



Article Production of Coconut Oil Bioturbosine without Water by Using Ultrasound as a Source of Energy and Ion Exchange for Its Purification

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Highlights:

What are the main findings?

- The removal of caustic impurities by means of an ion exchange resin can be attractive as it does not use water as a rinse in the final bioturbosine washes.
- Ultrasonic radiation used as an energy source in the transesterification reaction can help to reduce production times;

What is the implication of the main finding?

Bio-jet fuel from biomass can replace a portion of jet fuel;

Abstract: Jet fuel production is a key element in the aviation industry's strategy to reduce operating costs and environmental impacts. Alternatives are required, and bioturbosine obtained from biomass can replace significant amounts of jet fuel. In this investigation, the properties of the production of bioturbosine from coconut oil and mixtures of B5, B10, B20, B1OO, bottom, and jet fuel were measured according to the ASTM standards. A transesterification reaction between coconut oil and methanol was carried out using ultrasound, resulting in 99.93% conversion of triglycerides into bioturbosine at room temperature for 10 min, with a 6:1 molar ratio of methanol and oil. The catalyst concentration was 1.0 g/100 g of oil, and purification was carried out without water using an ion-exchange resin to remove impurities. The results obtained for density and viscosity were within the regulations. The temperature of the clogging point for a cold filter in the mixtures was up to -30 °C. The average caloric values of mixtures B5, B10, and B20 were 45,042, 44,546, and 43,611 MJ/Kg, respectively. In a copper corrosion test, the result for all samples was class 1A. It is expected that the results of this research may influence the use of bioturbosine in the aviation industry.

Keywords: jet fuel; bio jet; ASTM; mixtures; ultrasound; caloric power

1. Introduction

Bioturbosine is an alternative sustainable fuel for aviation that can be produced from biomass (organic matter of plant or animal origin, organic waste and residues), which can be used for energy purposes. Biofuels are mainly generated from jatropha seeds,



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Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). microalgae, palm oil, fig oil, and others, but production is lower when based on coconut oil. The energy applications of biofuels are equivalent to those of fossil fuels. That is to say, they can be used to generate electricity, to generate heat, or to generate movement, among others, in domestic, industrial, or transport areas, with their main application in air transport [1].

The Boeing and Airbus companies, together with the International Air Transport Association (IATA), have decided to contribute to the reduction in greenhouse gas emissions and ensure the availability of affordable fuel by gradually incorporating a fraction of bioturbosine into jet fuel [1]. In Mexico, the "Flight Plan for Sustainable Biofuels" is intended to reduce greenhouse gas emissions by more than 50% and, through technological advances, to reduce the cost of bioturbosine [1].

Due to the increasing volume of air transport, the demand for jet fuel has grown significantly in the last decade. Hydrocarbon processing companies and different research groups have begun to investigate possible production routes for kerosene fractions suitable for producing jet fuel not only from crude oil, but also from alternative sources. The International Aviation Carbon Offsetting and Reduction Program will be launched in the near future, with the goal of significantly reducing carbon dioxide emissions from aviation. This carbon dioxide reduction can only be achieved when using jet fuels derived from alternative sources [1].

According to the International Air Transport Association (IATA), the demand for air transport continues to grow, with a projected total of 7 billion passengers by 2030, which represents an average annual growth of 3.8% compared to the base year, 2014. In 2015, more than 2000 flights from 22 airlines used biofuel for jets, but the prices remain higher than those of conventional fuels, thus limiting their commercial diffusion [2,3].

Since 2015, bioturbosine has been added to jet fuel at a concentration of 1% (bioturbosine is combined with fossil fuel); in 2017, it reached 10%, and it is expected to reach at least 50% by 2050. In Mexico, a sale of around 700 million liters was estimated for 2020 [4,5].

Bioturbosine use has intensified since 2011, when ASTM International approved blending up to 50% bioturbosine in commercial and military aircraft engines. However, production demands land and resources that compete with those used for the generation of food, which has caused a shortage of biofuels worldwide [6,7].

