($n = 1$).

Unsaponifiable Matter Extraction, Sterol and Triterpene Alcohol (TA) Analysis

For lipid saponification, 150 mg of lipids combined with 0.5 mg of dihydrocholesterol (internal standard) were dissolved in 1.5 mL of 2 M solution of potassium hydroxide in ethanol–water (100/5, v/v) and heated in a 90 °C water-bath with constant stirring for 60 min. After cooling, 3 mL of water and 3 mL of diethyl ether were added. The mixture was vigorously mixed and after it separated into two phases, the upper phase was recovered. Extraction was repeated two times by adding 3 mL of diethyl ether, gentle shaking by hand, and recovering the upper phase after phase separation. The three upper phases were combined, dried under a nitrogen stream and the resulting unsaponifiable fraction was weighed. Sterols and TA were then purified by thin-layer chromatography according to the standard procedure ISO-6799. Briefly, the unsaponifiable fraction was dissolved into 300 µL of diethyl ether and spotted on pre-coated TLC plates (silica G 60, 20 × 20 cm, 0.25 mm thickness) from Merck (Darmstadt, Germany). Unsaponifiable lipids were separated using the developing solvent system *n*-hexane/diethyl ether (1/1, v/v). A 0.1% 2,7-dichlorofluorescein ethanolic solution was sprayed on the plates and the sterol and TA band was identified under UV (366 nm) by comparing the retention factors with that of dihydrocholesterol, scraped off the plate and transferred into 4 mL of diethyl ether. After heating at 60 °C for 15 min, the supernatant was recovered. Sterol and TA extraction from silica was repeated two additional times. The three supernatants were combined, dried under a nitrogen stream and the resulting sterolic fraction was dissolved into 250 µL of dichloromethane. Sterol and TA analyses were performed using an HP 6890 GC system with flame ionisation detection (FID). A SAC-5 capillary column (Supelco, France), 30 m × 0.25 mm × 0.25 µm was used. Analyses were carried out at 285 °C. The carrier gas was Helium at 40 cm s^{-1}. Both injector and detector were at 300 °C. Sterols and TA were identified by comparison with known standards and were quantified by comparison with the internal standard area.

Carotenoid Analysis

For carotenoid measurement, 400 mg of lipids were dissolved in 1 mL of acetone and left for 2 h at −20 °C to promote triacylglycerol solidification. The liquid fraction of frozen samples was very rapidly recovered after they were taken out from the freezer and filtered with a 0.45 µm PTFE syringe filter. Aliquots (20 µL) were directly subjected to HPLC analysis. The chromatographic system consisted of a Dionex P680 pump, a C18 (Waters ODS2 spherisorb) column (4.6 mm inner diameter × 150 mm, 3 µm particle size) and a Dionex UVD340U photodiode array detector. A concave gradient was applied from 95:5:0 to 60:20:20, maintaining this proportion until the end of the run. Standard curves were run at 450 nm with commercial standards of α-carotene, β-carotene and lutein from Sigma.

Tocopherol and Tocotrienol Analysis

The lipid extract (10 mg) was dissolved in 1 mL of *n*-hexane and aliquots (30 µL) of this solution were injected into the HPLC system, which consisted of the following components: injector LC 508 (Beckman Coulter), pump LC 126 (Beckman Coulter), oven (Croco-Cil), and a fluorescence detector (Waters) set at an excitation wavelength of 290 nm and an emission wavelength of 330 nm. The HPLC column was a Lichrospher Si-60 (25 cm × 4.6 mm internal diameter, 5 µm particle size) from Merck. The mobile phase was *n*-hexane/propan-2-ol (99:1, v/v) at a flow rate of 1 mL/min. All solvents were filtered prior to analysis. Standard curves were run with commercial standards of α-, β-, γ- and δ-tocopherol from Sigma. γ-tocotrienol was identified by comparison with the chromatogram of a sample of crude *Elaeis guineensis* oil, whose richness in γ-tocotrienol is well-established, obtained using the same chromatographic conditions.

Results and Discussion

The mesocarp of *O. bataua* is rich in lipids, i.e. 51.6% of its dry weight (Table 1). Compared with the other two species included in this study, *O. bataua* had a higher lipid content than *O. bacaba* and *Euterpe oleracea*, with only 3.1 and 7.2%, respectively. Studies quantifying the lipid content of *O. bataua* fruits are scarce [3, 8, 10], and the results of these latter studies cannot be directly compared to those obtained here because the lipid content was expressed in percentage of fresh weight.

