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Original Article

Physicochemical analysis of amazonian plant oils: implications for biodiesel synthesis

Análisis fisicoquímico y transesterificación de aceites de plantas amazónicas para la síntesis de biodiesel

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Spanish version

Abstract

Introduction: The composition and properties of each raw material are relevant to the transesterification process and the production of high-quality biodiesel.
Materials and methods: A comparative theoretical analysis of four possible raw materials for industrial-scale biodiesel production is carried out: Attalea Maripa, Andiroba, Sejé, and Sacha Inchi, to determine the most suitable one based on its commercial availability and physicochemical analysis of the oils extracted from each. The commercially available oils are then transesterified to compare their methyl ester content.
Results: Chromatography was used to identify the most predominant fatty acids in three of the oils, which can be: linolenic, linoleic, oleic, and palmitic. Attalea Maripa oil was excluded due to its lack of commercial availability. After experimentation, it was only possible to obtain biodiesel from Sejé and Sacha Inchi oils. In the first case, the biodiesel needs to be filtered for cleaning and refining, and the reaction has a yield of over 90%, while in the second case, the biodiesel does not require additional processing but has a low yield of 25%.
Conclusions: Biodiesel obtained from Sejé oil is defined as a viable alternative from a technical standpoint, with adequate performance and market availability. These findings contribute to the advancement of raw material diversification for biodiesel and promote the development of sustainable sources.

Keywords: Vegetable oil, physicochemical analysis, biodiesel, Amazonian plants, transesterification.

Resumen

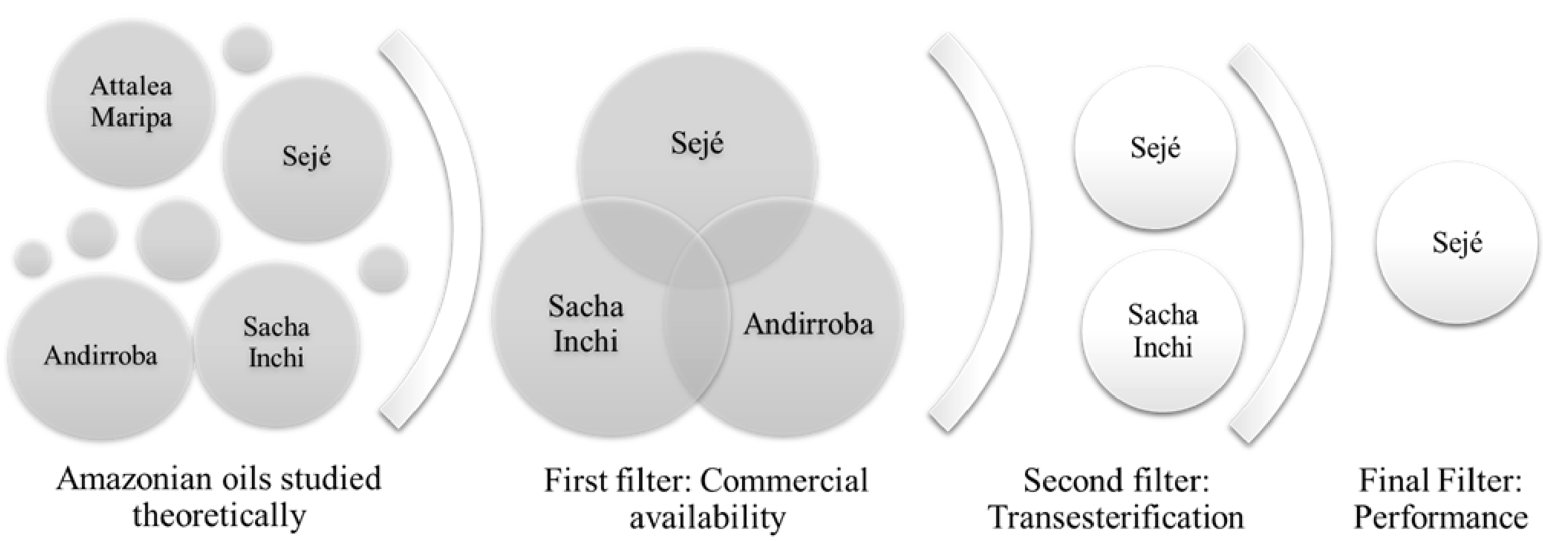
Introducción: La composición y propiedades de cada materia prima, es relevante para el proceso de transesterificación y producción de biodiesel de alta calidad.
Materiales y métodos: Se realiza un análisis teórico comparativo de cuatro posibles materias primas para la producción de biodiesel a escala industrial: Attalea Maripa, Andiroba, Sejé y Sacha Inchi, para determinar la más adecuada según su disponibilidad comercial y análisis fisicoquímico de los aceites extraídos de cada una. Luego se hace la transesterificación de los aceites disponibles comercialmente para comparar su contenido de metil estéres,
Resultados: En tres de los aceites se identificaron, mediante cromatografía, los ácidos grasos que cuentan con mayor predominancia, que pueden ser: linolénico, linoleico, oleico, palmítico, se excluyó el aceite de Attalea Maripa dada su falta de disponibilidad comercial. Tras la experimentación solo fue posible obtener biodiesel a partir de los aceites de Sejé y Sacha Inchi, en el primer caso existe la necesidad filtrar el biodiesel para su limpieza y refinado y la reacción presenta un rendimiento superior al 90%, mientras que en el segundo caso el biodiesel no requiere procesamiento adicional, pero tiene bajo rendimiento que corresponde al 25%.
Conclusiones: Se define el biodiesel obtenido a partir del aceite de Sejé puede ser una alternativa viable desde el punto de vista técnico, con adecuado rendimiento y disponibilidad en el mercado. Estos hallazgos contribuyen al avance en la diversificación de materias primas para el biodiesel y promueven el desarrollo de fuentes sostenibles.

Keywords: Aceite vegetal, análisis fisicoquímico, biodiesel, plantas amazónicas, transesterificación.

Why was this study conducted?
The study was conducted to find alternative and sustainable sources for biodiesel production in Colombia, given the increasing consumption of fossil fuels and environmental pollution. Currently, the main raw material used in the country is palm oil, whose intensive use has generated environmental problems such as monoculture and biodiversity loss. Therefore, the research sought to evaluate Amazonian oils: Andiroba, Sejé, Attalea Maripa, and Sacha Inchi, to determine their suitability as raw materials for biodiesel synthesis, through physicochemical characterization, chromatographic analysis, and experimental transesterification tests.

What were the most relevant findings?
The study results demonstrated that Sejé oil is the most suitable raw material for biodiesel production, achieving a 90% yield and exhibiting a composition rich in fatty acids, primarily oleic acid, which promotes the stability and quality of the biofuel. Sacha Inchi oil also yielded biodiesel, although with a low 25% yield due to its high content of unsaturates and precipitates formed during washing. Andiroba oil, on the other hand, did not yield biodiesel due to the formation of soaps and impurities that inhibited the reaction. Attalea Maripa oil, while theoretically suitable, could not be analyzed experimentally due to its limited commercial availability.

