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ORIGINAL ARTICLE

# Agroindustrial valorization of the pulp and peel, seed, flour, and oil of moriche (*Mauritia flexuosa*) from the Bita River, Colombia: a potential source of essential fatty acids

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**Abstract**
The expansion of the agricultural frontier in the eastern llanos region of Colombia has endangered the moriche palm (*Mauritia flexuosa*) which has an important ecological function and provides various ecosystem services. In particular, the moriche that grows in this region is wild and has been little studied; therefore, there are no reports of its potential as a source of monounsaturated and polyunsaturated fatty acids, information that could be useful for the conservation of the species. This study performed a physicochemical characterization of the oil extracted from the dried pulp of moriche and identified the fatty acids present in the oil, pulp and peel, seed, and flour of this fruit from the Bita River Basin, Vichada, Colombia. The fatty acid composition was characterized by gas chromatography, including physicochemical tests of interest in the oil according to AOCS protocols. The results showed that the highest fatty acid content was found in the extracted oil, with a distribution of 81.64% unsaturated fat and 18.36% saturated fat. These fats included 79.20% oleic acid (omega-9), 0.26% palmitoleic acid (omega-7), 1.01% linoleic acid (omega-6), 1% linolenic acid (omega-3), 16.91% palmitic acid, and 1.33% stearic acid. We conclude that moriche from Bita Basin is an oleaginous fruit due to its high nutritional value in terms of unsaturated fatty acids and that both the flour and the oil obtained are bioproducts with potential industrial application.

**Keywords** Oleic acid · Gas chromatography · Omega-9 · Peroxides · Atherogenic potential

## 1 Introduction

The moriche palm (*Mauritia flexuosa*), also known as *buriti* in Brazil and *aguaje* in Peru [1–3], is a neotropical dioecious species that is distributed over a wide and heterogeneous range of landscapes, from lowland rainforests in the Amazon basin to more open savanna landscapes in countries such as Brazil, Peru, Venezuela, and Colombia [4]. Despite its wide distribution, the moriche of the Orinoquia region has been little studied; this region corresponds to the eastern plains of Colombia and Venezuela, which are mainly characterized by extensive savannas and gallery forests, with a diversity of ecosystems and little-known flora [5].

Particularly in the eastern plains of Colombia or the eastern llanos, the moriche palm is one of the most representative species of the landscape and is highly important thanks to its ecological function and ecosystem services, e.g., water supply, water regulation, and supply of fruit to different species, and to its role in the production of handicrafts and local gastronomy.

An area of high biological richness in the eastern llanos is the Bita River Basin (822,820 ha), in the municipality of Puerto Carreño, Department of Vichada, Colombia, where the ecosystems are conserved. In this area, the pressures on biodiversity have intensified in recent years. In particular, land-use changes, hydrocarbon exploitation, and practices associated with extensive livestock and agriculture on the wild savannas have affected moriche populations, the natural regeneration of riparian vegetation, and its ecosystem function [5]. To reverse this trend and help conserve moriche in the Bita River Basin, the Wildlife Conservation Society

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of Colombia (WCS Colombia) has implemented ecological restoration projects and signed conservation agreements with owners for the harvest and utilization of moriche fruits for the preparation of different products and evaluated their potential as a sustainable production system. However, little is known about the moriche of the eastern llanos, particularly its fatty acid content and the agroindustrial value of its fruits from the Bita River Basin. Such information could be useful for the conservation of the species.

The fruit of the moriche palm is a drupe with a reddish purple epicarp and yellow mesocarp with recognized potential uses in the food, cosmetics, and nutraceutical industries due to its fatty acids and antioxidants [6, 7]. This characteristic of the fruit is in line with the trend in human nutrition and dietetics of consuming foods rich in unsaturated acids, which help to mitigate diseases caused by excess lipid storage, a trend that requires the identification of plant foods that are sources of vitamins, minerals, and healthy fatty acids [8]. Currently, the high consumption of processed foods rich in trans-fats and saturated fatty acids, added to a sedentary lifestyle, has triggered various diseases in humans caused by excess lipid storage, such as high cholesterol, obesity, heart problems, and cerebrovascular diseases, that can become a risk factor for some types of cancer [9]. However, decreased intake of saturated fat and increased intake of monounsaturated and polyunsaturated fatty acids such as omega-3 and omega-6 can have a protective effect against cognitive and cardiovascular diseases [10, 11]. In this context, the objective of this study is to present the physicochemical characterization of the oil and the distribution of the fatty acids present in the pulp and peel, seed, flour, and oil obtained from moriche fruit from Bita River, Puerto Carreño, Colombia.

