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PRODUCTION OF AVIATION BIOFUEL FROM HYMENAEA SP OIL USING HETEROGENEOUS CATALYST DERIVED FROM CAO CALCINATION - EGGSHELL

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ABSTRACT
Oilseeds are emerging as a promising fuel source, given the circumstances of the oil crisis and the urgent need to seek substitute alternatives compatible with sustainability. In this context, the present study aims to analyze the feasibility of the biofuel produced from the oil extracted from the seeds of Hymenaea sp, using CaO from the eggshell as a catalyst, aiming at its application in aviation. The methods used comprised the following steps: collection and cleaning of the material; extraction of oil from the seeds of Hymenaea sp; physicochemical characterization; determination of the acidity index; density measurement; calculation of the saponification index; evaluation of humidity (%H2O); kinematic viscosity measurement; characterization of the catalyst; carrying out the catalytic reaction and subsequent analysis of the products formed; biofuel production; evaluation of the levels of acidity, iodine, lead, sulfur and hydrocarbons present in the residues resulting from the process of obtaining biofuel; and testing the application of biofuel in a model airplane aircraft. In the physicochemical analyses of the crude and processed oil, the following values were obtained: acidity index (mg KOH/g) of 3.32 ± 0.03 and 3.38 ± 0.07, moisture content (%) of 0.75 ± 0.05 and 0.74 ± 0.05, iodine index (Wijs)% of 1.62 ± 0.04 and 1.72 ± 0.05, saponification index (mg KOH/g) of 167.3 ± 0.03 and 168.64 ± 0.01, and relative density at 25º C (g/mL) of 0.914 ± 0.03 and 0.913 ± 0.03. Regarding the mass balance tests, the transesterification reaction resulted in 56.22% of biofuel, 21.27% of glycerin, 12.02% of ethanol recovered and 10.44% of losses. The analysis of the phases obtained after calcination revealed the formation of calcium carbonate (CaCO3) in 48.3%, calcium oxide (CaO) in 41.4% and calcium hydroxide (Ca(OH)2) in 10.3%. The interaction between these chemical components contributes to maintaining the high pH of the oil, promoting the disintegration of impurities and allowing the filtration of the material before the distillation of the biofuel. In the analysis of the biofuel produced, low levels of lead (1.243g), sulfur (< 0.066%), carbon (< 0.12mgKOH/g), iodine (1.63/200ml) and hydrocarbons (0.064g/l) were

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observed compared to commercial fuels. This composition results in a significantly lower emission of carbon dioxide and the production of waste that is less harmful to the environment, reducing environmental impacts by 78%, 79% and 96%, respectively, compared to the production of fossil fuels.

Keywords: Seeds. Biokerosene. Sustainability.

INTRODUCTION

The narrative of the evolution of fuels used in aviation had its genesis in the application of automotive gasoline engines and their equivalents. In the first half of the last century, air propellants consisted predominantly of piston internal combustion engines in linear or radial configurations, fueled by gasoline. Subsequently, the need to adapt conventional gasoline to meet the demands of aircraft arising from war conflicts emerged, characterized by its volatility and low flash point, making it intrinsically flammable under normal operating conditions (AERO MAGAZINE, 2013).

After the outcome of World War II, a significant innovation emerged in the form of aviation kerosene. This new fuel has shown notable advantages in terms of the ratio of weight to power, as well as providing high thrust, particularly in the context of gas turbines. The latter have established themselves as the predominant propellers in aircraft, restricting the use of aviation gasoline to smaller planes and helicopters equipped with piston engines (AERO MAGAZINE, 2013).

In the period between the 1950s and 1960s, fuel formulations enriched with additives were developed. The design of the first jet engine by Frank Whittle in the United Kingdom used kerosene due to the shortage of gasoline during the war context. Today, kerosene remains the primary energy agent for jet aircraft, powering both commercial airline operations and military fleets (AERO MAGAZINE, 2013).