What do these findings contribute?
The findings of this study offer a promising alternative for diversifying the raw materials used in biodiesel production in Colombia, highlighting Sejé oil as a sustainable and efficient source. These results contribute to the scientific knowledge of biofuels, promote the use of native Amazonian species, and foster the development of a sustainable bioeconomy that reduces dependence on fossil fuels. Furthermore, the work provides valuable information for the national energy industry, encouraging the use of biofuels that reduce pollution and facilitate the transition to renewable energy sources while complying with current regulations.



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Introduction

In response to rising fossil fuel consumption and environmental pollution, biodiesel synthesis has experienced significant growth (1). This drive frames the search for alternative and renewable energy sources to promote sustainable development.

In Colombia, the main source of energy is based on fossil fuels, which has led to the emission of toxic gases (CO_2, CO, SO_2 and NOx) derived from fuels obtained from hydrocarbons (2). The mitigation of these pollutants, although not a simple task, becomes viable through biodiesel synthesis. The biodiesel industry in Colombia has great potential in the field of biofuels (3).

According to ASTM D-6751 (American Society for Testing and Materials), biofuels are derived from biomass. Furthermore, biodiesel is defined as a fuel composed of monoalkyl esters of long-chain fatty acids derived from vegetable oils or animal fats (4). In Colombia, the use of biofuels has been implemented in major cities (5), and the average biodiesel production in 2022 was 685,000 tons, a 40% increase over the previous year (6)

Currently, the main raw material for biodiesel production is palm oil, specifically the OxG hybrid, which is a cross between Elaeis oleífera and Elaeis guineensis (7). However, its excessive use has generated monoculture problems, which reduces the resilience of crops to pests and increases their risk of damage and food instability (8). Colombian regulations (Resolution 40111 of 2021) require all diesel to contain at least 10% biodiesel for use in combustion engines. Despite the advantages, the implementation of this regulation has faced difficulties, with price being the most significant barrier (9).

For efficient biodiesel production, a thorough study of oil selection is essential, as not all oils are suitable as feedstock. This process involves evaluating the composition and concentration of fatty acid methyl esters (FAMEs) through physicochemical analysis and characterization of the input material. In Colombia, the predominant feedstocks for biodiesel synthesis include palm, coconut, castor oil, avocado, jatropha, rapeseed, peanut, soybean, and sunflower (10).

Oils derived from oilseeds must meet certain characteristics that indicate their suitability as feedstocks. Important parameters include oil content in the kernel and yield per hectare. For example, sunflower, peanut, rapeseed, and jatropha have high oil content in the kernel, ranging from 40% to 60% (11). Furthermore, factors such as production costs per hectare, market availability, and fatty acid percentage are crucial when selecting suitable feedstock.

The biodiesel production cycle begins with the extraction of oil from plant material, using sterilized bunches of fresh fruit, followed by the separation of the fruits. The fruits then undergo a digestion process to extract their oil, which is clarified and moisture reduced (12). The second process focuses on the refining of the obtained oil, which includes filtration, bleaching, and deodorization. Finally, the refined oil is ready to be transformed into biodiesel through transesterification.

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This comparative study expands scientific knowledge on biofuels, promoting the diversification of raw material sources and the development of sustainable renewable fuels. It also provides valuable information for the Colombian biodiesel industry, boosting its growth and reducing dependence on fossil fuels to reduce environmental pollution. The physicochemical characteristics of the Amazonian oils Attalea Maripa, Andiroba, Sejé, and Sacha Inchi are analyzed, along with their market availability, which allows for their transesterification to determine the most suitable for biodiesel synthesis.

Materials and methods

The applied methodology considers five stages: first, the theoretical characterization of the raw materials; second, their commercial availability in Colombia is considered; in the third phase, the fatty acid composition of the oils available in the market is determined by the method standardized by EN 14103 using a 6890N gas chromatograph with a 5973 mass selective detector from Agilent Technologies ® running the samples on a polyethylene glycol column with a length of 30 meters, internal diameter of 0.32 µm and film size of 0.25 µm, the temperature program used allowed the effective separation determining the FAMEs present and majority in the samples; fourthly, in order to obtain biodiesel, the transesterification of unrefined Sejé, Sacha Inchi and Andiroba oils is carried out using 96% purity reactive sodium hydroxide as a catalyst and analytical grade methanol, which allows to see that a previous esterification is required to reduce impurities, in addition to the refining process that includes three steps: degumming, neutralization and cleaning using phosphoric acid, distilled water, centrifugation and temperature, after which biofuel is obtained from Sacha inchi and Sejé oil; to finally compare their performance and FAMEs content by chromatography, which allows to select the most suitable oil for the production of biodiesel.

In the first phase, four Amazonian oils are identified in the literature that theoretically meet the fundamental characteristics to serve as raw material for the transesterification that allows the production of biodiesel. The characterization involves consulting and analyzing different parameters, obtained through physicochemical tests: a) Relative density of the oil, following the specifications of the CODEX Stan 33-1981 standard, which establishes a range of 0.910-0.916., b) Refractive index (RI) which is used to control purity and quality, both at the laboratory and industrial level; This index is related to the average degree of unsaturation and is also useful for monitoring the progress of reactions such as hydrogenation and isomerization (13), c) Acid number closely related to the quality of vegetable oils, the degree of refining and changes during storage (14), and d) Iodine number, which is a property directly related to unsaturation, refractive index and density (15).

The design of the experiment for obtaining biodiesel from commercially available oils is summarized in Table 1.

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Table 1. Experimental design for obtaining biodiesel

Oil type	**Andiroba**	**Sancha Inchi**	**Sejé**
Test 1	Transesterification of crude oil		
Refined	Degumming with phosphoric acid, water, centrifugation, and temperature		
	Neutralization to remove saponifiable substances		
	Washing with water and moisture removal		
Refined	With ion exchange resin		
Test 2	Transesterification of refined oil with sodium hydroxide, a high-purity analytical reagent, as a catalyst by raising the temperature to 60°C and increasing the stirring speed.		
Determination of metrics		Calculation of the percentage yield of biodiesel obtained from oil Determination of FAMEs by chromatography	

Results

Theoretical characteristics of the raw materials of oils

Andiroba, a tree of the mahogany family, has valuable properties, including antimalarial, antifungal, anti-inflammatory and repellent properties, and its high content of essential oils makes it popular in cosmetics (16). Andiroba oil meets acceptable quality standards and has a high repellent capacity against weevils (17). Triterpenes such as gedunin, as well as lipids, flavonones, flavonoids, triterpenes and coumarin are isolated from andiroba oil (18). In (19) they studied its characteristics that are presented in Table 2.