## 2 Materials and methods

### 2.1 Collection and preparation of the sample

Moriche fruits at the commercial maturity stage were harvested on the banks of Bita River, Puerto Carreño, Colombia. Healthy and whole fruits weighing 28–30 g were cleaned with water and disinfected with 150 ppm sodium hypochlorite for 15 min. The fruits had a pH of 3.96 ± 0.41, % acidity of 0.93 ± 0.02, and °Brix of 7.11 ± 0.09. The moriche fruits were divided into four batches: the first batch consisted of an integrated mixture of pulp and raw peel. The second batch corresponded to the raw seed, which was separated manually. The third batch corresponded to the moriche pulp flour, which was obtained from the fruits that were peeled manually, removing the peel and seed; the approximate pulp, peel, and seed yields of the fruits were 40%, 14%, and 46%. The pulp separated from the fruits was dehydrated in natural convection oven at below 60 °C to a final moisture percentage of 9–10%. Then, the samples were crushed in an electric mill and sieved (0.25 mm) until obtaining the moriche pulp flour. The fourth batch consisted of the oil obtained from dehydrated moriche pulp. Oil extraction was carried using 95% pure hexane as solvent in a Soxhlet extractor for 8 h at continuous reflux. Lastly, the oily extract was concentrated in a rotary evaporator at 60 °C with 66,661.184 Pa vacuum pressure to remove the organic solvent. The yield percentage obtained in the extraction of moriche oil was calculated, using Eq. 1:

$$R(\%) = \frac{P}{Wf} \times 100 \tag{1}$$

where R is % in g of oil/100 g of dehydrated moriche pulp, P is weight of the oil (g), and Wf is weight of dehydrated moriche pulp subjected to extraction (g).

### 2.2 Physicochemical characterization

The physicochemical properties evaluated in the oil obtained from dried moriche pulp were % moisture, % acidity (% oleic acid), refractive index (method Cc 7–25), saponification value (method Cd 3–25), iodine (method Cd 1–25), peroxide index (method Cd 8b-90), and Lovibond color (method Cc 13e-92), according to the protocols established by AOCS [12] and the methods reported by Martinez et al. [13] but replacing palm oil with moriche oil.

### 2.3 Determination of fatty acids and nutritional quality and health indices

The fatty acid compositions present in moriche pulp and peel, seed, flour, and oil were determined by method Ce 1–62 [12]. A Shimadzu 17A gas chromatograph (Kyoto, Japan) equipped with a flame ionization detector and a Chromatopac C-R6A integrator was used. The identified fatty acids were compared with a standard according to their retention time in each respective chromatogram and are expressed as percentages. To calculate the nutritional quality and health indices, the equations reported by Szpicer et al. [14] were used:

$$\text{AI : atherogenic index} = (C12:0 + 4\times C14:0 + C16:0) / (MUFA + PUFA) \tag{2}$$

$$\text{TI}: \text{ thrombogenic index } = (\text{C12}:0 + \text{C16}:0 + \text{C18}:0)/[(0.5 \times \text{MUFA}) + (0.5 \times \text{n}-6\ \text{PUFA}) + (3 \times \text{n}-3\ \text{PUFA}) + (\text{n}-3\ \text{PUFA}/\text{n}-6\ \text{PUFA})] \quad (3)$$

$$\text{h/H}: \text{ hypocholesterolemic/hypercholesterolemic ratio } = [(\text{C18}:1 + \text{PUFA})/(\text{C14}:0 + \text{C16}:0)] \quad (4)$$

where C12:0, C14:0, C16:0, and C18:0 refer to lauric, myristic, palmitic, and stearic fatty acids, respectively; MUFA refers to the sum of monounsaturated fatty acids; and PUFA refers to polyunsaturated fatty acids. The nutritional index (NI) was calculated using Eq. 5, as reported by Méndez-Cid et al. [15]:

$$\text{NI} = (\text{C18}:0 + \text{C18}:1\text{n}-9)/\text{C16}:0 \quad (5)$$

### 2.4 Statistical analysis

The results are expressed as means. The properties evaluated in this study were investigated in a completely randomized, balanced, one-factor experimental design. When necessary, the Tukey test ($p \leq 0.05$) was run in statistical software to verify the differences between the means.

