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Fatty Acid Profile of Cerrado Fruit Byproducts: Plant-Based Oil Alternatives to Conventional Commodities

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Abstract

The global reliance on commodity oils has intensified the search for alternative plant-based sources capable of meeting increasing worldwide demand. The utilization of fruits from the Brazilian Savanna and their associated byproducts offers numerous possibilities, as these native species are rich in nutrients and bioactive compounds with nutraceutical potential. However, gaps remain in the characterization of their lipid profiles, particularly with respect to processing residues. Therefore, the objective of this study was to investigate the fatty acid profiles of various parts of araticum (*Annona crassiflora*), baru (*Dipteryx alata*), buriti (*Mauritia flexuosa*), and pequi (*Caryocar brasiliense*) fruits using gas chromatography coupled with mass spectrometry (GC–MS). The total content of monounsaturated fatty acids exceeded that of saturated fatty acids in residues, including baru pulp and peel, buriti peel, and pequi seed. Notably, essential fatty acids were abundant in the fruit side streams, with omega-9 fatty acids particularly abundant in buriti peel. Baru seeds were notable for their high omega-6 fatty acid content, which was also observed in the pulp and peel of baru. Lipid quality indices (AI, TI, h/H, and HPI) varied substantially among fruit fractions. The lowest TI values were observed in buriti peel (0.2) and pequi pulp (0.2), while high h/H and HPI values were found in buriti peel (155.8 and 46.5, respectively), pequi pulp (133.4 and 48.6, respectively), and araticum seed (48.8 and 13.3, respectively). These results indicate favorable lipid quality characteristics in some fruit fractions and highlight the potential of these byproducts as alternative sources of nutritionally relevant lipids. Their utilization may also support sustainable and responsible consumption, provide additional income opportunities for producers, and contribute to biome preservation. Further biological and clinical studies are needed to determine whether these lipid characteristics translate into measurable health effects.

Keywords: biowaste; lipid quality indices; GC-MS

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1. Introduction

It is estimated that the global annual production of plant-based oil amounts to approximately 204 million tons [1]. The global consumption of plant-based oils is predominantly derived from nine major crops: palm, soybean, canola, sunflower seed, peanut, cottonseed, coconut, and olive [2]. This reliance on commodity-based oils results in a high degree of dependence, which may generate both economic and supply vulnerabilities, as monoculture practices reduce the diversity of cultivated plant species.

The search for alternative sources of plant-based oils has posed significant challenges in recent decades. Owing to the high dependence on oils for human consumption and, more recently, for biodiesel production, most countries are unable to satisfy domestic demand and must rely on imports from other producers [1,2]. This phenomenon highlights the pressing global challenge of ensuring adequate and sustainable sources of plant-based oils. In this context, there is an urgent need to identify alternative oil-bearing plant resources that can provide favorable profiles of unsaturated fatty acids (UFA). Of particular importance are monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA), which have been consistently associated with positive health outcomes and play a critical role in the prevention of diet-related chronic diseases [3]. Consequently, assessing the nutritional quality of foods through detailed analysis of their fatty acid profiles provides valuable insights into the diverse physiological effects exerted by different fatty acid classes. To this end, several indices have been developed to evaluate the health implications of dietary fats, such as the Health Promotion Index (HPI), the Hypocholesterolemic/Hypercholesterolemic (h/H) ratio, the Atherogenicity Index (AI), and the Thrombogenicity Index (TI). These indices serve as critical tools for understanding the relationship between dietary lipid composition and human health [4,5].

Brazil hosts a wide diversity of underutilized and relatively little-known plant species, many of which produce fruits with substantial oil content [6]. Some of these native species, although currently exploited primarily through extractive practices, demonstrate considerable technological and economic potential for large-scale utilization in plant-based oil production, such as babassu (*Attalea speciosa*), macauba (*Acrocomia aculeata*), and licuri (*Syagrus coronata*), whose oils have attracted increasing attention due to their nutritional value and possible industrial applications [1,7–11]. In this context, the Cerrado, recognized as the second largest Brazilian biome, represents a particularly important reservoir of plant biodiversity, harboring numerous native species with promising potential for plant-based oil production [12]. Among these, there are potential species, such as the baruzeiro (*Dipteryx alata*) [13], buritizeiro (*Mauritia flexuosa*) [14], pequi (*Caryocar brasiliense*) [15] e araticunzeiro (*Annona crassiflora*) [16]. Although the fruits of the species baru, buriti, pequi, and araticum are widely recognized for their high nutritional, biological, and bioactive value, significant knowledge gaps remain concerning their lipid profiles, particularly in relation to the potential applications of their processing by-products.

Most studies and commercial uses of these fruits focus on the pulp, except for *baru* (*Dipteryx alata*), where the seed is predominantly marketed. Nonetheless, underexploited fruit side streams may constitute valuable sources of bioactive compounds and nutrients, including polyunsaturated fatty acids [17–19]. Furthemore, discarded fractions of these fruits—such as baru pulp with skin, buriti and pequi seeds, and araticum skin, constitute over 40% of the total fruit mass [20–22].

According to the Food and Agriculture Organization of the United Nations (FAO), fruits and vegetables constitute approximately 32% of global food waste [23]. While 13% of global food is lost along the supply chain, from post-harvest to the retail stage, an additional 19% is wasted at the household, food service, and retail levels [24]. Therefore, the utilization of native Cerrado species, with an emphasis on underexploited fruit fractions, represents a

sustainable strategy to generate economic value from organic fruit side streams [25], while contributing to the preservation of Brazilian biodiversity. Moreover, studying these species is essential for understanding the nutritional, technological, and economic potential of their fruits, as well as for identifying applications of each fraction that could serve as alternatives to the limited number of established market commodities. Accordingly, the objective of this study was to investigate and characterize the fatty acid profiles of araticum, baru, buriti, and pequi using Gas Chromatography–Mass Spectrometry (GC–MS).