Attalea maripa, a palm of the genus Attalea, is a common plant in the Amazon, with around 40 species in the Aracaceae family. It is found in habitats from savannas to virgin forests. Its crown is formed by 10 to 22 leaves, with petioles up to 2 meters long and leaves up to 10 meters long. It produces ovoid fruits of 5 to 6 cm with a fibrous and leathery epicarp of orange-yellow color and slightly sweet flavor, and a thick and hard endocarp containing one to three seeds (20). The quality of the essential oil of Attalea maripa was analyzed by (21, 22). The ratio between the absorbances at 232 nm and 270 nm is greater than 8, results that agree with the values reported for olive and almond oil in reference pharmacopoeias (21). The characteristics of Attalea Maripa oil suggest its suitability for biodiesel synthesis, correlating with other virgin oils.

The Sacha Inchi plant has aroused interest due to its high content of essential fatty acids, especially linolenic acid (omega-3) and linoleic acid (omega-6), also oleic acid (omega-9), these are recognized for their health benefits, since they contribute to maintaining an adequate lipid balance and are associated with the reduction of the risk of cardiovascular diseases. Furthermore, Sacha

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Inchi is considered a sustainably cultivated plant, since it does not require large amounts of water or the use of pesticides and fertilizers. This makes it a promising option for obtaining essential oils with diverse applications, including biodiesel production. The physicochemical analysis performed by (7), summarized in Table 1, not only allows to determine its suitability for biodiesel production, but may also reveal other potential uses and applications, such as in the cosmetics and food industries. It was observed that the water content of the oil exceeds the maximum allowable limit according to the ASTM D6751:2002 standard, indicating the need for reprocessing to reduce this parameter. Another parameter analyzed is the saponification index, which reveals the unsaturations present in the oil's fatty acids. This indicates the presence of a higher amount of unsaturated fatty acids in the oil's triglycerides. The comprehensive use of this plant could contribute to its valorization and promote sustainable production practices.

Table 2. Physicochemical characteristics of the initial raw materials vs. Colombian palm oil

Oil	**Andiroba**	**Attalea**	**Sacha Inchi**	**Sejé**	**Palm**
Refractive Index	1,5	1,45 ± 0,002	1,48	1,46	1,4561
Relative Density	0,91	0,93 ± 0,011	0,92	0,9	0,9
Saponification Index	161,67	65,63 ± 2,83	185,2	193,55	189,3
Acidity Index	1,84	2,47 ± 0,002	0,11	0,58	-
Peroxide Index	-	16,50 ± 0,98	-	3.7	-
Iodine Index	48,41	18,29 ± 1,97	168,9	97,68	53
Solubility	Soluble in chloroform, immiscible in water	Soluble in petroleum ether, partially soluble in ethanol, and immiscible in water.	Partially soluble in water.	Partially soluble in water and methanol.	Insoluble in water, soluble in ethanol, ether, chloroform, and carbon disulfide.
Organoleptic Characteristics	Viscous liquid, light yellow transparent	Viscous liquid, translucent white when solidified	Viscous liquid, pale yellow	Viscous liquid, yellow	Semi-solid at room temperature, reddish yellow
% Unsaturation	70,45	-	91.6	82	53
UV Spectrum	-	0.2 a 270nm	365 nm	-	-
Absorbance Ratio	-	>8 a 232nm y 270nm	-	-	-

Note: Authors from: Andiroba: (19); Attalea: (20, 21); Sacha Inchi: (7); Sejé: (24); Palma (25).

Sejé is a palm tree that can grow to between 12 and 15 meters in height, with a simple stem that has a diameter of 15 to 25 cm, its leaves are arranged in a spiral and produces fruits throughout the year of violet or black color, it is considered a source of protein, in addition to having acceptable amounts of lipids and vitamins. The average oil content in Sejé is approximately 7.4%, being

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comparable in quality with olive oil, to extract the oil, it is necessary to use the mesocarp and pericarp of the fruit (22). In studies conducted by (23, 24) physicochemical characteristics of Sejé oil have been determined. In Sejé oil oleic acid is predominant. Oleic acid molecules are linked in the form of triolein in 45% (22). Sejé oil shows potential as a raw material for the synthesis of biodiesel, which could benefit from an ecological and energy perspective.

Comparative analysis allows examining the characteristics of the oils from the four raw materials studied theoretically. Observing the characteristics presented in Table 2 some similarities can be identified, in the case of the refractive index, the minimum value is found in Attalea oil (1.45) and the maximum in andiroba oil (1.50) with values close to palm oil, the relative densities are also very close with an average of 0.91 very close to the density of palm oil, acidity indices show comparable values between andiroba - Atalea and Sacha inchi - Sejé. A significant variation is observed in the saponification and iodine indices, Attalea oil has the lowest saponification index and the high value of Sacha Inchi in the iodine index stands out, which triples that of palm oil. The lowest percentage of unsaturation is presented by palm oil. These results indicate that, although the oils have similar characteristics in certain aspects, there are differences in saponification and iodine values. These variations may be relevant when considering their use in biodiesel production.

Commercial availability of oils

Obtaining the oils from andiroba, Sacha Inchi, and Sejé was feasible. However, obtaining Attalea Maripa oil was hampered by its limited commercial availability due to deforestation and climate change. This impacts production, preventing thorough characterization and chromatographic analysis to assess its potential.

Fatty acid composition of oils

The composition of FAMEs is crucial for biodiesel quality: saturated fatty acids offer greater stability. Fatty acid evaluation is crucial for determining the use of oils obtained from various raw materials; gas chromatography identifies fatty acid esters, determining their predominance and quantity. The oil must have a low free fatty acid content, since contamination by the catalyst can occur during catalysis (26). Therefore, this parameter must be carefully controlled.

Gas chromatography, following EN 14103, separates esters according to their chain length and the number of double bonds, indicating the purity of the biodiesel. Quality biodiesel must have at least 96.5% w/w methyl esters when pure (27). A low methyl ester content may indicate unfavorable reactions or the presence of contaminants such as alcohol, glycerides, glycerol, metals, and other components.

Linoleic acid, essential for health and disease prevention, must be obtained from plant sources since mammals cannot synthesize it (28).

Palmitic acid, a 16-carbon saturated fatty acid, is common in the human diet and contributes to the oxidative stability of biodiesel, although it may affect its low-temperature properties (29).