By 2025, the vast majority of countries must comply with European Union (EU) regulations, which require the blending of biofuels into jet fuel, or they will pay significant fines and face exclusion from routes if they are unable to supply the biofuels. This represents a worrying situation due to the low supply in the world market [6,7], For this reason, many companies in search of raw materials for the production of bioturbosine have become interested in Mexico. Mexico has an extensive territory, favorable climate, and other elements that make it ideal for the production of raw materials and technology for the development of biofuels [8]. Although there are several crops used for producing oil in Mexico, only jatropha and castor beans are being worked on, and recently, microalgae have gained special attention [9].

Mexico is a diverse country with the capacity to offer a large quantity of raw materials and oils for the production of biofuels. Among them, *Jatropha curcas* L., or the Mexican pine nut, which is native to Mesoamerica, presents a wide genetic variability in Mexico. It is a plant with a high oil content in its seeds (26.4% to 56.9% in laboratory tests). Higuerilla (*Ricinus communis* L.) is adaptable to various climates in the Mexican territory, although it has not been cultivated in large areas. Although Malaysia produces 50% of the world's African palm, its production has intensified in American countries due to climatic requirements. Agave is adaptable to lands that are not suitable for cultivation; its production is estimated to be 40 to 100 tons of dry matter per hectare per year, and it has low input requirements [8]. Microalgae are an important source of non-edible oil, and Mexico is well-suited for their production. Used edible fats, tallows, and oils have been developed on a large scale in European countries and in Brazil. Production costs are reflected in the oil-recycling process. There are several ways to produce bioturbosine. Among the most commonly used are hydrotreatment, pyrolysis, hydrolysis, hydrothermal methods, gasification and the Fischer–Tropsch method, fermentation, and oligomerization [7]. For the production of bioturbosine at a commercial level, the ASTM has certified only two processes: the hydroprocessing of triglycerides combined with the Fischer–Tropsch method and the thermochemical conversion of biomass through gasification [9]. A disadvantage of these processes is that most require large amounts of water. For example, corn stover processing using gasification and the Fischer–Tropsch method requires 17.09 MT of water per hour for each ton of biomass processed [4].

Today, efforts are being made to use coconut oil in the production of bioturbosine, since it has been reported that coconut oil is produced at a rate of 2689 L/ha/year. They contain an oil content of 63–65%. Crude coconut oil has a heating value of 37 MJ/kg and a density of 0.9089 g/mL [4].

Hydroprocessing is the most widely used technique for processing oils into jet fuel, and with coconut oil, a specific energy of 44.2 MJ/kg of alternative jet fuel has been recorded; this is greater than that of Jet A1 fuel, which has a specific energy of 43.2 MJ/kg [10]. In addition, with the cracking and isomerization/hydroisomerization of coconut oil, conversion yields of up to 77.6% have been achieved [11].

A disadvantage of cracking in hydroprocessing is that it maximizes the production of polluting gases. An alternative to this problem is the use of 5–10% bioparaffin blends with commercial Jet A1 fuel to drive gas-turbine aviation engines without redesigning the fuel system or fuel supply infrastructure [12]. Hydrocarbons for jet fuel have been obtained from biokerosene derived from coconut oil soap without using hydrogen or metal catalysts; however, this does not comply with ASTM standard D1655 [13], and it is necessary to mix it at concentrations of up to 10% with Jet A1 fuel to meet the standard requirements [14]. Other recent techniques have used microwaves to produce bioturbosine from coconut oil, and yields of up to 70.86% have been obtained in 15 min [15]; likewise, through transesterification and the microwave process, a yield of up to 74.45% was reached [16].

Other methods included an ultrasonic pretreatment process to improve the physicochemical properties of biomass with the aim of improving bio-oil yields [17]. However, the process has been widely used in the production of biodiesel, but not in bio-jet fuel [18].

To counteract the use of water in bioturbosine production, processes such as Centia and bio-synfining have been developed [19]. The Centia process is based on the rapid pyrolysis of biomass, and water is not directly used in the conversion [20,21]. On the other hand, bio-synfining combines biomass gasification with the Fischer–Tropsch process. Although gasification may involve water, it is not an essential component of the entire process, making it an interesting option from the point of view of sustainability [22]. The Fischer–Tropsch process, for its part, is capable of converting carbon monoxide and hydrogen into hydrocarbons without requiring the direct use of water, thus representing an alternative approach to the production of bioturbosine [23–25]. Hydrotreatment is a process that uses water as a reagent and as a means of generating the steam necessary for the hydrogenation reaction of hydrocarbons, eliminating impurities and improving the quality of the final product [26,27].