Grounded in fossil resources (such as oil, natural gas, and coal), our economy thrives. Oil sustains the largest share of the transportation sector, while natural gas and coal play a preponderant role in electricity generation. In the specific context of aviation, the fuel used is a petroleum derivative, obtained by direct distillation at temperatures between 150°C and 300°C, in order to confer properties that are in line with the energy requirements of the engines, due to significant pressure and temperature fluctuations (COWSPIRACY, 2014; PETROBRAS).

Emissions from aeronautical engines cause environmental pollution, with adverse effects on both biodiversity and human health. The combustion of these fuels gives rise to a variety of harmful pollutants that exacerbate the phenomenon of global warming, encompassing substances such as carbon monoxide and carbon dioxide, gaseous hydrocarbons, and nitrogen, sulfur, and lead oxides – the latter attributing the characteristic blue color to kerosene, which, in turn, boasts high flammability. Also noteworthy are the fundamental characteristics of kerosene, applicable to any variation of it: insolubility in water, characteristic and unpleasant odor, lower density in relation to water, and high toxicity to living organisms According to the recent report of the World Health Organization

(WHO/UN) in 2021, this type of fuel imposes contributions to climate change, acid rain, and toxicity that impact food grown in the vicinity of major airports Global.

The problem gains prominence in the environmental sphere due to the intrinsic characteristic of aircraft, which have maximum weight limits for both the takeoff and landing phases. Due to this restriction, a meticulous calculation is carried out in order to determine the precise amount of fuel to be filled to the aircraft, thus ensuring its safe take-off and successful landing on each itinerary. This calculation includes an estimate of consumption during the flight. In anticipation of such circumstances, it is common for most aircraft models to be equipped with relief valves, located on the wings and away from the propulsion units, intended for the controlled exudation of fuel during the air route (SOARES, 2022 $ RABELO 2001).

Global unrest over climate change and oil supply volatility has culminated in a growing demand for renewable energy sources. This has driven continuous research in order to enable the large-scale adoption of more sustainable fuels. Investigative efforts have been undertaken and persist with the purpose of identifying fuel alternatives that reduce the environmental footprint (GARBIN and HENKES, 2020).

For the aviation industry, a promising solution lies in biofuels, which offer a more environmentally friendly and readily available option. This transition is crucial, since the fuels traditionally used in aviation have harmful impacts on fauna, flora, water resources, and human health.

Thus, the imperative need to diversify energy sources, overcoming dependence on fossil fuels, has been a critical challenge in the trajectory of society. The trigger for this movement occurred during the oil crisis in the 1970s, promoting the incentive to establish programs aimed at the development of alternative energy sources and biofuels (SILVA, 2011).

The continuous interest in environmental precepts, among which the reduction of particulate, carbon monoxide and carbon dioxide emissions, as well as the elimination of sulfur and aromatic compounds, has expanded the scope of research dedicated to the progress and production of fuels from renewable sources, which have less environmental impact. This interest is manifested both in the industrial and academic spheres, marking a substantial growth in research aimed at formulating more sustainable energy solutions (FERRARI et al., 2011).

The growing global awareness of climate change and the instability of oil supply has intensified the search for renewable energy sources. Within this context, biofuels emerge as a concrete example of the use of biomass for energy generation, offering multiple advantages compared to petroleum diesel. Notably, biofuels demonstrate non-toxicity, derive from renewable sources, and exhibit better quality emissions during the combustion process (LOTERO et al., 2005; CORREA and ARBILLA, 2006).

These liquid and biodegradable biofuels, in turn, can be characterized as alkyl monoesters derived from long-chain and linear fatty acids. They are obtained from a variety of raw materials, such as vegetable oils, animal fats, and waste oils and fats (OGR), also resulting in glycerol as a co-product. The production of biodiesel involves several routes (LÔBO et al., 2009; PINTO et al., 2005).

A particularly interesting alternative for the production of aviation fuels lies in seeds that contain oil, configuring themselves as an environmentally beneficial solution to mitigate air and soil pollution. In addition, this approach can considerably reduce costs in the biofuel production chain, since a substantial portion of these costs is directly linked to the feedstock (SORANGE et al., 2008).