Chromatographic analysis (Figure 1) of andiroba, sacha inchi, and sejé oils were performed to identify the FAMEs present. Figure 1a shows the chromatogram of andiroba oil, which reveals three

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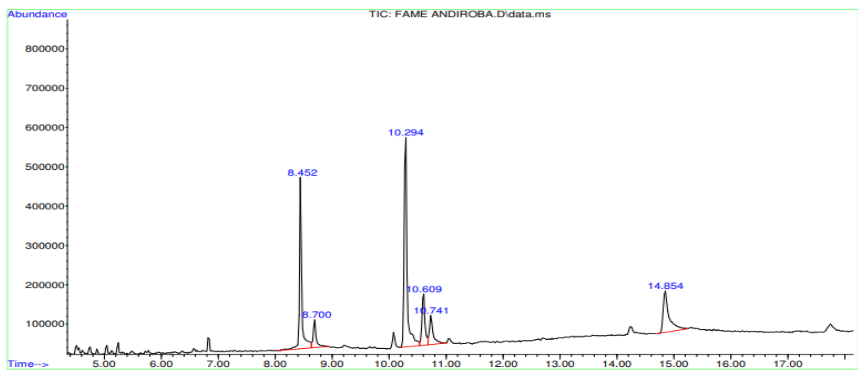
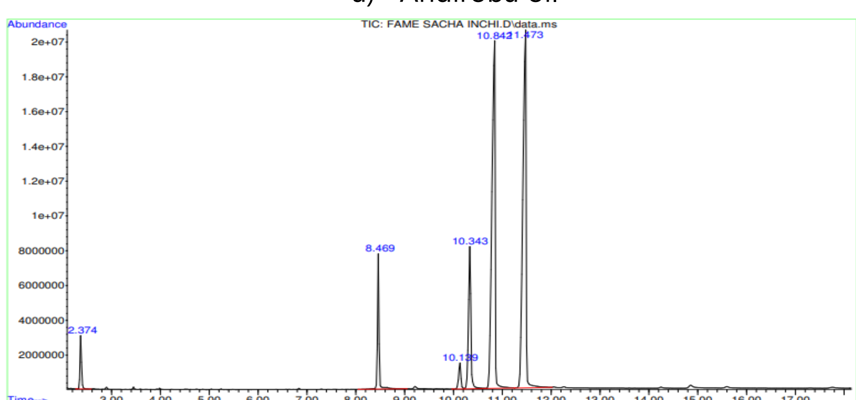
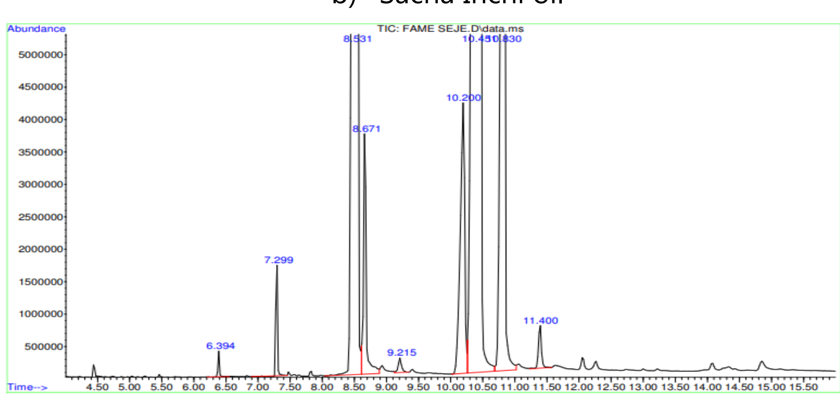
main fatty acids: oleic acid is the most abundant, constituting 45.62% of the identified FAMEs, followed by palmitic acid with 12.14%, and linoleic acid with 11.52%. Figure 1b presents the analysis of Sacha Inchi oil, where the presence of 4 acids can be identified: the majority linolenic acid with a value of 58.17%, linoleic acid with 15.4%, and palmitic and oleic acids with 10.25%. The acids present in the oil and in the biodiesel show similarities in palmitic, oleic, stearic, and linoleic acids. This finding suggests that oil has potential as a raw material for biodiesel production, supporting its viability and promoting a sustainable option in the energy sector. Figure 1c presents the gas chromatography of Sejé oil with 8 FAMEs: oleic acid predominated with 72.15%, followed by palmitic (11.45%) and stearic acids (6.80%); other acids were detected in smaller proportions that are consistent with each other. Sejé stands out as a raw material for biodiesel due to its abundant fatty acid content, satisfying the growing demand for sustainable energy sources. This composition facilitates the transesterification process, which is crucial in the conversion to biodiesel.



a) Andiroba oil



b) Sacha Inchi oil



c) Sejé oil

Figure 1. Chromatograms of FAME analysis by GCMS

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Transesterification process of oils

Equivalent conditions were determined for conducting the transesterification reaction using a homogeneous catalyst. The first test was performed without cleaning the oil. Under these analytical conditions, none of the oils reacted; neither glycerin nor biodiesel was formed. This can be attributed to the presence of moisture in the oil and the lack of refining. The oils used were crude, so direct reaction is not possible, and cleaning is necessary to remove moisture, impurities, mucilage, proteins, and free fatty acids. If hydroxide is added to the crude oil during the transesterification process, a soap will form, inhibiting the reaction. Therefore, this soap is generated during refining to remove these impurities. Figure 2 shows the crude oils subjected to the transesterification reaction. Of the three, only the Sacha Inchi oil is liquid; the other two are solid at room temperature.

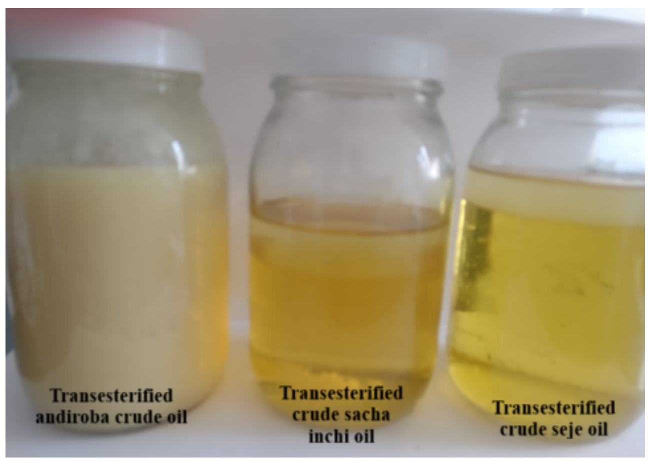

Figure 2. Transesterification results of crude oils.

In the upper part of the image in Figure 2, methanol is observed, which is not present in the case of andiroba oil; therefore, the catalyst is changed to a high-purity one (analytical reagent sodium hydroxide) to test its effectiveness.

For refining, the three oils underwent a degumming process to remove soluble material. This involved using phosphoric acid, distilled water, centrifugation, and heat. The mixture was then neutralized to eliminate saponifiable substances, ensuring high triglyceride purity and allowing the transesterification reaction to proceed smoothly. Finally, the oil was washed to remove moisture, making it ready for biodiesel synthesis.

Figure 3 shows andiroba oil after the refining process. The top layer displays liquid oil at room temperature, the middle layer soap, and the bottom layer water from washing. After refining, oil loss can be high. Therefore, to eliminate these byproducts that hinder the reaction, a saponification process was carried out using an ion-exchange resin to reduce the loss. During esterification, after two hours, a methanol phase and another phase formed. The methanol was removed, and the remaining oil was transesterified without the formation of biodiesel. In this respect, esterification

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with the ion-exchange resin does not improve the process, and the andiroba oil does not yield satisfactory results. There is no reaction, and therefore no biodiesel production, from the oil after the cleaning process. Adding a sodium hydroxide solution results in complete saponification, with the formation of clumps and emulsion.