## 3 Results and discussion

### 3.1 Physicochemical characterization

The results show that the oil extracted from dried moriche pulp (*Mauritia flexuosa*) from Bita Basin in Orinoquia region had a yield of 24.64% and good physicochemical quality (Table 1). The moisture value in the oil (8.33% ± 0.02) indicated a good percentage of dry matter, approximately 92%. The percentage acidity (6.05% ± 0.01) and refractive index values (1.45 ± 0.01) were characteristic of crude (unrefined) oils. The saponification value (193.1 ± 0.04 mg KOH/g) indicated the degree of neutralization of the oil in basic medium (potassium hydroxide), which is characteristic of oils with double bonds. The iodine index (72.9 ± 0.03 g $I_2$/100 g) indicated that the oil had a degree of unsaturation,

**Table 1** Comparison of the physicochemical properties of moriche oil from Orinoquia region (Colombia) and Amazonian region (Brazil and Peru)

| Description and parameters | Colombia Authors | Brazil Cruz et al. [19] | Brazil Silva et al. [16] | Brazil Aquino et al. [2] | Brazil Serra et al. [3] | Peru Vásquez-Ocmín et al. [1] |
|---|---|---|---|---|---|---|
| Common name | Moriche | Buriti | Buriti | Buriti | Buriti | Aguaje |
| Scientific name | *Mauritia flexuosa* | *Mauritia flexuosa* L | *Mauritia flexuosa* | *Mauritia flexuosa* | *Mauritia vinifera* | *Mauritia flexuosa* L.f |
| Origin of oil extraction | Pulp | Pulp | nr ** | nr ** | nr * | Pulp |
| Moisture (%) | 8.33 ± 0.02 | nr | nr | nr | nr | nr |
| Acidity (%) or acid value (mg KOH/g) | 6.05 ± 0.01 | 5.75 | 3.12 | 4.27 | 17.44 | 2.13 |
| Refractive index | 1.45 ± 0.01 | nr | 1.46 | 1.47 | 1.47 | nr |
| Saponification value (mg KOH/g) | 193.10 ± 0.04 | 239.79 | 192.88 | nr | 183.91 | 186.25 |
| Iodine index (g $I_2$/100 g) | 72.90 ± 0.03 | nr | 74.44 | 90 | 77.40 | 70.38 |
| Peroxide index (mmol/kg) | 1.19 ± 0.01 | 0.03 | 7.10 | 7.41 | 6.02 | 5 |
| Lovibond color | Red, yellow, blue 76 70 00 | nr | red, yellow 60 9 | nr | red, blue, yellow 40 63 00 | nr |

*nr* not reported

*Donated by a company

**Purchased at a popular market

which was positive in terms of the fatty acid composition (oleic, linoleic, and linolenic acids). The peroxide index of 1.19 mmol/kg ± 0.01 indicated that the oil did not show oxidative rancidity. The Lovibond color value (76 red, 70 yellow, 00 blue) was characteristic of oils with a red-yellow hue extracted from the yellow pulp of moriche fruits [16]. The results indicate that moriche oil complies with the established regulations for crude and oils such as palm, soy, and sunflower oils, according to the provisions of the 2001 Codex Alimentarius.

The extraction yield of moriche oil of 24.64% is within the average range of oils obtained from palm trees by extraction with solvents, being an important factor due to its relationship with the economic potential.

Ibiapina et al. [17] reported a similar yield of 22% for the extraction of moriche oil by Soxhlet extraction using hexane as solvent. However, Cardona-Jaramillo et al. [18] reported a yield greater than 33% in moriche oil and a yield of less than 18% in acai fruit oil (*Euterpe precatoria*) by solvent extraction, indicating that the differences in the oil yield percentages are due to the chemical nature of the fruits and the extraction method used [18]. The extraction yield of moriche oil varies depending on the extraction method selected, e.g., by cold pressing or the Bligh and Dyer method (approximately 38%) and by microwave (37%). However, supercritical fluid extraction and enzymatic extraction generate higher yields, although their high cost is a limitation [17].