GC–MS is one of the main analytical platforms for the chemical characterization of foods, as it combines high chromatographic separation capability with compound identification based on mass spectra. In lipid analysis, this technique is widely employed for the determination of fatty acids after derivatization, which converts these compounds into more volatile and thermally stable derivatives, thereby improving their separation and identification. The comparison of mass spectra with reference libraries provides high selectivity and reliability for analyte identification, making GC–MS a widely used tool in studies of lipid composition, chemical characterization, and the authentication of foods and natural products [26,27].

2. Materials and Methods

2.1. Plant-Based Material

Fruits of araticum (*Annona crassiflora* Mart.), baru (*Dipteryx alata* Vogel), buriti (*Mauritia flexuosa* L.), and pequi (*Caryocar brasiliense* Camb.) were collected from distinct locations in the Cerrado Mineiro region of Brazil during 2022 and 2023 (Figure 1).

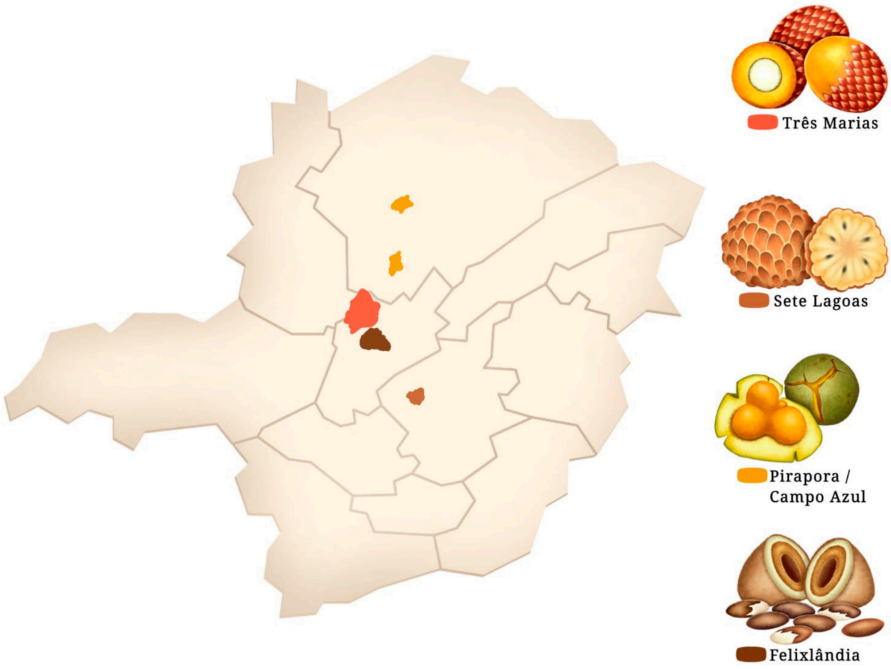

Figure 1. Illustrative map of the regions of the state of Minas Gerais (Brazil) where the fruits were collected. Illustration by Lucas Victor Ribeiro.

Sampling sites included Sete Lagoas (19°27′57″ S, 44°14′49″ W) for araticum; Felixlândia (18°45′28″ S, 44°53′56″ W) for baru; Três Marias (17°49′16″ S, 44°19′11″ W) for buriti; and Pirapora (17°20′42″ S, 44°56′31″ W) and Campo Azul (16°30′14″ S, 44°48′39″ W) for pequi. Species identification was based on the morphological characteristics of the fruits and comparison with taxonomic references. The access to Brazilian genetic heritage was

registered in the National System for the Management of Genetic Heritage and Associated Traditional Knowledge (SisGen) under registration number A709DE.

The fruits were washed under running water, sanitized in a 0.5% (*v*/*v*) sodium hypochlorite solution for 10 min, rinsed with distilled water, and dried with paper towels. They were manually separated into peel, pulp, and seed fractions, which were individually packaged in plastic containers, stored at −18 °C, and protected from light. Prior to fatty acid analysis, each fraction was ground using an analytical mill (IKA A11 Basic, Wilmington, NC, USA). In the case of buriti seeds, oven drying at 50 °C for 96 h was required to enable subsequent grinding.

2.2. Fatty Acid Profile

The determination of the fatty acid profile by gas chromatography–mass spectrometry (GC–MS) was performed in three sequential steps: extraction, hydrolysis, and methylation. Briefly, 30 g of ground sample was extracted with 100 mL of hexane in an ultrasonic bath (Sanders, Soniclean 2, 40 kHz, 280 W, Minas Gerais, Belo Horizonte, Brazil) at room temperature for 15 min. The extract was filtered through qualitative filter paper of 11 cm diameter and particle retention capacity of 4–12 µm (Unifil®, model 501011, São Paulo, Brazil), and the resulting hexane phase was collected. Each 30 g portion of homogenized sample underwent three consecutive extraction cycles with hexane, and the resulting filtrates were combined. When the combined extract did not yield approximately 10 mg of crude extract, an additional 30 g portion of the same homogenized sample was subjected to the same three-cycle extraction procedure, and the resulting extract was combined with the previous one. The combined filtrates were homogenized and left to evaporate in a fume hood at room temperature for 24 h. Hydrolysis was performed following the procedure described by Minighin [28], with minor modifications. A 10 mg aliquot of the extract was dissolved in 100 µL of a 1 mol·L^{-1} NaOH solution prepared in EtOH/water (95%). The mixture was vortexed for 10 s and hydrolyzed in a domestic microwave oven (Electrolux MEX55, 2450 MHz, 1000 W, Curitiba, Brazil) at 30% of the maximum power for 4 min. Due to the small reaction volume and the use of Eppendorf microtubes, temperature monitoring was not performed during hydrolysis. To prevent internal pressure accumulation caused by heating, a small hole was made in the tube cap using a needle, allowing pressure release during microwave irradiation.