Hydrotreatment is the only process that directly depends on the use of water, and although the other processes offer innovative and efficient alternatives in terms of water consumption, they still require it in some of their processes, thus necessitating alternatives that do not use water.

The objective of this work is to develop an alternative method for the generation of a biofuel that can be mixed with gasoline for airplanes, thus reducing the consumption of fossil gasoline for airplanes. In the production of biojet fuel, no water was used for the purification of the caustic residues, and amberlite resin was used; since no water was used, no subsequent treatment was necessary since no wastewater was generated. Likewise, regarding the production of biojet fuel based on coconut oil, there is little published literature related to this topic using coconut oil and the ultrasound technique, so the proposal of this work is innovative.

2. Materials and Methods

2.1. Materials and Reagents

Coconut oil was obtained from the company Liconsa S.A. DE C.V. (Ciudad de México, México) It was composed of at least 82% saturated fat by weight (wt.%), and more than 55.0 wt.% of the fats were in the form of medium-chain fatty acids, as shown in Table 1.

Table 1. Fatty acids from coconut oil.

No.	Fatty Acid Profile	Range (wt. %)
1	Caproic acid C-6	0.0–0.6
2	Caprylic Acid C-8	4.6-9.4
3	Capric Acid C-10	5.5-7.8
4	Lauric Acid C-12	45.1-50.3
5	Myristic Acid C-14	16.8–20.6
6	Palmitic acid C-16	7.7–10.2
7	Stearic acid C-18	2.3–3.5
8	Oleic Acid C-18:1	5.4-8.1
9	Linoleic acid C-18:2	1.0-2.1
10	Linolenic acid C-18:3	0.0-0.2
11	Arachidic acid C-20	0.0-0.2
12	Gadoleic acid C-20:1	0.0–0.2

Aqueous solutions were prepared with MilliQ water with a resistivity of 18.2 M Ω ·cm. To produce bioturbosine, anhydrous methanol (CH₃OH from Merck, Ciudad de México, México, max. 0.003% H₂O) and potassium hydroxide (Meyer's anhydrous KOH, \geq 99.97%) were used. For the purification of the bioturbosine, AMBERLITE resin was usedTM. BD10DRYTM was provided by the company Rohm and Haas in Mexico City.

2.2. Bioturbosine Production

A mixture was prepared with a molar ratio of methanol and oil of 6:1 [28]. This mixture was placed in a UP 200S ultrasonic device (Hielscher Ultrasonic Gmblt, Teltow, Germany). The ultrasonic process was operated at 200 W and a frequency of 24 kHz with a S26d14 Sonotrode (titanium sonotrode, 100 mm long and 14 mm in diameter) for 10 min. Each assay was performed in triplicate at room temperature. The samples were placed in a centrifuge (IEC centrum CL2 model, Thermo Brand (Kunshan, China)) at 3000 revolutions per minute (RPM) for 5 min. Subsequently, the glycerin and bioturbosine that formed were separated and measured. The bioturbosine was introduced into an ion-exchange column to eliminate the impurities—mainly those present due to potassium hydroxide. Then, experimental data on the conversion, performance, and physicochemistry of each sample were obtained, and they were statistically processed in Excel using the Microsoft 365 software to obtain the arithmetic mean and the standard deviation. Figure 1 shows the process of obtaining bioturbosine on a small scale with the following equipment: an ultrasonic device with a positive pressure module for the measurement probe and flow (200 W at an operation frequency of 24 kHz), an electric power meter, a 20 L processing tank, a 1.5 kW heating element, a 2 L premixed catalyst tank, a premixed catalyst stirrer, a 1.0 HP centrifugal pump with speed variation to control the flow of the mixture towards the ultrasound, a back-pressure valve to adjust the pressure in the flow cell, a supply manometer, a centrifuge to separate bioturbosine from glycerin, and an ion-exchange column.