A literature review shows that there are few studies in Colombia, and particularly in the Orinoquia region, on the physicochemical characterization of moriche oil, unlike in Brazil and Peru in the Amazon region, where there are reports characterizing the oil of this fruit [1–3, 16, 19] (Table 1). The significant differences in the physicochemical characterization values of moriche oil from the Amazonian region and the Colombian Orinoquia region can be mainly explained due to the country and ecosystems type of origin, the changes in soil properties and climatic conditions, the cultivation conditions or wildness origin of the sample, and the oil extraction technique used.

When comparing the main physicochemical properties evaluated between moriche oil from Orinoquia and the edible oils of other fruits and oilseeds, we found that the oil obtained had similar physicochemical characteristics as olive, sunflower, palm, and coconut oil [13, 20–22] (Table 2). This makes moriche oil from Bita River Basin an alternative oleaginous raw material that could be explored to add agroindustrial value to this wild fruit, which to date has been a subject little studied in Colombia.

### 3.2 Fatty acid composition and nutritional quality and health indices

The saturated and unsaturated fatty acid composition present in pulp and peel, seed, flour, and oil extracted from dried moriche pulp from Orinoquia region are presented

**Table 2** Comparison of the physicochemical properties of the oil obtained from moriche from Orinoquia region and the oils of other fruits and/or oilseeds

| Physicochemical property | Moriche oil Authors | Olive oil Azlan et al. [20] | Sunflower oil Nehdi et al. [21] | Palm oil Martínez et al. [13] | Coconut oil Sivakanthan et al. [22] | Pumpkin oil Nyam et al. [23] | Roselle oil Nyam et al. [23] | Sesame oil Sivakanthan et al. [22] | Colocynth oil Nehdi et al. [21] |
|---|---|---|---|---|---|---|---|---|---|
| Moisture (%) | 8.33 | nr | 3.75 | nr | nr | nr | nr | nr | 7.51 |
| Acidity (%) or acid value (mg KOH/g) | 6.05 | 0.84 | 2.80 | 0.05 | 0.39 | 1.6 | 12.90 | 1.25 | 3.14 |
| Refraction index | 1.45 | nr | 1.47 | 1.45 | 1.45 | nr | nr | 1.47 | 1.47 |
| Saponification value (mg KOH/g) | 193.10 | 189.30 | 197.45 | 197.50 | 243.15 | 185.30 | 172.30 | 184.40 | 204.63 |
| Iodine index (g $I_2$/100 g) | 72.90 | 83.10 | 118.56 | 56.43 | 9.03 | 86.70 | 105.50 | 116.18 | 123.31 |
| Peroxides index (mmol/kg) | 1.19 | 3.99 | 3.06 | 1.07 | 0.30 | 0.75 | 3.25 | 1.00 | 4.71 |

*nr* not reported

in Tables 3 and 4. In the evaluated treatments, we found retention times and areas corresponding to commercial standards of different fatty acids present in vegetables, mainly of oleic (omega-9), palmitoleic (omega-7), linoleic (omega-6), and linolenic acids (omega-3) in the four samples evaluated (Table 4). Capric acid was identified only in moriche seed (Table 3). Butyric, caproic, erucic, and nervonic acids were all absent from the evaluated samples (Tables 3 and 4). The chromatograms of the moriche fruit showed 15 signals in pulp and peel, 17 in seed, 17 in flour, and 13 in oil. The results allowed us to compare the different fatty acids present in the four evaluated samples (pulp and peel, seed, flour, and oil) of moriche fruit. The most abundant saturated fatty acid in the samples was palmitic, and the most abundant unsaturated fatty acid was oleic. In the seed, the most abundant fatty acid was linoleic acid (Tables 3 and 4). This indicates that this fruit has good nutritional value, since, like olive oil, it had a significant content of oleic acid [24]. Moriche oil had a higher oleic acid (omega-9) content than other vegetable oils, such as soybean oil (24%), corn oil (29%), palm oil (40%), camellia oil (58%), canola oil (61%), and safflower oil (77%) [10].