After cooling, 400 µL of HCl (20%), 20 mg of NaCl, and 600 µL of ethyl acetate were added. The mixture was vortexed for 10 s and allowed to stand for 1 min. A 300 µL aliquot of the upper organic phase was collected into a 2 mL microcentrifuge tube (*Eppendorf*) and concentrated in a SpeedVac (Eppendorf Concentrator Plus, Hamburg, Germany) at 30 °C for 3 h to obtain free fatty acids. Methylation was performed in the same tube by adding 100 µL of a 14% (*w*/*v*) BF_3–methanol solution. The reaction was conducted at 60 °C for 10 min in a digestion block (Tecnal, TE-019, São Paulo, Brazil). After cooling, methylated fatty acids were extracted with 500 µL of hexane, followed by vortexing for 10 s to allow phase separation. The upper organic layer (200 µL) was collected and transferred to a GC vial for analysis.

Chromatographic separation was performed using a 7890A gas chromatograph system equipped with a 5975C quadrupole mass spectrometer (Agilent Technologies®, Santa Clara, CA, USA) and an Agilent J&W DB-5MS capillary column (30 m length, 0.250 mm i.d., 0.25 µm film thickness; part number 122-5532; Agilent J&W Scientific, Santa Clara, CA, USA) containing 5% diphenyl and 95% dimethylpolysiloxane as the stationary phase. Data were acquired in full scan mode (*m*/*z* 50–600) using Agilent MassHunter Data Acquisition software version 10.0 (Agilent Technologies®, Santa Clara, CA, USA). The temperature program began at 60 °C, ramping to 325 °C at 10 °C·min^{-1}, and was held for 15 min. The

carrier gas was ultrapure helium at a constant flow rate of 0.8 mL·min^{-1}. The injector was maintained at 250 °C and operated in split mode (1:5), with an injection volume of 2 µL. Electron ionization was conducted at 70 eV. The interface, ion source, and quadrupole temperatures were set at 290 °C, 250 °C, and 150 °C, respectively. Compound identification was performed using Agilent MassHunter Qualitative Analysis software version 10.0 by comparing the obtained mass spectra of chromatographic peaks with the NIST and Fiehn libraries and retention times were confirmed using a standard mixture of FAMEs (C_4–C_{24}; Sigma-Aldrich, Burlington, MA, USA).

2.3. Nutritional Quality Indices of Lipid Fractions

Lipid quality indices were calculated using the relative percentage of fatty acids obtained from GC-MS relative peak area, following the equations proposed by Chen and Liu [5], including the hypocholesterolemic/hypercholesterolemic ratio (h/H) (Equation (1)), atherogenicity index (AI) (Equation (2)), health-promoting index (HPI) (Equation (3)), and thrombogenicity index (TI) (Equation (4)), where SFAs, MUFAs, and PUFAs denote saturated, monounsaturated, and polyunsaturated fatty acids, respectively. As these values were derived from relative peak area data rather than absolute concentrations corrected using individual analytical standards or calibrated detector response factors, the resulting indices should be regarded as semi-quantitative estimates reflecting the relative fatty acid distribution, rather than absolute quantitative measurements.

$$\mathrm{h/H} = \frac{(cis - C18:1 + \Sigma PUFA)}{(C12:0 + C14:0 + C16:0)} \quad (1)$$

$$\mathrm{AI} = \frac{[C12:0 + 4 \times C14:0 + C16:0]}{\Sigma \mathrm{UFA}} \quad (2)$$

$$\mathrm{HPI} = \frac{[\Sigma UFA]}{[\mathrm{C12:0} + (4 \times \mathrm{C14:0}) + \mathrm{C16:0}]} \quad (3)$$

$$\mathrm{TI} = \frac{(C14:0 + C16:0 + C18:0)}{[(0.5 \times \Sigma \mathrm{MUFA}) + (0.5 \times \Sigma \mathrm{n-6PUFA}) + (3 \times \Sigma \mathrm{n-3PUFA}) + (\mathrm{n-3/n-6})]} \quad (4)$$

3. Results

Fatty acids (FAs) can be classified based on their carbon chain length, chemical structure, and degree of saturation, and are generally categorized as saturated, monounsaturated, or polyunsaturated. FAs constitute the principal components of dietary fats and are essential for a wide range of physiological processes. Beyond serving as a major source of metabolic energy, they facilitate the absorption and transport of fat-soluble vitamins (A, D, E, and K) and contribute to the structural integrity and functional properties of cellular membranes [5]. Most naturally occurring fatty acids possess an unbranched hydrocarbon chain with an even number of carbon atoms, typically ranging from 4 to 28. Understanding the compositional profile of fatty acids is of considerable importance, given their well-documented contributions to human health. A balanced intake of specific fatty acids has been associated with the prevention of oxidative stress, the modulation of inflammatory responses, and the reduction of risk factors linked to chronic and non-communicable diseases [29–35].

Saturated fatty acids (SFAs) typically contain an even number of carbon atoms, ranging from 4 to 20, with lauric (C12:0), myristic (C14:0), palmitic (C16:0), and stearic (C18:0) acids being the most common in the human diet [36]. SFAs serve as important energy sources and structural components of cell membranes, and they also play roles in the regulation of

gene transcription. In human tissues, SFAs account for approximately 30–40% of the total fatty acid content [37].