Figure 1. The ultrasound process for bioturbosine generation.

2.3. Methods of Analysis

2.3.1. High-Performance Liquid Chromatography (HPLC)

The percentage of triglyceride conversion was determined by using reverse-phase high-performance liquid chromatography with an ultraviolet (UV) detector at 205 nm. For this analysis, a 150 mm Zorbax 300 SB C18 4.6 column with a flow rate of 1 mL/min was used. High-performance liquid chromatography testing was performed on an Agilent 1100 HPLC system (Germany) that included G1315A DAD, G1316A Col-Comp, G1329A ALS, G1311A QuatPump, and G1322A. A degasser and reservoir pan were required in order to process the data, and a Windows computer running the Chemistation software version 15 was used. To determine the triglyceride profile of bioturbosine, 38 μ L of bioturbosine and 962 μ L of hexane mixed with 2 propanols (4 parts hexane and 5 parts of the 2 propanols) were added to 1 cc screw-cap bottles made explicitly for use in HPLC equipment. The difference between the triglycerides in the oil and those in bioturbosine was used to determine their percentage of conversion.

2.3.2. Physicochemical Analysis

To meet the ASTM standard D1655 [13], the water content was determined using a Mettler Toledo Model coulometric Karl Fischer titrator *C10SX*.

To calculate the density, a precision balance (Metter Toledo model XPR 404S/A) and a pycnometer were used. The viscosity was determined at temperatures of 40 °C and -20 °C according to the reference EN ISO standard 3104 [29]. The cold-filter clogging point (CFOP) was determined according to the reference EN standard 116 [30] using a cold-filter clogging point measurement device of the Tester PT-2000 brand. The caloric value was determined according to the reference standard ASTM standard D240 [31] using a C6000 combustion bomb calorimeter with the global standards.

2.3.3. Crystallization Point

For the determination of the crystallization point, the ASTM standard D2386 [32] was used. For this, 25 mL of kerosene was introduced into a test tube (clean and dry) together with a cork and a stirrer. A bath of dry ice and acetone $(-78 \,^\circ\text{C})$ was prepared, and then the sample was cooled. Next, the fuel was stirred until the first paraffin crystals were observed, and the temperature (T1) was noted. The temperature at which the hydrocarbon crystals formed by cooling was reached, and the sample disappeared when subjected to heating

(T2), which was also recorded. The value of the crystallization point was the average of T1 and T2.

2.3.4. Corrosion of Copper

A corrosion test was carried out with a copper sheet using the ASTM standard For the determination of the crystallization point, the ASTM standard D2386 [32] was used ASTM D130 [33] method to determine the relative degree of active sulfur compounds in the bioturbosine samples. A bath in test tubes with copper strips from Koehler Instruments Model K25330 (New York, NY, USA) was used. The ASTM standard D130 method of copper corrosion analysis consisted of immersing a polished copper sheet in a 30 mL sample for analysis at a high temperature of 50 $^{\circ}$ C, depending on the type of fuel to be tested, for a three-hour period. At the end of this period, the sheet was cleaned and examined for evidence of degradation. The results were measured by comparing the spots on the sheet with an ASTM standard color scale of 1A to 4C. The 1A classification was given by the appearance of a freshly polished copper sheet with a slight discoloration that was almost imperceptible; 1B indicated slight tarnishing, and the ratings continued to go down the scale as the corrosion increased. The 4C classification was the worst, and was characterized by a corroded, blackened, and pitted plate. The ASTM standard D130 [33] method covers the determination of corrosivity to copper for aviation gasoline, aviation turbine fuels, automotive gasoline, cleaning solvents (Stoddard), kerosene, diesel fuel, distillate fuel oil, lubricating oil, and natural gasoline or other hydrocarbons.

3. Results and Discussion

3.1. Physicochemical Characterization

3.1.1. High-Performance Liquid Chromatography (HPLC)

The following chromatograms correspond to the tests that were carried out to verify the conversion of crude coconut oil into methyl ester through the transesterification process, which was confirmed by the results obtained through HPLC.