Despite the nutritional value of moriche fruit, there are very few studies in Colombia of the fatty acid composition of moriche fruits and particularly no one from the Bita River Basin in the Orinoquia region. Therefore, there is a gap in information on the composition and nutritional value of the fruit from this geographical area. As well, few such studies have been conducted in other geographical areas of Colombia.

**Table 3** Percentages of saturated fatty acids in moriche pulp and peel, seed, flour, and oil from Orinoquia region

| Saturated fatty acids | Pulp and peel | Seed | Flour | Oil |
|---|---|---|---|---|
| Butyric C4:0 | nd | nd | nd | nd |
| Caproic C6:0 | nd | nd | nd | nd |
| Caprylic C8:0 | 0.04$^{b}$ | 0.22$^{a}$ | 0.004$^{c}$ | nd |
| Capric C10:0 | nd | 0.06 | nd | nd |
| Lauric C12:0 | 0.03$^{b}$ | 1.12$^{a}$ | 0.01$^{c}$ | 0.01 |
| Myristic C14:0 | 0.05$^{a}$ | 3.54$^{bc}$ | 0.04$^{a}$ | 0.04$^{a}$ |
| Pentadecanoic C15:0 | 0.02$^{b}$ | 0.19$^{a}$ | 0.03$^{b}$ | 0.03$^{b}$ |
| Palmitic C16:0 | 17.39$^{c}$ | 27.96$^{a}$ | 19.39$^{b}$ | 16.91$^{c}$ |
| Heptadecanoic C17:0 | 0.02$^{b}$ | 0.54$^{a}$ | 0.05$^{b}$ | nd |
| Stearic C18:0 | 1.32$^{b}$ | 5.39$^{a}$ | 1.22$^{bc}$ | 1.33$^{b}$ |
| Arachidonic C20:0 | 0.04$^{b}$ | 0.11$^{a}$ | 0.03$^{b}$ | 0.03$^{b}$ |
| Behenic C22:0 | nd | 0.22$^{a}$ | 0.004$^{c}$ | 0.01$^{b}$ |
| Lignoceric C24:0 | nd | 0.14$^{a}$ | 0.012$^{c}$ | nd |
| Total (%) | 18.91 | 39.49 | 20.79 | 18.36 |

*nd* not detected, *C* number of carbons

Values in the same row followed by a different letter are significantly different ($p < 0.05$)

**Table 4** Percentages of unsaturated fatty acids in moriche pulp and peel, seed, flour, and oil from Orinoquia region

| Unsaturated fatty acids | Pulp and peel | Seed | Flour | Oil |
|---|---|---|---|---|
| Monounsaturated | | | | |
| Palmitoleic C16:1n-7 (omega-7) | 0.17$^{c}$ | 2.22$^{a}$ | 0.18$^{c}$ | 0.26$^{bc}$ |
| Heptadecenoic C17: 1n-7 | 0.009$^{c}$ | 0.09$^{a}$ | 0.03$^{b}$ | nd |
| Oleic C18:1n-9 (omega-9) | 75.94$^{b}$ | 21.10$^{c}$ | 74.44$^{b}$ | 79.20$^{a}$ |
| Gadoleic C20:1n-9 | 0.20$^{a}$ | 0.08$^{c}$ | 0.16$^{b}$ | 0.17$^{b}$ |
| Erucic C22:1n-9 | nd | nd | nd | nd |
| Nervonic C24:1n-9 | nd | nd | nd | nd |
| Polyunsaturated | | | | |
| Linoleic C18:2n-6 (omega-6) | 1.12$^{b}$ | 27.22$^{a}$ | 1.16$^{b}$ | 1.01$^{c}$ |
| Linolenic C18:3n-3 (omega-3) | 0.64$^{c}$ | 2.40$^{a}$ | 0.81$^{b}$ | 1.00$^{bc}$ |
| Total (%) | 78.08 | 53.11 | 76.78 | 81.64 |

*nd* not detected, *C* number of carbons, *n* unsaturation

Values in the same row followed by different letters are significantly different ($p < 0.05$)