Monounsaturated fatty acids (MUFAs) are characterized by the presence of a single double bond in their carbon chain, distinguishing them from SFAs, which contain no double bonds, and polyunsaturated fatty acids, which possess two or more [5,38]. In dietary sources, MUFAs predominantly occur in the *cis* configuration, with oleic (C18:1), palmitoleic (C16:1), and vaccenic (C18:1) acids being the most abundant [38,39]. These fatty acids represent approximately one-third of the total fatty acid intake in the human diet and are associated with beneficial effects on immune function and overall metabolic health. On the other hand, PUFAs are characterized by the presence of more than one double bond in their carbon chain. They are classified into families according to the position of the first double bond relative to the terminal methyl group, primarily the omega-3 series, derived from α-linolenic acid (ALA, C18:3, n-3), and the omega-6 series, derived from linoleic acid (LA, C18:2, n-6) [40]. PUFAs play essential roles in maintaining the normal function of the brain, eyes, and nervous system. However, humans are unable to synthesize double bonds beyond the ninth carbon atom, which prevents endogenous production of omega-3 and omega-6 fatty acids. Consequently, their precursors, also referred to as essential fatty acids (EFAs), must be obtained through dietary intake [41].

Table 1 presents the fatty acid profile of the analyzed fruits, expressed as the percentage of the relative total area of chromatographic peaks. Only fatty acids representing more than 1% of the total area, or those detected in at least one of the fruit samples, are included.

Table 1. Fatty acid composition (%) of Cerrado fruit lipid fractions.

	Araticum (*Annona crassiflora*)			**Baru (*Dipteryx alata*)**		**Buriti (*Mauritia flexuosa*)**			**Pequi (*Caryocar brasiliense*)**	
	PEEL	**PULP**	**SEED**	**PULP**	**SEED**	**PEEL**	**PULP**	**SEED**	**PULP**	**SEED**
C8:0	1.63	0.6	ND	ND	ND	0.09	ND	ND	0.03	ND
C12:0	0.95	0.61	0.10	0.4	ND	0.12	0.1	ND	0.13	ND
C14:0	3.68	4.57	0.83	1.26	0.04	0.45	0.43	2.89	0.25	ND
C16:0	16.73	ND	ND	24.65	10.52	ND	ND	36.91	0.2	ND
C16:1(ω-9)	ND	1.11	0.21	3.82	0.07	0.55	1.61	ND	3.05	1.77
C17:0	ND	0.25	0.33	0.32	0.19	0.31	0.34	ND	ND	0.27
C18:0	33.66	9.92	17.71	7.97	6.95	7.25	6.93	42.61	6.23	6.96
C18:1(ω-9)	35.65	61.22	45.39	44.42	31.12	88.81	55.84	ND	48.74	51.12
C18:2(ω-6)	ND	ND	ND	2.3	36.56	ND	ND	ND	1.94	ND
C20:0	ND	3.11	6.15	3.63	1.71	0.7	0.56	ND	2.75	0.94
C20:1(ω-9)	ND	ND	ND	ND	ND	ND	1.5	ND	ND	ND
C22:0	2.36	0.52	1.10	4.04	5.24	ND	0.16	ND	0.15	0.16
C24:0	3.48	0.41	0.68	3.82	6.79	0.5	0.22	ND	0.16	0.27
ΣSFA	64.34	36.77	54.29	45.86	31.25	9.02	41.61	82.41	43.38	46.01
ΣMUFA	35.65	62.33	45.60	48.59	31.23	89.36	57.45	ND	52.94	52.89
ΣPUFA	ND	ND	ND	2.3	36.56	ND	ND	ND	1.94	ND

NOTE: ND (not detected) indicating that the compound concentration was below the detection limit of the analytical method and not necessarily absent from the sample. C8:0—caprylic acid. C12:0—lauric acid. C14:0—myristic acid. C16:0—palmitic. C16:1—palmitoleic acid. C17:0—margaric acid. C18:0—Stearic acid. C18:1—oleic acid. C18:2—linoleic acid. C20:0—arachidic acid. C20:1—eicosenoic acid. C22:0—behenic acid. C24:0—lignoceric acid. ΣSFA: Total Saturated Fatty Acids. ΣMUFA: Total Monounsaturated Fatty Acids. ΣPUFA: Total Polyunsaturated Fatty Acids.

In general, fatty acids with 18 carbon atoms predominated across the analyzed fruits. With the exception of baru seeds, in which PUFAs were particularly abundant, MUFAs predominated in all fractions of pequi and buriti, as well as in the pulps of baru and araticum. In buriti seeds, stearic acid (C18:0) represented the most abundant saturated fatty

acid, whereas in baru seeds, linoleic acid (C18:2), a PUFA, was predominant; this fatty acid was also detected in pequi pulp. Oleic acid (C18:1), a MUFA, was the major component in the remaining fruit fractions. It is noteworthy that unsaturated fatty acids (UFA) are considered antiatherogenic, and thus the consumption of foods rich in these compounds may contribute to reductions in total and LDL cholesterol levels in human plasma [42].

As complementary information, previous studies conducted by our research group determined the lipid content of the fruit fractions evaluated in the present study. The mean lipid contents were 33.00 and 48.00 g/100 g for pequi pulp and seed, respectively; 0.99, 0.38, and 6.51 g/100 g for araticum pulp, peel, and seed, respectively; 3.13, 30.98, and 0.16 g/100 g for buriti peel, pulp, and seed, respectively; and 36.94 and 1.24 g/100 g for baru seed and pulp, respectively (unpublished data). These data provide complementary information on the total lipid abundance of the evaluated matrices and contextualize the relative fatty acid profiles determined in the present study.

Several authors have reported that the monounsaturated fatty acids content of buriti oil is notable, with oleic acid (Figure 2a) predominating in the whole fruit, seed, and pulp [2,43,44]. Furthermore, Silva [44] reported that oleic acid was the predominant fatty acid in buriti fruits from different regions, accounting for 69.58–78.57% of the fatty acid profile. In the present study, oleic acid represented 88.81% of the relative peak area in buriti peel, indicating a high relative proportion of this fatty acid. The higher relative proportion of oleic acid observed in buriti peel may reflect the combined influence of genetic background, environmental conditions, fruit maturity, and tissue-specific lipid metabolism. However, because these factors were not experimentally controlled in the present study, their individual contributions cannot be established [45,46].