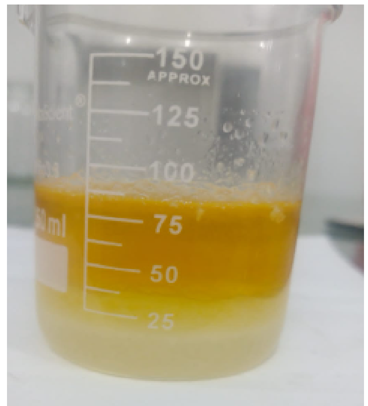

Figure 3. Andiroba oil in the refining process

Andiroba oil undergoes a refining process. As shown in Figure 3, the upper portion represents the refined oil, which is liquid at room temperature at the end of the process. The middle portion is a soap formed by the presence of free fatty acids, which inhibit transesterification. The lower portion is the water from washing. Oil loss can be significant after refining. Therefore, to eliminate these byproducts that hinder the normal reaction, a saponification process was carried out using an ion-exchange resin to minimize oil loss. During esterification with the ion-exchange resin, after two hours, a methanol phase and another phase formed. The methanol was removed, and this oil was then transesterified, yielding the same results but without the formation of biodiesel. In this regard, esterification with ion-exchange resin does not improve the process; andiroba yields unsatisfactory results, with no reaction and therefore no biodiesel production. In the case of andiroba oil, a cleaning process is performed, sodium hydroxide solution is added, and complete saponification occurs, resulting in the formation of lumps and an emulsion; therefore, refining is unsuccessful.

The transesterification process is carried out with Sacha Inchi oil, by changing the catalyst, raising the temperature to 60°C and increasing the stirring speed, which allowed the reaction to be effective in obtaining biodiesel.

The transesterification of Sejé oil was carried out, replicating the transesterification process of refined Sacha Inchi oil. At the end of the reaction, a dark-colored biodiesel was obtained, and the glycerin appeared opaque, indicating that the oil should be degummed. It is also possible to produce the biodiesel and then filter it for purification and refining. The separation of methyl esters and glycerin was observed, and the reaction yielded over 90%, a highly productive value in biodiesel synthesis. The coloration did not affect the reaction, indicating that the percentage of free fatty acids was low and therefore saponification was not achieved. These results suggest that a final purification process to remove the color is possible.

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The biodiesel obtained from Sacha Inchi oil is the result of successful transesterification, but it has a low yield due to high precipitation during washing, resulting in a biodiesel yield of only 25%. Figure 4 shows the biodiesel produced from Sacha Inchi oil in the foreground, with a yellow color, while the biodiesel produced from Sejé oil in the background has a reddish color.

Figure 4. Biodiesel obtained from Sacha Inchi (front) and Sejé (rear) oils

The Sacha Inchi oil (Figure 5a) has a golden-yellow color. The entire transesterification process was successful, but the results show a low yield. During washing, precipitation occurred, resulting in a biodiesel yield of only 25%. The Sejé oil (Figure 5b) was purified. To remove the color, it must be processed with bleaching agents; however, this does not affect the characteristics of the Sejé biodiesel.

(a) Sacha Inchi oil product (b) Sejé oil product

Figure 5. Filtered biodiesel

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Fatty acid composition of biofuels

The determination of FAMEs presents in biodiesel obtained from Sejé and Sacha Inchi oils was performed using gas chromatography. For the determination, the sample was pretreated with methanolic potassium hydroxide. Using hexane, the separation of two phases was observed, from which the organic phase was extracted for analysis. A blank was run, followed by a FAME standard. Subsequently, the biodiesel samples from Sejé and Sacha Inchi oils were injected, with a blank run between each sample.

The chromatogram (Figure 6a) shows four distinct peaks, two of which (the first and third) correspond to the most abundant. Each peak was integrated using a ChemStation integrator (Agilent), and subsequently, the mass spectra of each peak was extracted and compared with the NIST library. Figures 6b, 6c, and 6d present the mass spectra of the most representative fatty acids found in the Sejé sample. Three fatty acid methyl esters were observed, a reduction compared to the eight identified in the virgin oil. The most abundant were palmitic acid at a concentration of 7.35%, oleic acid at 50.14%, and myristic acid at less than 5%.

In the case of Sacha Inchi, Figure 7a shows the chromatogram obtained from the biodiesel sample. This shows two characteristic and well-defined peaks, corresponding to the most representative fatty acid methyl esters. Each peak was integrated using a ChemStation integrator (Agilent), and subsequently, the spectrum was extracted from each peak, with the corresponding mass values being compared to the NIST library. Figures 7b, 7c, and 7d present the mass spectra of the most representative acids found in the biodiesel sample obtained from Sacha Inchi. For the biofuel obtained from Sacha Inchi, three fatty acid methyl esters are observed, a reduction compared to the initial acids in the virgin oil. However, the most representative is linoleic acid, with a concentration of 45.32%. oleic acid with a concentration of 38.14% and palmitic acid with a concentration of less than 7%.

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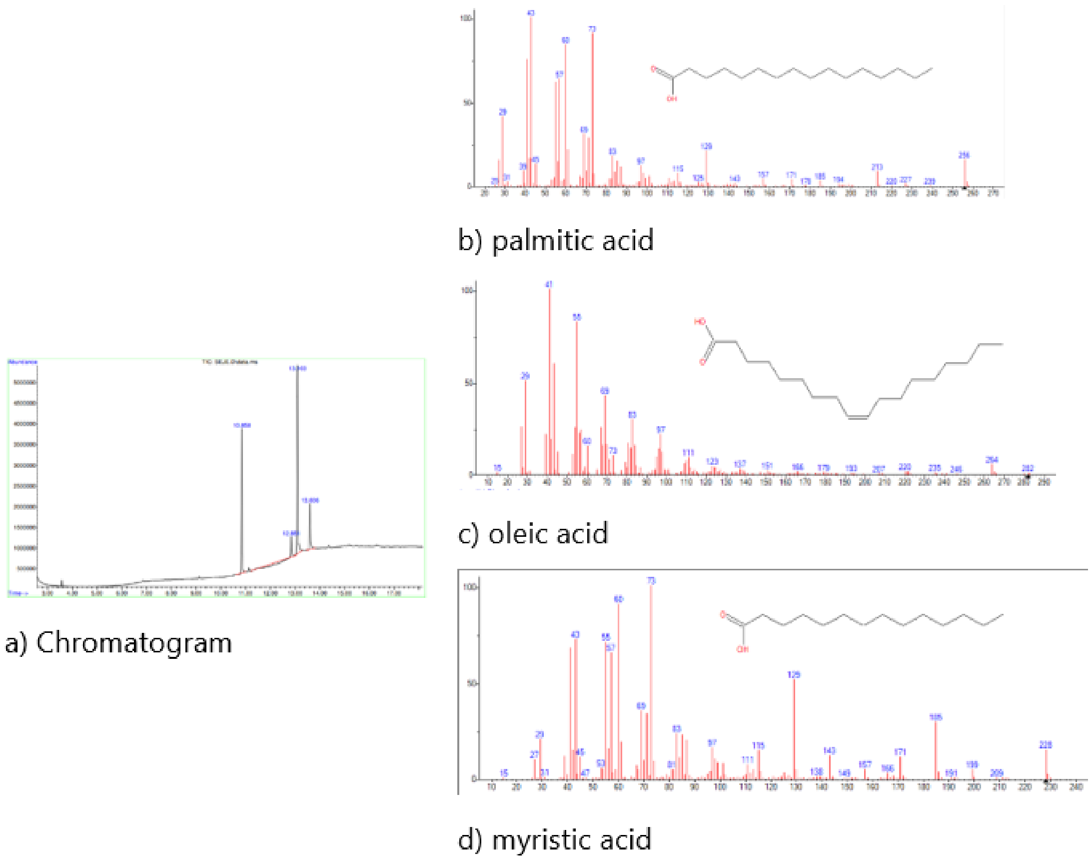