According to the chromatogram of crude coconut oil shown in Figure 2, the total retention time was 14 min (see black line), with an adequate resolution due to the fact that the peaks did not overlap (see violet line). The components were fatty acids from the oil used in this analysis.



Figure 2. The triglyceride profile of crude coconut oil.

The chromatogram Figure 3 shows that there was 99.93% conversion of coconut oil after the transesterification process (see violet line) at room temperature for 10 min. This result was obtained from the straight line observed in the time interval from minute 2.1 to minute 7.75 (see black line).



Figure 3. Chromatogram of the conversion of coconut oil triglycerides with a ratio of 6:1 and 1.0% catalyst.

3.1.2. Water Content

Table 2 shows the results for seven samples in mg/kg according to the regulations (ASTM standard D1655 [13]) for the determination of the water content with the Karl Fischer method by means of columbimetric titrations. Here, the previously weighed sample was introduced into the titration container of the Karl Fischer equipment Compact C10SX, Coulometer, Mettler Toledo made in China, which induced the generation of iodide in the anode through electrochemical oxidation. When all of the water had been titrated, excess iodide was detected by an electrometric endpoint electrode (the absence of iodine). From the amount of iodide generated, the amount of electricity required was calculated according to Faraday's Law. The water content was proportional to the iodide generated.

Table 2. Water content in bioturbosine mixtures from crude coconut oil.

Mixtures	Average mg/kg
Commercial jet fuel	47.1 ± 1.5
B5	54.8 ± 1.6
B10	79.5 ± 1.9
B20	123.2 ± 4.8
B100	265.3 ± 6.4
Bottom	132.8 ± 10.7
Crude coconut oil	955.0 ± 11.8

The previous table shows the water contents of four mixtures (B5, B10, B20, and B100), which were prepared with 5%, 10%, 20%, and 100% bioturbosine from coconut oil and 95%, 90%, 80%, and 0% commercial jet fuel.

The bottom was the heavy fraction from the distillation of FAME (fatty acid methyl ester) of coconut.

3.1.3. Density

The density values at 15 °C were measured for all fuels and are shown in Table 3.

Table 3. Density of bioturbosine mixtures from crude coconut oil.

Mixture (15 °C)	ρ (g/mL)
Commercial jet fuel	0.806 ± 0.05
B5	0.812 ± 0.03
B10	0.814 ± 0.06
B20	0.817 ± 0.03
B100	0.856 ± 0.05
Bottom	0.875 ± 0.04
Crude coconut oil	0.910 ± 0.01

The data found in the experiment that was carried out to determine the density at 15 °C were compared with the values specified in the regulations in Table 4.

Fuel	Regulations	$\rho_{15^{\circ}C}(g/mL)$	
Kerosenes	ASTM standard D1655 [13] DEFSTAN 91-91 [34] DEFSTAN 91-86 [35]	0.775–0.840 0.775–0.840 0.788–0.845	
	DEFSTAN 91-87 [36]	0.775-0.840	

Table 4. Density values according to regulations.

By comparing the tests carried out in the laboratory, it could be seen that the commercial jet fuel and three of the mixtures of crude coconut oil—B5, B10, and B20—complied with the kerosene regulations regarding density, while the FAME distillation products—both bioturbosine (B100) and the heavy fraction of the distillation (bottom)—had the highest density, which was not compliant with the regulations for kerosene. The literature reported densities of 0.780 g/mL and 0.778 g/mL in mixtures of 5% and 10% with Jet A1, and the mixtures reported to have the highest percentage of bio-jet fuel did not correspond to the regulations. Our experimental values were in the range of the normative standard for mixtures of up to 20% [6].

3.1.4. Viscosity

The result for the viscosity of bioturbosine from crude coconut oil at 40 °C was 2.2739 (mm²/S), and the viscosity results at -20 °C for the other samples are presented below in Table 5.

Table 5. Viscosity of turbosine (commercial jet fuel) and crude coconut oil mixtures.