Variations in the fatty acid profile are influenced by multiple factors, including species, cultivation site, fruit ripeness, initial quality of the raw material, extraction method, and storage conditions, as well as soil and climatic characteristics. Moreover, different fractions of the same fruit exhibit distinct physical and chemical properties [2]. Oleic acid (C18:1) was the predominant fatty acid in all parts of araticum. This monounsaturated fatty acid is the principal in the human brain and is widely distributed in nature, occurring in various food matrices [44]. These findings are consistent with the study by Gutiérrez-Luna [47], which identified oleic acid as the main fatty acid in araticum seed oil. In the present study, araticum pulp exhibited a high relative proportion of monounsaturated fatty acids (62.33% of the total relative peak area), rep-resenting the highest proportion among the evaluated araticum fractions and other fruit matrices, except for buriti peel. The predominance of monounsaturated fatty acids may contribute to the potential of these matrices for applications in the food and cosmetic sectors [47]. In baru seeds, oleic acid accounted for 31.12% of the total relative peak area, a proportion comparable to that previously reported (30.43%) [48]. Although there are no prior reports on C18:1 content in baru pulp, the levels observed in this study were comparable to those found in the seed. This indicates the potential use of the pulp as a valuable residue, given that C18:1 is a biological precursor of monoene acids and the omega-9 family. Monounsaturated fatty acids are associated with multiple health benefits, including protection against cardiovascular insulin resistance, alleviation of endothelial dysfunction and inflammation, and contributions to the prevention of atherosclerosis [44,49,50].

Faria [51] reported that oleic acid, present in high concentrations in olive oil, exerts blood pressure-lowering effects. This finding further supports the health-promoting properties of buriti oil, as the high oleic acid content contributes to its nutritional quality and highlights its potential as an ingredient in the food industry, including in margarines or foods subjected to heating. The potential thermal stability of oleic acid, combined with its low degree of unsaturation and its synergistic interaction with antioxidants naturally

present in buriti oil, enhances the oil's resistance to oxidation [6]. In pequi, oleic acid represented a high proportion of the fatty acid profile in the present study, consistent with the values reported for pequi seed oils obtained using different extraction methods, which ranged from 48.7 to 51.1% [52]. These methods included Soxhlet extraction and pressurized isopropyl alcohol, with variations in extraction time and temperature. According to these authors, the extraction method did not significantly affect the fatty acid composition. Higher relative proportions of oleic acid have also been reported in other studies of pequi pulp oils, including 65.5% [53] and 58.7–60.6% [54], as well as in dehydrated pulp (56.8%) [55]. However, these comparisons should be interpreted with caution because differences in analytical methods and data expression may affect the reported fatty acid proportions.