Fifteen FAs (Table 1) from mesocarp of *O. bataua* were identified in this study, while only six or seven FAs were reported in previous works [3, 8–11]. Therefore, the present data currently represent the most detailed description of the FA composition reported for *O. bataua*. Oleic acid (72.7%) followed by palmitic acid (18.1%) were the major components and both account for approximately 90% of total FAs. Other minor FAs were *cis*-vaccenic, linoleic, stearic, palmitoleic and alpha-linolenic acids (Table 1).

Table 1 Fatty acid composition of oil extracted from the mesocarp of *Oenocarpus bataua* and other palm species

Fatty acid	Species	*Oenocarpus bataua*							*O. bacaba*	*Euterpe oleracea*	*Elaeis guineensis*	*Cocos nucifera*	*Mauritia flexuosa*	*Olea europaea*
	Study	This study		[3]	[9]	[8]	[10]	[11]	This study	This study	[24]	[24]	[24]	[24]
	n	38		12	1	1	1	1	1	1				
	Origin	Peru/French Guiana		Amazon	Venezuela	French Guiana	Brazil	Colombia						
	Lipid content (%DW)	51.61 ± 6.62		nd	34.4	nd			3.16	7.24				
	Fatty acid name	Mean ± SD (%)	Min/Max (%)	Mean ± SD (%)	%	%	%	%	%	%	Min/Max (%)	%	Min/Max (%)	Min/Max (%)
12:0	Lauric	0.01 ± 0.01	0/0.03					0.13	0.18	0.54	0.1	50		
13:0	Tridecanoic	0.10 ± 0.06	0/0.19						0.26	0.24				
14:0	Myristic	0.09 ± 0.05	0.03/0.29		0.16			0.29	0.59	0.65	0.9/1.1	16		
15:0	Pentadecanoic	0.27 ± 0.08	0.14/0.50						0.63	0.07				
16:0	Palmitic	18.12 ± 5.58	9.68/25.96	13.2 ± 2.1	28.56	21	11.3	14.22	32.27	28.48	43.1/45.3	6.5	17.3/23.7	7.4/14.3
16:1ω7	Palmitoleic	0.89 ± 0.37	0.31/1.61	0.6 ± 0.2		1	0.6	0.14	1.32	1.69	0.1/0.3		0.3/0.7	0.9/3.0
17:0	Margaric	0.06 ± 0.01	0.09/0.03											
17:1	Heptadecenoic	0.07 ± 0.01	0.11/0.05											
18:0	Stearic	1.74 ± 0.79	0.87/3.50	3.6 ± 1.1	5.75	1.5	3.9	1.99	2.75	2.16	4.0/4.8	1	1.4/2.0	3.5/4.8
18:1ω9	Oleic	72.69 ± 5.39	64.78/81.91	77.7 ± 3.1	46.06	70	77.7	82.53	40.82	47.32	38.4/40.8	18.2	70.7/76.5	63.3/81.5
18:1ω7	*cis*-Vaccenic	2.28 ± 0.66	0.97/3.41						2.01	2.44				
18:2ω6	Linoleic	1.93 ± 0.43	1.18/3.41	2.7 ± 1.0	18.04	4	4.9	0.5	9.78	9.95	9.4/11.1	1	1.9/2.1	5.1/15.5
18:3ω3	α-Linolenic	0.79 ± 0.19	0.47/1.26	0.6 ± 0.4	0.68	tr	0.5		1.93	4.39	0.1/0.4		1	
20:0	Arachidic	0.07 ± 0.02	0.03/0.12			2	0.1		0.48	0.08	0.1/0.4			1.2/2.6
20:1	Eicosenoic	0.11 ± 0.01	0.07/0.13						0.13					
Others		0.65 ± 0.13	0.00/0.59	1.6									0.6/0.8	

Values are expressed as percentages of total fatty acids

n number of independent samples studied, *DW* dry weight, *tr* trace amounts, *nd* not determined

cis-Vaccenic acid, which has not been recorded in previous studies of the species, was the third most predominant FA detected in our analyses. *cis*-Vaccenic acid has already been found at low concentrations in other plant families [16].

Values obtained in previous studies concerning the predominant FAs of *O. bataua* are conflicting [3, 8–11]. For example, the percentage of oleic acid reported by Rios et al. [11] reached 82.5%, whereas Alemán et al. [9] detected only 46%. The FA composition of *O. bataua* oil reported by Alemán et al. [9] from the Upper Orinoco region (Venezuela) was closer to *O. bacaba* and *Mauritia flexuosa* than to *O. bataua*. The misidentification of the material analyzed (e.g. particularly between *O. bacaba* and *O. bataua*) or the inclusion of interspecific hybrids (*O. bataua* × *O. bacaba*) could explain these outlier values. The percentage of FAs reported by other authors [3, 8, 10, 11] fell within the biochemical variation observed in our data. For instance, the 70 and 82% of oleic acid reported by Lubrano and Robin [8] and Rios et al. [11], respectively, are within the 65–82% range described in this study. Similarly, the 11 and 21% of palmitic acid found by Mambrim and Barrera-Arellano [10] and Lubrano and Robin [8], respectively, fell within the 10–26% range obtained here, which was likely due to the large sampling performed.