Figure 6. Chromatogram and mass spectrum of the most representative acids of the Biodiesel obtained from Sejé oil.

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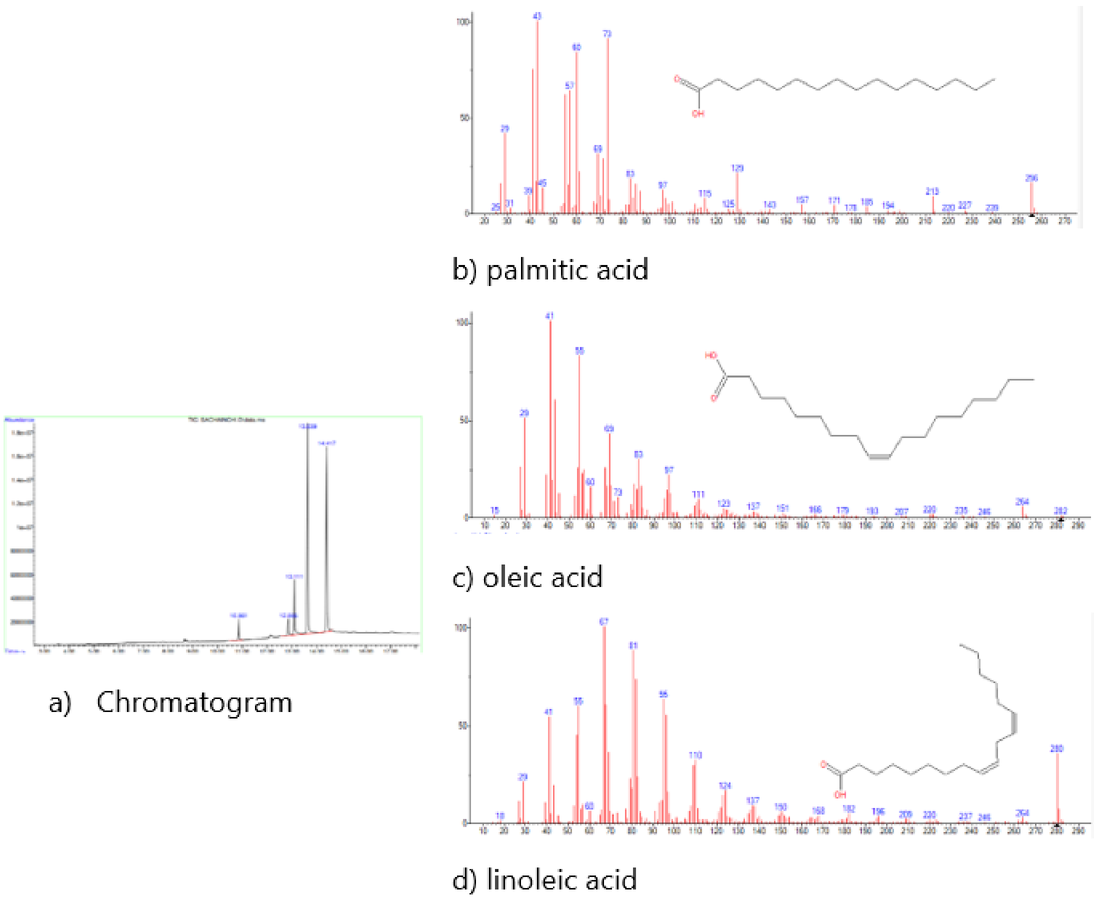

Figura 7. Chromatogram and mass spectrum of the most representative acids of the biodiesel obtained from Sacha inchi oil.

Discusion

The first raw material analyzed is andiroba, which contains oleic, palmitic, and linoleic acids, with an unsaturated fatty acid percentage of 69.28%. The second raw material is sacha inchi, which contains palmitic, oleic, stearic, and linoleic acids, with an unsaturated fatty acid percentage of 83.82%. Finally, the oil extracted from sejé contains oleic, palmitic, stearic, caprylic, lauric, myristic, and linoleic acids, with an unsaturated fatty acid percentage of 90.40%. It is important to note that some variations in the fatty acids present may be related to the natural and geographical conditions of origin of the oils, as indicated by other studies (30-32).

Chromatographic analysis allowed us to determine not only the unsaturated fatty acids present in the samples analyzed but also the proportion of each. It was observed that the Sejé sample showed a high proportion of eight different fatty acids, with oleic and palmitic acids being the most characteristic. In contrast, the Sacha Inchi and Andiroba samples had a lower acid content, but their proportions were adequate for biodiesel synthesis. Research has been conducted to determine the effect of fatty acid esters (FAEs) on the resulting biodiesel, influencing its quality and

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performance. During transesterification (one of the main processes in the transformation of oil to biodiesel), it has been observed that the fatty acid composition is not affected (33). These esters, which react with alcohol, will have the same FAME profile as the original vegetable oil (34).

It is important to note that biodiesels that comply with established standards and regulations, such as ASTM D6751, EN 14214:2013, and NTC 1438:2013, are suitable for use in diesel engines without affecting their operation. Table 3 summarized the main content of these standards. NTC 5444:2020, the Colombian standard for diesel engine fuels, includes related definitions.