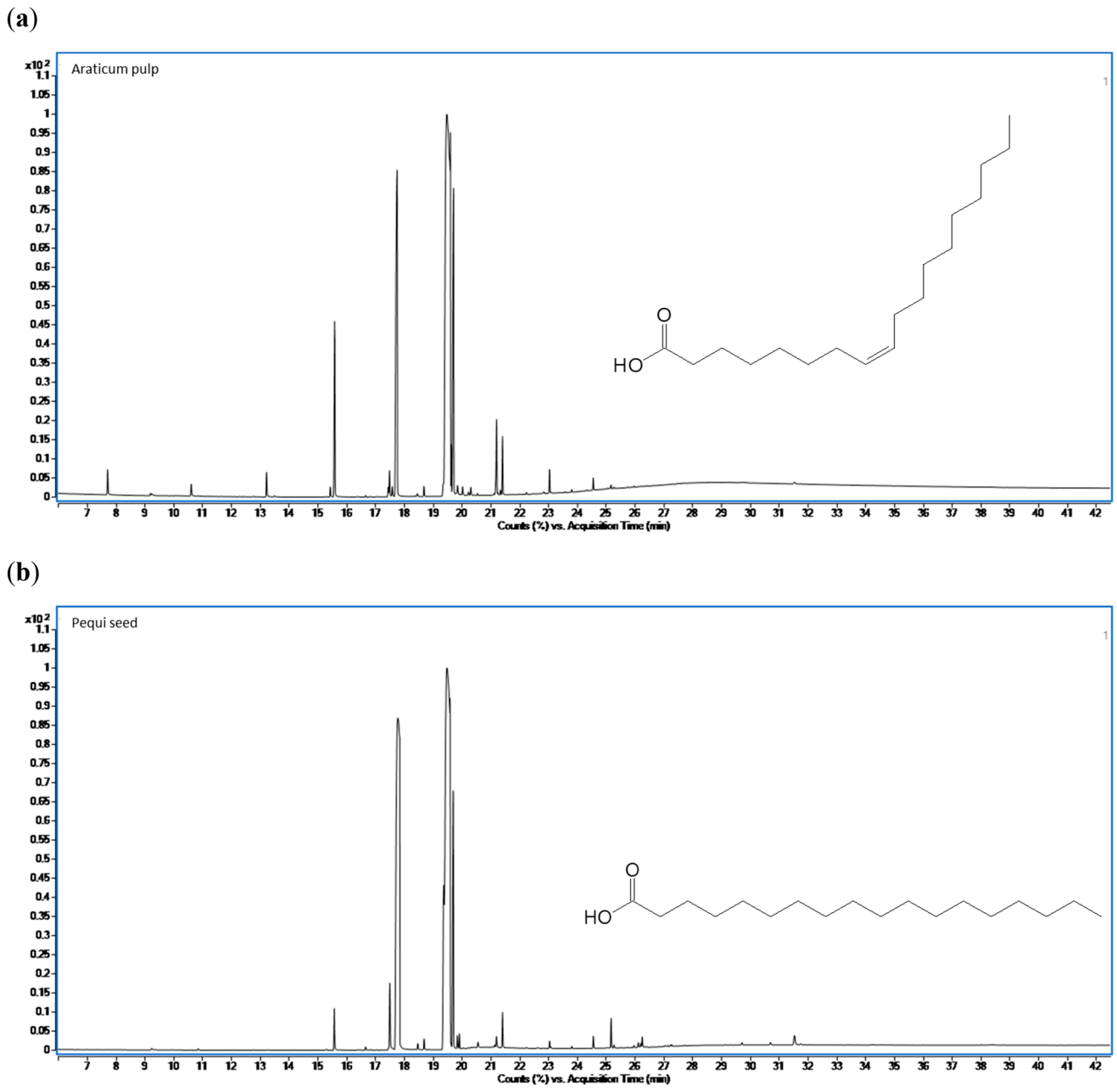

Figure 2. *Cont.*

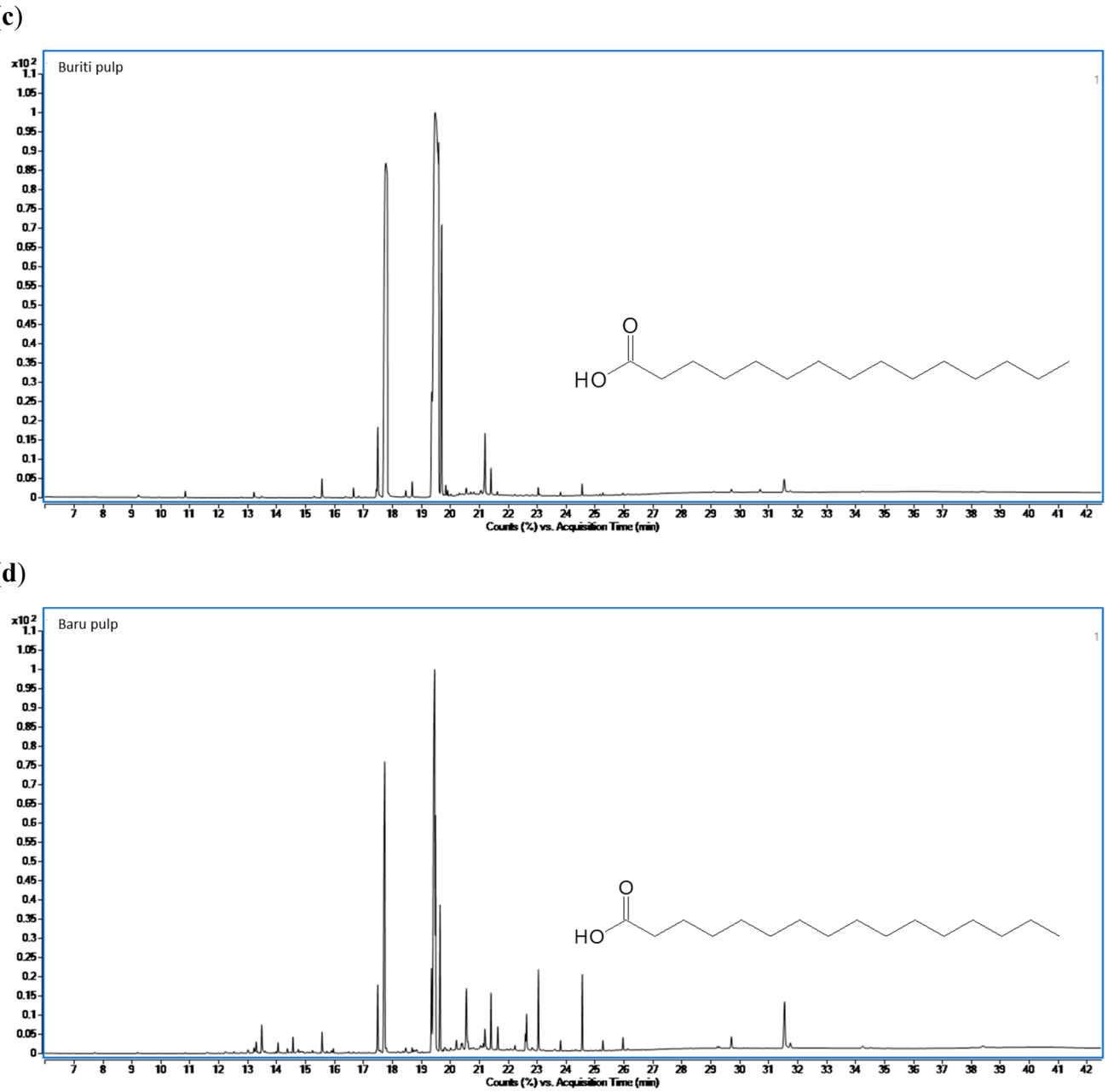

Figure 2. Illustrative chromatograms of fruit pulp with chemical structures of the major fatty acids. (**a**) Oleic acid, retention time (Tr) 19.469 min; (**b**) Stearic acid, Tr 19.701 min; (**c**) Pentadecanoic acid, Tr 17.774 min; (**d**) Palmitic acid, Tr 18.362 min.

Among the SFAs, pentadecanoic acid (C15:0) predominated in buriti peel and pulp (Figure 2c), account-ing for a high relative proportion of the fatty acid profile. Previous studies have re-ported C15:0 in buriti pulp oil at relative proportions ranging from 0.02 to 0.53% [56–59]. In the present study, C15:0 was also detected in pequi samples; however, it was not reported in previous studies evaluating the fatty acid profiles of pequi seed and pulp oils [56–59] or dehydrated pequi pulp [55].