Edible oil derived from *O. bataua* fruits has a great potential as a new source of monounsaturated oil. The main monounsaturated acid in *O. bataua* oil was oleic, with around 73% of total fatty acids. The high oleic content of *O. bataua* oil is comparable to olive and "high oleic" sunflower oil. These former vegetable oils have a substantial nutritional value, since high intake of monounsaturated fatty acids is considered to be a dietary factor involved in lowering cholesterol, and the incidence of coronary heart diseases and hypertension [1, 2]. However, *O. bataua* oil is poor in linoleic (2%) and alpha-linolenic acids (0.8%) compared with the recommended values of 12 and 2%, respectively. This deficit in polyunsaturated FAs might be improved by genetic breeding. Furthermore, the deficit of some FAs could be enhanced by using other sources of vegetable oil like *O. bacaba* and *Euterpe oleracea*, which are particularly rich in linoleic and α-linolenic acids (Table 1). *O. bataua* and *O. bacaba* grow together in the tropical forest of the Guiana region. A mixed oil derived from these two palm species would produce a vegetable oil that is rich in oleic acid and linoleic acid. In eastern Amazonia, *O. bataua* oil could be processed together with the fruits of *Euterpe oleracea* to offset this deficit in linoleic acid and α-linolenic acid.

The sterol content of *O. bataua* oil, i.e. 368 mg/kg oil (Table 2), is rather low in comparison with rapeseed, sunflower or soybean oils, but is comparable to that of oil palm or coconut oils [12]. The sterol composition obtained in the present study is consistent with that reported by Lubrano and Robin [8]. With the exception of a minor (2.2%) unidentified peak, the sterols identified in *O. bataua* oil correspond to those generally found in edible oils [12]. However, the sterol fraction of *O. bataua* oil is particularly rich in Δ5-avenasterol (21.3%), which has been reported to show antioxidant activity [17], and is relatively poor in campesterol (7.2%). These characteristics could serve as markers to authenticate *O. bataua* oil. A significant amount of cycloartenol (10.5 mg/100 g oil) was also detected in *O. bataua* oil. This triterpenic alcohol was also found in the kernel oil of five other palm species native from Amazonia and in the mesocarp lipids of oil palm [18, 19]. The only carotenoid found in *O. bataua* oil was β-carotene, the most common and most effective provitamin A in vegetable oils. The carotenoid content of *O. bataua* oil (2.4 mg/kg) is slightly higher than that of sunflower, soybean or peanut oils (0.1–0.3 mg/kg), slightly lower than that of olive oil (6.9 mg/kg), but considerably lower than values identified in the palm species *Elaeis guineensis* (oil palm) and *E. oleifera* (around 800 and 1,500 mg/kg, respectively) [20, 21]. Regarding the other lipophile antioxidants, α-tocopherol and γ-tocotrienol were detected in the samples analyzed. As in olive oil and a minority of seed oils (grape seed and sunflower), α-tocopherol is predominant in *O. bataua* oil. The mesocarp lipids of this palm species are particularly rich in tocopherols, i.e. about 1,700 mg/kg. Such high values are encountered in a very limited number of edible oils, e.g. maize and soybean oils [21]. The major tocopherol identified in *O. bataua* oil was α-tocopherol (86%; Table 2). This result is in agreement with the relative proportions of α- and γ-tocotrienol reported by Lubrano et al. [8]. Since α-tocopherol is the most effective tocopherol isoform regarding vitamin E activity [22], the present data suggest that *O. bataua* oil could be useful for improving the human diet in developing countries.

Table 2 Contents in minor constituents and sterol composition of *O. bataua* oil

Minor constituent content (mg/kg)		Sterol composition (%)	
Sterols	368	β-sitosterol	34.2
β-Carotene	2.38	Δ^5 avenasterol	27.8
α-Tocopherol	1,704	Stigmasterol	19.2
γ-Tocotrienol	269	Campesterol	7.2
Cycloartenol	105	Campestanol	6.0
		Cholesterol	3.4
		Unidentified 1	2.2

Conclusion

In the present study we demonstrated that *O. bataua* is an under-tapped source of high-quality oleic oil from the Amazonian forest. Its beneficial FA and minor constituent composition could help to improve the nutritional conditions for the native people in this region. In addition, oil extracted from *O. bataua* seeds (kernel oil) is rich in lauric acid [23] and could be utilized simultaneously.

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