Table 3. Comparative table of the main regulations related to biofuels

Standard	**ASTM D 6751**	**EN 14214:2013**	**NTC 5444:2020**
Contents	Specification for biodiesel (B100) as a fuel or for blending up to a certain level.	European standard for fatty acid methyl esters for use in diesel engines at 100% (B100) or as a component of blends.	Specifications for biodiesel for use in diesel engines (B100) in Colombia.
Origin	United States	Europe	Colombia
Kinematic viscosity at 40°C	1,9-6,0 mm²/s	3,5-5,0 mm²/s	1,9-6,0 mm²/s
Flash point	≥ 93 °C	> 120 °C	≥ 120 °C
Sulfate ash	≤ 0,020% mass	≤ 0,020% mass	≤ 0,020% mass
Water and sediment	≤ 0,050 % vol	-	-
Methanol or ethanol content	≤ 0,20 % mass	≤ 0,2 % mass	≤ 0,2 % mass
Cethane number	≥ 47	≥ 51	≥ 47
Methyl ester content	-	≥ 96,5 % m/m	≥ 96,5 % m/m
Density at 15°C	-	860-900 kg/m³	860-900 kg/m³
Sulfur content	S15: ≤ 15 mg/kg S500: ≤ 500 mg/kg	≤ 10 mg/kg	≤ 10 mg/kg
Iodine value	-	< 120 g I_2/100 g	< 120 g I_2/100 g
Water content	≤ 500 mg/kg	≤ 500 mg/kg	≤ 500 mg/kg
Total contamination	-	≤ 24 mg/kg	≤ 24 mg/kg
Oxidation stability	≥ 3 hours	≥ 6 hours	≥ 6 hours
Free glycerin	≤ 0,020 % mass	≤ 0,020 % mass	≤ 0,020 % mass
Total glycerin	≤ 0,240 % mass	≤ 0,250 % mass	≤ 0,240 % mass
Phosphorus	≤ 1,0 mg/kg	≤ 4,0 mg/kg	≤ 4,0 mg/kg

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The European standard is stricter in some parameters (cetane number and viscosity) compared to the United States standard; however, the latter has more specific parameters for glycerin, phosphorus, etc., making it comprehensive for B100. In most cases, the Colombian standard adopts the criteria of the European standard but maintains the viscosity and cetane number of the United States standard and is slightly more flexible than both standards regarding the percentage of total glycerin.

Biodiesels with low oxidation stability and low-temperature properties may require the use of additives to improve their performance and ensure efficient combustion. Furthermore, the linolenic acid content in biodiesel must be controlled, as an excess can cause oxidative stability problems and engine deposits, as is the case with biofuel derived from Sacha Inchi. In general, it is necessary to comply with the limits established in Table 3 to guarantee optimal performance and avoid the need for frequent maintenance.

Conclusions

The theoretical study of Sejé, andiroba, and Sacha Inchi oils reveals their potential as raw materials for biodiesel production, exhibiting similar properties in refractive index, relative density, and fatty acid content. These findings suggest they are viable options for biodiesel synthesis. However, significant variations in saponification and iodine values have been observed among the different oils studied. This suggests that these differences should be considered when selecting the appropriate oil for biodiesel production, as these parameters can affect the quality and properties of the resulting fuel.

The composition of Sejé oil features an abundant quantity of fatty acids, making it the best oil studied for use as a raw material in biodiesel production. This distinctive quality not only highlights its potential but also addresses the growing demand for sustainable energy and fuel sources. The significant presence of these fatty acids also facilitates the transesterification process in the conversion of the oil into biodiesel, as demonstrated in the tests.

Additionally, after experimentation, it was not possible to obtain biofuel from andiroba oil; the transesterification of Sacha Inchi oil shows a yield of only 25%, while that of Sejé oil is 90%, which confirms it as the best option to obtain a high-quality biodiesel, with properties suitable for use in diesel engines and thus contribute to the search for cleaner and more sustainable alternative fuels.

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References

1. Wan Osman WNA, Hakimi Rosli M, Athirah Mazli WN, Samsuri S. Comparative review of biodiesel production and purification. Carbon Capture Science & Technology. 2024; 13:100264. doi: https://doi.org/10.1016/j.ccst.2024.100264

2. Guerra Sánchez M, Assaf Montaño JC, Ascanio Mantilla NJ. Implementación de energías renovables como garantía al derecho fundamental a un ambiente sano en Colombia. Rev CES Derecho. 2021;12(2):87-106. doi: https://doi.org/10.21615/cesder.6163

3. Colmenares-Quintero RF, Rico-Cruz CJ, Stansfield KE, Colmenares-Quintero JC. Assessment of biofuels production in Colombia. Cogent Eng. 2020;7(1):1740041. doi: https://doi.org/10.1080/23311916.2020.1740041

4. Chidambaram PK, Lokhande DA, Ramachandran DM, Saravanan V, Prasanth V. A Review on Biodiesel Properties and Fatty acid composites. REST J Emerg Trends Modelling Manufact. 2021;7(3):87-93. https://doi.org/10.46632/7/3/4

5. Vega LP, Bautista KT, Campos H, Daza S, Vargas G. Biofuel production in Latin America: A review for Argentina, Brazil, Mexico, Chile, Costa Rica and Colombia. Energy Rep. 2024;11:28-38. doi: 10.1016/j.egyr.2023.10.060. https://doi.org/10.1016/j.egyr.2023.10.060

6. Fedebiocombustibles. Federación Nacional de Biocombustibles de Colombia. Boletín informativo. 2023 Ene;(165). Disponible en: https://www.fedebiocombustibles.com/

7. Basto-Florez LE, Millán-Alvarado SA, Medina-Caballero LF, Mora-Vergara LZ, Caballero-Hernández YT. Estudio del biodiesel obtenido a partir de aceite de Sacha inchi (Plukenetia volubilis Linneo). Biotec Sect Agropecu Agroind. 2022;20(1):41-53. doi: https://doi.org/10.18684/rbsaa.v20.n1.2022.1585

8. Chávez Parra EG. Huertos agroecológicos en fincas campesinas que trabajan con el Frente de Defensa de la Amazonía-FDA del cantón Lago Agrio y su contribución a la soberanía alimentaria de las familias [tesis maestría]. Quito, EC: Universidad Andina Simón Bolívar, Sede Ecuador; 2024. https://repositorio.uasb.edu.ec/bitstream/10644/9803/1/T4294-MEPAD-Chavez-Huertos.pdf

9. Cañón Gaitán C. Análisis de nuevas tecnologías para la producción de biodiesel con fluidos supercríticos [tesis maestría]. Universidad Nacional de Colombia; 2021. https://bffrepositorio.unal.edu.co/server/api/core/bitstreams/e380a21c-979c-44b2-8c2e-06b241ac6e07/content

10. Acevedo ELB, Jurado JMV, Lombana J. Alternativas productivas para la industria de biodiésel en Colombia. Cuad Lat Adm. 2017;13(24):135-48. doi: https://doi.org/10.18270/cuaderlam.v13i24.2159

11. Hernández NS, Galvan A. Eficiencia y emisiones del motor de combustión interna de encendido por compresión impulsado por aceites vegetales. ENERLAC Rev Energ Latinoam Caribe. 2024;8(1). Disponible en: https://enerlac.olade.org/index.php/ENERLAC/article/view/275