De Camargo and Calderón [25] conducted an evaluation of the fatty acid composition of moriche fruits from the banks of the Tomo River, Colombia, and found in the pulp (mesocarp) mainly palmitic acid 1.02 g/100 g, oleic acid 0.60 g/100 g, and linoleic acid 0.78 g/100 g. Restrepo et al. [26] reported the fatty acid composition of moriche oil of fruits from Leticia, Amazonas, Colombia, finding palmitic acid (21.27%) and oleic acid (68.69%) as the major fatty acids. Unlike in Colombia, there are more studies in Brazil and Peru on the fatty acid composition of moriche oil, though there are few reports on the fatty acid composition of the seed and pulp flour of this fruit, such as those reported in this study.

When comparing our results obtained in moriche oil from Orinoquia region, we found that they are similar to those reported by Cruz et al. [19], who found that the two major fatty acids in moriche pulp oil from Brazil are palmitic acid (22.18%) and oleic acid (72.23%). Serra et al. [3] found 17.59% palmitic acid and 78.55% oleic acid in the moriche oil of fruits from Brazil. Likewise, Nobre et al. [27] found 19.73% palmitic acid and 72.14% oleic acid in moriche oil of fruits from Brazil. Silva et al. [16] also characterized moriche oil of fruits from Brazil, finding palmitic acid (16.78%) and oleic acid (74.06%) as the major fatty acids. Aquino et al. [2] reported 19.60% palmitic acid and 72.70% oleic acid in pulp oil of moriche fruits from Brazil. Vásquez-Ocmín et al. [1] reported 19.61% palmitic acid and 75.63% oleic acid in pulp oil of moriche fruit from Peru.

Table 5 compares the fatty acid composition of moriche oil with edible oils of other fruits and oilseeds. The obtained oil has good nutritional quality because its composition is

**Table 5** Comparison of the lipid profile (% fatty acids) of the oil obtained from moriche and the oils of other fruits and/or oilseeds

| Fatty acid Identified | Moriche oil Authors | Olive oil Monfreda et al. [24] | Sunflower oil Monfreda et al. [24] | Palm oil Teh and Lau [28] | Coconut oil Sivakanthan et al. [22] | Peanut oil Konuskan et al. [29] | Avocado oil Cicero et al. [30] | Peach palm oil Restrepo et al. [31] | Sesame oil Sivakanthan et al. [22] | Mustard oil Konuskan et al. [29] |
|---|---|---|---|---|---|---|---|---|---|---|
| Myristic C14:0 | 0.04 | 0.01 | 0.1 | 0.90 | 21.20 | nr | 0.01 | 0.12 | nd | nr |
| Palmitic C16:0 | 16.91 | 12.09 | 8.01 | 41.15 | 8.80 | 9.37 | 14.21 | 34.90 | 7.82 | 10.24 |
| Stearic C18:0 | 1.33 | 3.01 | 3.21 | 4.30 | 0.84 | 3.73 | 2.15 | 1.50 | 3.30 | 2.02 |
| Arachidonic C20:0 | 0.03 | 0.36 | 0.18 | 0.05 | nr | 1.83 | 0.41 | nr | nr | 0.92 |
| Behenic C22:0 | 0.01 | 0.11 | 0.45 | nr | nr | 1.57 | 0.08 | nr | nr | 0.72 |
| Lignoceric C24: 0 | nd | 0.05 | 0.14 | nr | nr | 1.62 | 0.06 | nr | nr | 0.81 |
| Palmitoleic C16:1n-7 | 0.26 | 1.15 | 0.12 | 0.32 | nr | nd | 7.06 | 7.90 | nr | nd |
| Oleic C18:1n-9 | 79.20 | 72.77 | 27.52 | 42.34 | 8.47 | 55.33 | 59.46 | 51.90 | 48.88 | 36.65 |
| Linoleic C18:2n-6 | 1.01 | 9.47 | 60.11 | 10.00 | 2.29 | 23.69 | 14.66 | 2.40 | 39.61 | 22.06 |
| Linolenic C18:3n-3 | 1.00 | 0.60 | 0.05 | 0.25 | nd | nd | 1.30 | 0.20 | 0.41 | 8.06 |