Fuel (-20 °C)	Viscosity (mm ² /s)
commercial jet fuel	2.2969 ± 0.05
B5	3.5851 ± 0.05
B10	3.6925 ± 0.05
B20	4.2236 ± 0.05
B100 *	2.2739 ± 0.01
Crude coconut oil	49.0 ± 2.0

* The viscosity must be measured at -20 °C to be able to be compared with the reference value of the regulations, but since the average CFOP of biofuels is -10 °C, it was not possible to carry out this test. Instead, the viscosity was measured at 40 °C.

Below in Table 6 the results were compared with the values specified in the regulations.

Table 6. Viscosity limit of turbosine.

Fuel	Regulations	Viscosity (-20° C) (mm ² /s)
	ASTM standard D1655 [13]	Maximum 8
Turbosines	DEFSTAN 91-91 [34]	Maximum 8
	DEFSTAN 91-86 [35]	Maximum 8
	DEFSTAN 91-87 [36]	Maximum 8

The mixtures had a viscosity of less than 8 at -20 °C, so they complied with the value established in the turbosine regulations. The mixtures of 10% bio-jet fuel with Jet A1 that were reported in the literature showed viscosities of up to 6.789 mm²/s; the values of the B20 mixtures in this experiment were in the same range [2].

3.1.5. Cold-Filter Plugging Point (CFOP)

The data on the lowest temperature at which 20 mL of the fuel passed through a filter in 60 s, according to the reference standard EN 116 [30], are shown in Table 7.

Mixtures	Average CFOP (°C)
commercial jet fuel	-30 ± 1
B5	-29 ± 1
B10	-29 ± 1
B20	-30 ± 1
B100	-10 ± 1

Table 7. CFOP Mixture of jet fuel, bioturbosin and crude coconut oil.

The results obtained for the CFOP with the different fuels were compared with the reference values in the regulations in Table 8. There is only a limit for this property in the regulations for automotive biodiesel. The CFOP is not a requirement specified in the standard for jet fuels.

Table 8. Limit for the automotive CFOP.

Weather	UNE EN Standard 14214 [37]	CFOP (°C)
	Degree A	5
	Degree B	0
	Degree C	-5
Mild weather	Degree D	-10
	Degree E	-15
	Degree F	-20
	Class 0	-20
	Class 1	-26
Winter weather	Class 2	-32
	Class 3	-38
	Class 4	-44

The fuel that contained only bioturbosine, B100, met the automotive CFOP specifications up to grade D, which corresponds to countries with temperate climates. However, the mixtures can be used in countries with arctic climates—specifically, the B5 and B10 mixtures complied with the standard up to class 2, and the B20 mixture complied with it up to class 1.

Reports of some 5% and 10% bio-jet fuel mixtures have been found to reach values of up to -54 °C, and they have presented low densities close to the lower limit stated in the regulations [1,38].

3.1.6. Caloric Value

The net caloric values obtained for all of the fuels, including the blends, with respect to the reference standard ASTM standard D3338 [39] are shown in Table 9.

Table 9. Calorific value of turbosine and bioturbosine mixes of crude coconut oil.

Fuel	Calorific Value (MJ/kg)
commercial jet fuel	47.526 ± 0.05
B5	45.042 ± 0.08
B10	44.546 ± 0.05
B20	43.611 ± 0.07
B100	37.485 ± 0.05

The previous table shows small differences among the values obtained for the caloric values of the B5, B10, and B20 mixtures with respect to the minimum required by the standards, which are presented in Table 10 for Jet A and Jet A1 fuels. Here, it can be observed that the values obtained for the caloric power of the three mixtures were above the minimum requirement.

Fuel	Regulations	Calorific Value (MJ/Kg)
	ASTM standard D1655 [13]	Minimum 42.9
T 1 ·	DEFSTAN 91-91 [34]	Minimum 42.8
Turbosine	DEFSTAN 91-86 [35]	Minimum 42.8
	DEFSTAN 91-87 [36]	Minimum 42.8

Table 10. Net heat power limits for Jet A and Jet A1 fuel.

In samples in which Jet A1 has been incorporated, caloric values of 44.4 MJ/Kg and 44.3 MJ/Kg have been found [36,40]; in mixtures with 5% and 10% coconut bio-jet fuel, the results have been similar to those of this work. We report a caloric value of 43.6 MJ/Kg for the B20 mixture, which is within the norm.