Palmitic (C16:0) and stearic (C18:0) acids (Figure 2b,d) were the predominant SFAs in baru oil, consistent with previous reports [48]. In baru, stearic acid represented a higher relative proportion than that reported by Jaramillo-Vivanco [60], who reported values of 4.99–5.21% in seed oil depending on the extraction method. The relative proportion of stearic acid reported for buriti pulp by Fetzer [61] was also consistent with the profile observed in the present study, particularly in buriti seed, where stearic acid accounted for

42.61%. In the pequi fractions analyzed, stearic acid accounted for more than 6% of the relative peak area, whereas previous studies reported proportions ranging from 1.43 to 3.66% [52,54,55]. Stearic acid has been reported to exert protective effects in thrombosis, blood pressure regulation, and atherosclerosis, in addition to improving symptoms in Parkinson's and Alzheimer's diseases. It may also reduce adipose tissue in obesity and, at low concentrations, confer hepatoprotective effects [62].

Hexadecanoic (palmitic) acid was particularly abundant in buriti seeds, whereas it was not detected in the buriti seed evaluated by Costa [63]. In the present study, palmitic acid accounted for 36.91% of the relative peak area in buriti seeds, while previous studies reported proportions ranging from 15.2 to 22.2% in buriti oil [64]. Palmitic acid was also detected in the pulp and baru seed, with relative proportions differing from those re-ported in previous studies of pulp oils (20.6–31.7%) and seed oils (11.3%) [48,65], as well as from the approximately 5% reported for baru seed oil by Jaramillo-Vivanco [60]. In araticum, palmitic acid was detected only in the shell (16.73%) [44].

Regarding PUFAs, linoleic acid (C18:2) accounted for a high relative proportion of the fatty acid profile in baru seed, compared with the proportions reported for seed oil in previous studies (25.5–30.7%) [66–68]. Linoleic acid was also detected in baru and pequi pulps. Previous studies have reported this fatty acid in pequi pulp from different Cerrado regions, with proportions ranging from 1.01 to 3.67%, as well as in pequi seed oil (8.22–10.92%) [55,69] and *Caryocar coriaceum* pulp oil (2.10–2.84%) [54]. Linoleic acid was not detected in araticum in the present study. Polyunsaturated fatty acids have been investi-gated for their roles in metabolic and physiological processes, including food intake and hypothalamic regula-tion of hepatic glucose production [44].

As previously noted, certain fatty acids confer health benefits. One way to evaluate their nutritional value and potential applications is through nutritional quality indices. In this study, four indices were considered: the atherogenicity index (AI), thrombogenicity index (TI), hypocholesterolemic/hypercholesterolemic ratio (h/H), and health promotion index (HPI) [5]. Table 2 presents the calculated nutritional indices for araticum, baru, buriti, and pequi.

Table 2. Nutritional indices of Cerrado fruit lipid fractions.

Fruto	Fruit Fraction	HPI	h/H	AI	TI
Araticum	Peel	1.1	1.7	0.9	3.0
	Pulp	3.3	11.8	0.3	0.5
	Seed	13.3	48.8	–	0.8
Baru	Pulp and peel	1.7	1.8	0.6	1.3
	Seed	4.4	6.4	0.2	0.5
Buriti	Peel	46.5	155.8	0.02	0.2
	Pulp	31.6	105.4	0.03	0.3
	Seed	–	–	–	–
Pequi	Pulp	48.6	133.4	–	0.2
	Seed	–	–	–	0.3

Note: Values indicated by "–" were not calculated because the required fatty acids for the respective index calculation were not detected or the calculation was not applicable. AI, atherogenicity index; TI, thrombogenicity index; h/H, hypocholesterolemic/hypercholesterolemic ratio; HPI, health promotion index.

Saturated fatty acids such as C12:0, C14:0, and C16:0 are considered pro-atherogenic and pro-thrombogenic because they promote lipid adhesion in cells of the immune and

circulatory systems. In contrast, unsaturated fatty acids (UFA) inhibit atheroma formation and reduce serum levels of total cholesterol, phospholipids, LDL, triglycerides, and esterified fatty acids [5]. In this context, the atherogenicity (AI) and thrombogenicity (TI) indices evaluate the balance between harmful and beneficial fatty acids for cardiovascular health. These lipid indices are frequently used to assess the nutritional quality of diverse foods, including oils derived from fruits, nuts, and seeds [4,70]. Both AI and TI reflect the potential of a food to stimulate platelet aggregation, with lower values indicating higher proportions of antiatherogenic and antithrombogenic fatty acids, namely MUFA and PUFA [42,71].

Table 2 presents the atherogenicity (AI) and thrombogenicity (TI) indices of the four fruits evaluated in this study. AI values ranged from 0.03 to 0.9 among the fractions for which the index could be calculated, whereas TI values ranged from 0.2 to 3.0. Baru seed and araticum pulp exhibited relatively low AI values (0.2 and 0.3, respectively), while buriti peel, and pequi pulp showed low TI values (0.2 both). These values are within or comparable to those reported for traditional vegetable oils, including olive oil (AI: 0.12; TI: 0.32), soybean oil (AI: 0.14; TI: 0.25), corn oil (AI: 0.17; TI: 0.37), sunflower oil (AI: 0.10; TI: 0.27), and cottonseed oil (AI: 0.30; TI: 0.58). They are also comparable to values reported for other vegetable oils, such as guava oil (AI: 0.12; TI: 0.35) and passion fruit oil (AI: 0.11; TI: 0.30), and lower than those reported for acai (*Euterpe oleracea*) oil (AI: 0.30; TI: 0.60), grape oil (AI and TI: 0.28), and avocado oil (AI and TI: 0.41) [4,42,72]. These results indicate a favorable relative distribution of fatty acids according to the AI and TI criteria. However, direct comparisons among studies should be interpreted with caution because differences in analytical methods, calibration procedures, and data expression may affect the reported fatty acid proportions. Moreover, AI and TI are theoretical indices based on fatty acid composition and should not be interpreted as direct measures of cardiovascular effects [5].