*nd* not detected, *nr* not reported, *C* number of carbons, *n* unsaturation

similar to that of olive oil and sunflower oil [24]. The nutritional quality and health indices of the fatty acids in each of the samples are presented in Fig. 1. The low AI and TI, particularly in the moriche pulp and peel, flour, and oil, indicate that these products of the fruit help control serum cholesterol, which can be explained by the low levels of myristic acid and the high levels of oleic acid detected in the evaluated samples (Tables 3 and 4). Additionally, a higher hypocholesterolemic/hypercholesterolemic ratio (h/H) and nutritional index (NI) were found in moriche pulp and peel, flour, and oil than seeds. High h/H and NI values are desirable because they represent a positive effect on cholesterol metabolism. The values obtained (Fig. 1) can be explained by the ratio of n-3 to n-6 polyunsaturated fatty acids. In terms of health, this is important because it indicates that the intake of fatty acids present in moriche fruits can have a protective effect, preventing the formation of blood thrombi and helping to prevent arteriosclerosis and cardiovascular disorders. In addition to the above, Méndez-Cid et al. [15] and Szpicer et al. [14] indicate that products made with vegetable fats rich in polyunsaturated fatty acids, such as canola oil, have low AI and TI values and high h/H values compared to animal fats such as beef tallow and *tocino*.

The results obtained for the fatty acid quality index are similar to those reported by Pereira et al. [32], who evaluated the atherogenic and thrombogenic potential of oils from seeds exotic and fruits of the Brazilian Amazon, finding AI values of 0.10, 0.23, and 0.20 and TI values of 0.18, 0.70, and 0.42 in the oils of patawa, pracaxi, and Brazil nut, respectively. However, they reported higher values in murumuru butter, bacuri fat, and tucuma seeds.

Taking into account the fatty acid composition, the nutritional quality and health indices, and the extraction yield (24.64%), the moriche oil has high economic potential, and its use is an alternative to strengthen the bio-economy of the Orinoquia region and for the establishment of conservation strategies linked to the sustainable use of the fruits in products with high added value. For the Colombian context, this is relevant and a great opportunity, given that the generation of added value and the development of bioproducts and services based on the sustainable use of natural capital is very low in the country [33].

The moriche's high economic potential is mainly because its fruits have a valuable oil composition for the cosmetics and food industries due to these oils' nutritional value, antioxidant, and antimicrobial properties [6]. Likewise, moriche oil is very useful in the area of biofuels for the production of biodiesel; in the pharmaceutical area because it is healing, anti-inflammatory and antibiotic; in the health and nutrition area because it is a source of Vitamin A, due to its carotenoid content, and a source of Vitamin E, due to its high content of tocopherols; in the food area due to the high concentration of oleic acid (omega-9), among others [17].

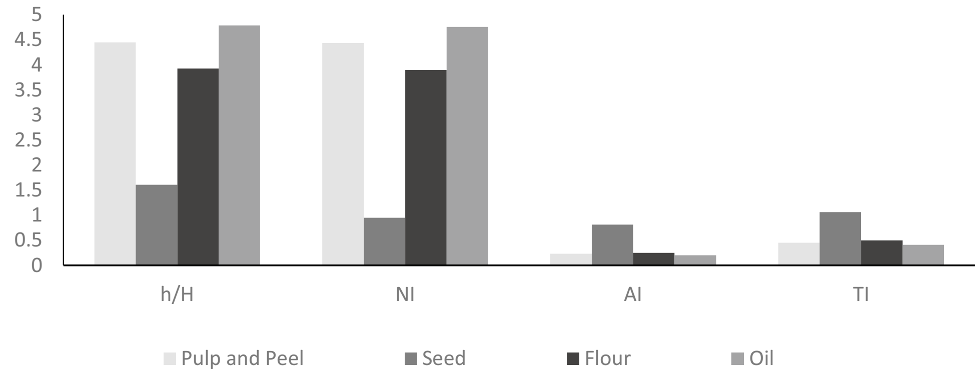


**Fig. 1** Nutritional quality and health indices of fatty acids in moriche pulp and peel, seed, flour, and oil from Orinoquia region. h/H, hypocholesterolemic/hypercholesterolemic ratio; NI, nutritional index; AI, atherogenic index; TI, thrombogenic index