12. Pérez-Bravo SG, Aguilera-Vázquez L, Castañeda-Chávez MDR, Gallardo-Rivas NV. Condiciones del proceso de transesterificación en la producción de biodiésel y sus distintos mecanismos de reacción. TIP Rev Esp Ci Quím Biol. 2022;25:e481. doi: https://doi.org/10.22201/fesz.23958723e.2022.481

13. Alviso D, Romano SD. Prediction of the refractive index and speed of sound of biodiesel from its composition and molecular structure. Fuel. 2021;304:120606. doi: https://doi.org/10.1016/j.fuel.2021.120606

14. Lourenço VA, Nadaleti WC, Vieira BM, Li H. Investigation of ethyl biodiesel via transesterification of rice bran oil: bioenergy from residual biomass in Pelotas, Rio Grande do Sul-Brazil. Renew Sust Energ Rev. 2021;144:111016. doi: https://doi.org/10.1016/j.rser.2021.111016

15. Huang Y, Li F, Bao G, Xiao Q, Wang H. Modeling the effects of biodiesel chemical composition on iodine value using novel machine learning algorithm. Fuel. 2022;316:123348. doi: https://doi.org/10.1016/j.fuel.2022.123348

16. Ferreira MR, Santiago RR, de Souza TP, Egito ES, Oliveira EE, Soares LA. Development and evaluation of emulsions from Carapa guianensis (Andiroba) oil. AAPS PharmSciTech. 2010;11:1383-90. doi:https://doi.org/10.1208/s12249-010-9491-z

17. De Brito Leal A, Dos Santos Hackbart HC, Macueia FBED, Rombaldi CV. Andiroba oil (Carapa guianensis): Descriptive analysis and applicability. Ind Crops Prod. 2023;202:117004. doi: https://doi.org/10.1016/j.indcrop.2023.117004

18. Farfán F. Árboles con potencial para ser incorporados en sistemas agroforestales con café. Chinchiná (Colombia): Cenicafé - Fondo Nacional del Café; 2012. https://www.sidalc.net/search/Record/oai:publicaciones.cenicafe.org:article-3242/Description

19. Da Silva EF, Montero IF, Melo Filho AA, Santos RC, Ribeiro PRE, Sangama DM, et al. Propiedades Físico-químicas por RMN de 1H y Constituyentes en el Aceite de Carapa guianensis por ESI-MS. Orbital Electron J Chem. 2014;6(4):246-54. http://hdl.handle.net/10662/25938

20. Salazar de Marcano E, Douglas B, Marín G, Moreno H. Cinética de deterioro del aceite de la semilla de la palma coroba (Attalea maripa). SABER Rev Multidiscip Cienc Univ Oriente. 2007;19(2):172-82.

21. D'oca MG, Morón-Villarreyes JA, Lemões JS, Costa CS. Fatty acids composition in seeds of the South American glasswort Sarcocornia ambigua. An Acad Bras Ciênc. 2012;84:865-70. doi: https://doi.org/10.1590/S0001-37652012005000044

22. Ocampo-Duran Á, Fernández-Lavado AP, Castro-Lima F. Aceite de la palma de seje Oenocarpus bataua Mart. por su calidad nutricional puede contribuir a la conservación y uso sostenible de los

doi: 10.25100/iyc.v27i3.15195

bosques de galería en la Orinoquia Colombiana. Orinoquia. 2013;17(2):215-29. https://doi.org/10.22579/20112629.20

23. Pérez Muñoz N, Uribe Morón J. Determinación de las condiciones óptimas para la producción de biodiesel a partir de aceite de Higuerilla (Ricinus Communis) y aceite de Palma Mil Pesos (Oenocarpus Bataua) [tesis pregrado]. Ingeniería de Procesos; 2008.

24. Chaves-Yela JA, Ortiz-Tobar DP, Bahos-Ordoñez EM, Ordoñez-Forero GA, Villota-Padilla DC. Análisis del perfil de ácidos grasos y propiedades fisicoquímicas del aceite de palma de mil pesos (Oenocarpus Bataua). Perspect Nutr Hum. 2020;22(2):175-88. doi: https://doi.org/10.17533/udea.penh.v22n2a05

25. DelgadoW, Echeverry LF, Suárez SR. Caracterización fisicoquímica del aceite de palma crudo proveniente de diferentes materiales genéticos y de dos zonas geográficas de Colombia. Palmas. 2024;25(Especial-Tomo II):74-83. https://publicaciones.fedepalma.org/index.php/palmas/article/view/1068

26. Vilas Bôas RN, Mendes MF. A review of biodiesel production from non-edible raw materials using the transesterification process with a focus on influence of feedstock composition and free fatty acids. J Chil Chem Soc. 2022;67(1):5433-44. doi: https://doi.org/10.4067/S0717-97072022000105433

27. Delgado EEG, Nabarlatz DA, Vargas FAA. Obtención de biodiésel por transesterificación in situ a partir de semillas de Jatropha curcas L. Rev UIS Ingenierías. 2022;21(2):21-38. doi: https://doi.org/10.18273/revuin.v21n2-2022003

28. Puchades Murgadas A. Efecto y consecuencias del cambio climático en el contenido de omega 3 en el pescado. Análisis de la viabilidad de otras fuentes de omega 3 para la nutrición humana [tesis doctoral]. Universitat Politècnica de València; 2021. https://riunet.upv.es/entities/publication/6a920c85-15f2-4b38-b7ca-c23eebf5eeb2

29. Rozo JRV, Ávila JMR, Valencia JLR. Influencia de los ácidos grasos de aceites animales de cerdo y pollo en la producción de biodiésel. Rev Ambient Agua Aire Suelo. 2023;14(2):1-8. doi: https://doi.org/10.24054/raaas.v14i2.2785

30. Pereira E, Ferreira MC, Sampaio KA, Grimaldi R, de Almeida Meirelles AJ, Maximo GJ. Physical properties of Amazonian fats and oils and their blends. Food Chem. 2019;278:208-15. doi: https://doi.org/10.1016/j.foodchem.2018.11.016

31. Darnet SH, Da Silva LH, Rodrigues AM, Lins RT. Nutritional composition, fatty acid, and tocopherol contents of buriti (Mauritia exuosa) and patawa (Oenocarpus bataua) fruit pulp from the Amazon region. Ciênc Tecnol Aliment. 2011;31(2):488-91. doi: https://doi.org/10.1590/S0101-20612011000200032

32. Rendón WJ, Chavez G, Torrico D. Evaluación química del aceite de oenocarpus bataua “aceite de majo”. Rev Boliv Quím. 2013;30(1):70-3.

33. Ramos MJ, Fernández CM, Casas A, Rodríguez L, Pérez Á. Influence of fatty acid composition of raw materials on biodiesel properties. Bioresour Technol. 2009;100(1):261-8. doi: https://doi.org/10.1016/j.biortech.2008.06.039

34. Knothe G. Some aspects of biodiesel oxidative stability. Fuel Process Technol. 2007;88(7):669-77. doi: https://doi.org/10.1016/j.fuproc.2007.01.005

doi: 10.25100/iyc.v27i3.15195