In the present study, the highest AI and TI values were observed in araticum peel, with values of 0.9 and 3.0, respectively. In contrast, the lowest AI values were observed in buriti pulp (0.03) and baru seed (0.2), while low TI values were observed in buriti peel (0.2), pequi pulp (0.2), buriti pulp (0.3), and araticum pulp (0.5). These differences reflect the variation in the relative distribution of fatty acids among the evaluated fruit fractions. Similar indices have been reported for other vegetable oils [42]. However, these indices should be interpreted as comparative indicators of fatty acid composition rather than direct measures of physiological or cardiovascular effects.

While the first two indices (AI and TI) should ideally exhibit the lowest possible values, the hypocholesterolemic/hypercholesterolemic ratio (h/H) and health promotion index (HPI) should be as high as possible. Elevated h/H and HPI values indicate a more favorable fatty acid profile according to these indices [73,74]. The H/H ratio is considered a more accurate indicator of the influence of fatty acid composition on cardiovascular health and has been widely reported for fish, algae, meat, and dairy products [73]. In the present study, the highest HH values were observed in buriti peel (155.8), pequi pulp (133.4), buriti pulp (105.4), and araticum seed (48.8). Lower HH values were observed for araticum pulp (11.8), baru seed (6.4), baru pulp and peel (1.8), and araticum peel (1.7). These differences reflect the relative contribution of hypocholesterolemic and hypercholesterolemic fatty acids in each fruit fraction. The HH values observed in the present study were higher than those reported for some conventional vegetable oils in the literature, although direct comparisons should be made cautiously because the values depend on the fatty acid composition and the analytical approach used [72,75].

The health promotion index (HPI) is commonly applied in dairy research, where values typically range from 0.16 to 0.68. In the present study, notably high HPI values were observed for pequi pulp (48.6) and buriti peel (46.5), reflecting a predominance of unsaturated fatty acids associated with cardiovascular health benefits. High HPI values

were also observed for buriti pulp (31.6) and araticum seed (13.3). These values exceed those reported by Rabail et al., (2024) [76]. For widely consumed oils such as flaxseed (15.85), sunflower (9.13), olive (3.96), and coconut (0.097) oils. These differences indicate a greater relative contribution of unsaturated fatty acids according to the HPI equation. However, because the HPI values in the present study were calculated from relative fatty acid peak areas obtained by GC–MS, they should be interpreted as comparative indicators of the relative fatty acid profile rather than as direct measures of health-promoting effects.

Overall, the application of these nutritional indices provides a complementary approach for comparing the relative fatty acid profiles of different lipid sources [72,74]. According to the World Health Organization (WHO, 2023), saturated and trans fatty acids in the diet should be replaced by PUFA and MUFA from plant-based sources. In this context, the Cerrado fruit fractions analyzed in this study, particularly those showing a greater relative contribution of unsaturated fatty acids, may represent interesting matrices for further investigation as alternative lipid sources. Moreover, incorporating oils extracted from these residues into blends with refined oils could be investigated as a strategy to modify the fatty acid profile of blended oils [52,54].

Importantly, the nutritional indices reported in Table 2 were calculated using the relative distribution of fatty acid peak areas obtained by GC–MS. Although these indices are dimensionless, differences in detector response among fatty acids may affect their quantitative interpretation. Therefore, the values reported herein should be regarded as comparative indicators of the relative fatty acid profiles rather than as absolute measures of lipid nutritional quality [74]. Further studies using individually calibrated fatty acid standards and absolute quantification would be valuable for confirming these relationships.

4. Conclusions

This study demonstrated that fruits from the Brazilian Cerrado and their respective byproducts represent promising sources of bioactive lipids, with a predominance of unsaturated fatty acids in several evaluated matrices. Among the residues analyzed, baru pulp, buriti peel, and pequi seed exhibited monounsaturated fatty acid contents higher than saturated fatty acids, highlighting their favorable lipid composition. Buriti peel showed the highest contribution of omega-9 fatty acids, whereas baru seeds and pulp presented relevant levels of omega-6 fatty acids.

Baru seed and pulps of pequi and buriti presenting the lowest atherogenicity (AI = 0.2) and thrombogenicity (TI = 0.2) indices, respectively. The nutritional lipid indices further supported the potential quality of these byproducts, with buriti peel exhibited the highest hypocholesterolemic/hypercholesterolemic (h/H = 155.8) and health-promoting (HPI = 46.5) indices, with values comparable to or higher than those reported for conventional vegetable oils.

These findings demonstrate that Cerrado fruit byproducts can be considered valuable sources of fatty acids and represent promising materials for further investigation regarding their potential applications. Their valorization may contribute to the circular use of agro-industrial residues and the sustainable exploitation of Cerrado biodiversity. However, further studies addressing biological activity, oxidative stability, safety, sensory characteristics, and bioavailability are necessary before considering these materials for functional food applications.

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Abbreviations

The following abbreviations are used in this manuscript:

GC–MS	Chromatography Coupled with Mass Spectrometry
WHO	World Health Organization
FAs	Fatty acids
MUFA	Monounsaturated Fatty Acid
PUFA	Polyunsaturated Fatty Acid
UFA	Unsaturated Fatty Acid
H/H	Hypocholesterolemic/Hypercholesterolemic ratio
HPI	Health Promotion Index
AI	Atherogenicity Index
TI	Thrombogenicity Index

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