Vegetable fats and oils play an important role in human nutrition because they are a major source of energy relative to their weight and because they can dissolve various flavor and aroma compounds and give a distinct consistency to food products due to their nutritional properties [10]. The higher concentrations of unsaturated fat found in flour (76.78% unsaturated fat vs. 20.79% saturated fat), pulp and peel (78.08% unsaturated fat vs. 18.91% saturated fat), and seeds (53.11% unsaturated fat vs. 39.49% saturated fat) and the high concentration of oleic acid C18:1n-9 (79.20%) found in the extracted oil make these components interesting alternatives for the food and nutrition industry, which is in search of new vegetable oils as a source of vitamins and essential fats [3].

The use of fats and oils by this industry in recent years has been restricted by nutritional aspects, given that the consumption of large amounts of saturated fatty acids and animal fats that contain cholesterol is considered a high-risk factor for arterial, coronary, and cardiovascular diseases, so it is recommended to replace foods rich in saturated fats with unsaturated oils [34]. Additionally, oils, particularly vegetable oils, are increasingly important as sources of essential unsaturated fatty acids that humans cannot synthesize and as providers of fat-soluble vitamins such as vitamins A, D, E, and K [10].

As for the pharmaceutical industry, Koolen et al. [6] report that the oil extracted from moriche fruit is popularly used to treat burns and as a potent vermifuge, which is attributed mainly to the carotenoids and tocopherols in the oil [3]. Likewise, the antioxidant and antimicrobial activities of moriche phenolic extracts show that they are quite potent and imply the presence of compounds with strong free radical scavenging activity. The results of antimicrobial tests against some pathogenic bacteria revealed the great ability of phenolic compounds from moriche to inhibit pathogen growth at low minimal inhibitory concentrations [6]. It has also been reported from computational chemistry that some carotenoid pigments in moriche oil can form ligands with molecular interaction energies that would allow inhibiting the action of peptidase 2GTB (main SARS-CoV peptidase) associated with the new coronavirus (SARS-CoV-2) responsible for the COVID-19 disease [35]. Likewise, photoprotective and neuroprotective effects have been reported for moriche fruit, since the oil may be considered a potential vehicle to transport antioxidant precursors and could also be used as an adjuvant in sun protection, especially in after-sun formulations [36]. The oil could also be applied as a microencapsulated lipid supplement for people whose diet is lacking in essential fatty acids or could be used in all types of creams, emulsions, or lotions for the skin. Particularly in cosmetics, both moriche flour (powder) and oil could be used in anti-aging creams and in the development of soaps, shower gels, and hair products, among others.

## 4 Conclusions

The moriche fruit from the Colombian Orinoquia region show an interesting potential as an oleaginous fruit because in its pulp and peel, seed, flour and extracted oil, compounds of interest were identified, especially fatty acids such as omega-3, -6, -7 and -9 acids, which makes this plant material a potential source of interest for the food, cosmetics, and pharmaceutical industries, having the latter the higher economic potential. In turn, the peroxide index, iodine index, and other parameters of the oil extracted from the dried pulp of moriche fruit indicate that it could become an alternative of interest for the development of new products in the oils and fats industry, such as emulsifiers, refined oils, encapsulated oils, and nutraceuticals.

Although the seed of the moriche fruit (which is about 46% of the fruit) has a higher amount of saturated than unsaturated fatty acids, the seeds still have a considerable amount of high-value fatty acids of interest for different industries. These fatty acids from the seed could be extracted to improve the oil yield from the fruit, so it is recommended that future research identifies the lipid profile and evaluates the physicochemical characteristics of the oil extracted from the seed to explore possible commercial applications.

Lastly, knowledge of the physicochemical characteristics of the oil and the fatty acids present in moriche fruits from the Bita River Basin, Vichada, Colombia, opens opportunities for the development of high-value-added products that can help curb threats to biodiversity and help conserve moriche in Orinoquia. In any case, the use of the species should be linked to a conservation strategy that favors the conservation of the moriche and other elements of biodiversity that are part of the important ecosystems of the Orinoquia.

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## Declarations

**Ethics approval** Not applicable.

**Consent to participate** Not applicable.

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