3.1.7. Crystallization Point

The formation of paraffin crystals can clog intake valves. The crystallization point allows for knowledge of the temperature at which the first paraffin compound (mixture of solid saturated hydrocarbons) is obtained. For aviation fuel, the freezing point is the lowest temperature at which the fuel remains free of solid hydrocarbon crystals that can restrict the flow of fuel through the filters, and the operating minimum must always be below the tank temperature.

As can be seen in Table 11, the values of the norms were highly variable for this parameter. The most permissive was that for Jet A ($-40 \degree C$), and all of the mixtures studied met this requirement. However, the mixtures did not meet the standards for JP-5 ($-46 \degree C$), Jet A1, or JPs-8 ($-47 \degree C$).

Table 11.	Crystallization	point.
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Fuel	Crystallization Point T $^\circ$ C
commercial jet fuel	-43.5 ± 1.0
B5	-42.8 ± 1.0
B10	-42.5 ± 1.0
B20	-42.3 ± 1.0
B100	-19.5 ± 0.5

3.1.8. Corrosion of Copper

Crude oil contains sulfur compounds, most of which are removed in the refining process. However, some of these compounds remain in refined petroleum products and can corrode various non-ferrous metals, so fuel must not corrode the materials with which it comes into contact during dispensing and use. For this, the manufacturers of engines and the equipment involved in fuel systems very strictly control this aspect of jet fuel to ensure the fuel's compatibility before approving the materials used for this purpose. Jet fuel contains potentially corrosive compounds, such as mercaptans and organic acids, although these are limited by specifications [14,41,42].

The results for all of the samples used in this project (commercial jet fuel, bioturbosine, the B5, B10, and B20 mixtures of crude coconut oil) were found to be of class A1. All of the regulations studied in this work require class 1A.

The color changes according to the ASTM standard D130/IP 154 standard [33] in all the samples analyzed were almost imperceptible, indicating that the corrosion of the copper strips was minimal.

4. Conclusions

In general, alternative biofuels for jets are produced through three main processes: thermochemical, oleochemical, and biochemical processes. Some of the improvement pathways that are currently under development include the conversion of lignocellulosic materials via the Fischer–Tropsch (FT) method, hydrothermal liquefaction (HTL), and

pyrolysis. Additional and optional methods include the hydrotreatment of lipid/fatty acid raw materials; fermentation of sugars or direct conversion of sugars into hydrocarbons (DSHC); and other hybrid technologies, such as alcohol-to-jet (ATJ) technology and aqueousphase reforming of sugars (APR). The development and deployment of these conversion pathways are topics of worldwide interest, and several research papers have addressed their current status from the perspectives of sustainability, economy, and technology.

With growing concern about environmental issues, it is obvious that the restrictions and production criteria for jet biofuels will become more stringent in the future.

There are still few alternatives to conventional fuels in aviation because the fuel must have specific characteristics, such as high calorific value, high energy density, adequate viscosity, low freezing point, low water content, thermal and chemical stability, and low corrosiveness. In addition to that, it should be as economically viable and widely available as Jet A1 fuel.

In this work, FAME was synthesized from oils rich in short- or medium-chain fatty acids, which are contained coconut oil. Coconut oil as a feedstock has advantages over other vegetable oils in that it contains more than 65% medium-chain fatty acids. These medium chain fatty acids are a good feedstock for jet fuel.

The B5, B10, and B20 blends of bioturbosine produced from the transesterification of coconut oil met ASTM standards. The use of ultrasound as an energy source influenced the transesterification reaction time, achieving a conversion rate of more than 99%. With an exposure time of 10 min at room temperature, this, together with the elimination of caustic impurities without the use of water, can be attractive for bioturbosine production at the industrial level.

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Abbreviations

CFOP	Cold-filter plugging point
EU	European Union (EU)
FT	Fischer–Tropsch
[ATA]	International Air Transport Association
HPLC	High-performance liquid chromatography
ASTM	American Society for Testing and Materials

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