Therefore, the use of biofuels is necessary to contribute to the reduction of greenhouse gas emissions, since the biomass used in its production absorbs the CO2 emitted during the burning of the biofuel. The magnitude of the reduction in greenhouse gas emissions varies depending on the type of biofuel.

In this context, the objective of this research is to analyze the feasibility of the biofuel produced from the oil extracted from the seeds of *Hymenaea sp*, using CaO from the eggshell as a catalyst, aiming at its application in aviation.

METHODOLOGY

MATERIAL USED IN THE PRODUCTION OF BIOFUEL FOR AIRCRAFT

The fruits were collected in a cerrado area in the rural area of the municipality of Cachoeirinha, in the state of Tocantins. Before use, the raw material of the pods of *Hymenaea sp* (jatobá mirim) were washed with soap and water to eliminate the presence of microorganisms. They were then placed on a stainless steel tray and exposed to the sun to eliminate moisture. The seeds will stay for 12 hours at an average temperature of 35°C. After this period, they were taken to the Philco brand electric oven, model PFE48IP, with a capacity of 46 liters and a voltage of 127V, at a temperature of 100°C for one hour to dry the shell and accelerate the ripening of the seeds. Next, the shells were removed to separate the seeds, which were placed on a stainless steel tray and taken to the oven for two hours at a temperature of 100°C. This process is necessary to ensure a more complete drying of the seeds, increasing the oil content present in them.

For the preparation of the catalyst, residual eggshells were used as precursors of CaO in this study. To remove any unwanted materials adhering to the surface, they were washed thoroughly with running water and rinsed several times with deionized water. After cleaning, the shells were kiln dried. Subsequently, the dried shells were crushed and sieved through a set of 75 mesh sieves. The resulting powder was calcined in a muffle furnace at different temperatures (700, 750, 800 and 850°C) and time periods (1, 2, 3, 4 and 5 hours) to determine the optimal calcination conditions.

PHYSICOCHEMICAL CHARACTERIZATION OF *HYMENAEA SP SEED OIL*

The acidity index was defined as the amount of milligrams of potassium hydroxide needed to neutralize one gram of the sample. This method is applicable to crude and refined oils, both of vegetable and animal origin, including animal fats (IAL, 2004).

The titration was performed using a 0.1 M sodium hydroxide (NaOH) solution.

After titration, the necessary calculations were performed using the following equation

$$I.A = \frac{V\ x\ (F)\ x\ 5,61}{\text{Amostra}} = \frac{IAC}{POH}\ x100$$

Where:

V volume (mL) of NaOH 0.1 M spent in titration, **F** correction NaOH = 0.9709, **P** mass (g) of the sample, C Constant = 5.61, **IA** acidity index, **IAC** constant acidity index calculated 0.1696 and **POH** –Hydrooxygenic potential.

The determination of the density of the oil extracted from the seeds of *Hymenaea sp* was conducted in triplicate. 3 ml of the sample were added to the Anton Parr densimeter, model DMA 4500.

The saponification indices of *Hymenaea sp* oil were performed in triplicate and the necessary calculations were performed using the appropriate equation after titration.

$$I.S = \left[\frac{28,\ 05.\ F\ [B\text{-}A]}{P.\ mostra}\right] = mgKOH/g$$

Is = saponification index

A = volume spent in the sample

B = volume spent on white

P = Constant sample weight = 28, 05

F Solution Factor = 1.03750

To determine the percentage of water (%H2O) was The necessary calculations were performed according to the indicated equation.

$$\%/H2O = \left[\frac{P1\text{-}P2}{P3.100}\right] x\ 100 \quad \textit{and} \quad \%/H2O = \frac{A1 + A2}{2}$$

Where:

%H2O = moisture content in percentage

P1 = capsule weight + dry sample

P2 = weight of dry capsule

P3 = wet sample weight

A1 = Sample result 1

A2 = Sample result 2

The kinematic viscosity of the oil extracted from the seeds of *Hymenaea sp* was determined in duplicate and the necessary calculations were performed according to the equation indicated.

$$V.C = \left[\frac{C(V2\text{-}V1)}{T2\text{-}T1}\right] x\ 100$$

Where:

V.C Kinematic Viscosity

C Constant calibration 0.1320

V2 Volume final

V1 Initial Volume

T1 Initial Temperature

T2 Final temperature

CHARACTERIZATION OF THE CATALYST

The CaO residues were examined using an electron microscope to emphasize the morphology of the catalyst. The crystal structure of the catalyst was analyzed by X-ray diffraction (XRD: XRD-6000, Shimadzu, Japan) at the Biological Formation Laboratory of UEMASUL. The particles were counted superficially and the pores were observed through microscopic images of the dry samples, which were placed on litmus paper in a circular format. The calculations for the amount of CaO particles were performed according to the equation below:

$$Cc = \left[\frac{q.4}{Constante}\right] x\ 100$$

Where:

Cc Catalyst Characterization

q Number of particles per quantity

4 Number of Fours

C Constanet 360° (angle)

100 (value of the fours x 25%)

mm³ cubic millimeters of porous particles

CATALYTIC REACTION PRODUCT ANALYSIS

The transesterification of the oil with methanol will be carried out using 20 ml of methanol were added to the oil, different proportions of methanol. Then, 10 ml of the CaO catalyst was introduced into the flask and the mixture was heated to a temperature of 100°C. After the reaction was complete, the liquid products were collected and cooled to room temperature. The liquid mixture, composed of methyl ester, methanol and glycerol, was left to rest for 24 hours for decantation to occur. The calculation of the percentage of each element obtained was performed using the following formula.

$$\left.\begin{matrix} A \rightarrow B \\ C \rightarrow X \end{matrix}\right] \Rightarrow X = \frac{B\,x\,C}{A}$$

Where:

A Value in ml added in the experiment

B Constant (100%)

C Amount of ml per decanting

X Result to be found (%)

PRODUCTION OF AVIATION BIOFUEL FROM THE SEED OIL OF *HYMENAEA SP* (JATOBÁ MIRIM) USING CAO (CALCIUM OXIDE) FROM EGGSHELLS

To produce the biofuel, seed oil and the catalyst CaO (calcium oxide) were used from eggshells applying a transesterification process, which converts vegetable oil into methyl or ethyl esters, the main components of biofuel.

For this methodology, the standards of ASTM D7566 (American Society for Testing and Materials) or "American Society for Testing and Materials" were used, which regulates the specific standards that can be established by civil aviation agencies of different countries. Brazil's National Petroleum Agency (ANP) still does not have standards that regulate the production of biofuel for airplanes, according to research carried out.

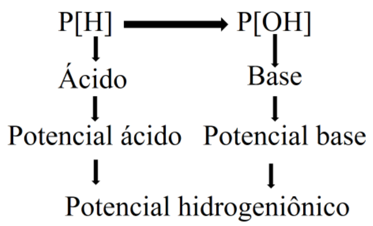
In this experiment, a transesterification process was carried out using Hymenaea sp seed oil (jatobá mirim) as raw material for the production of biofuel, with methanol as reagent, following a molar ratio of 3:1 (three parts methanol to one part oil). A catalyst, calcium oxide (CaO), was added to the mixture to speed up the reaction (200g).

After the reaction was complete, the biofuel produced was separated from the glycerin phase and went through washing and purification steps to remove residues and traces of catalyst, before quality tests were carried out to verify that the product meets regulatory specifications and is suitable for use as a fuel. For the purification phase, it went through 05 filtration and cleaning of impurities using silica gel (The chemical formula of silica gel is $SiO_2 * nH_2O$, where "n" represents a variable number that indicates the amount of water molecules associated with the structure of silica gel. Silica gel is a porous, amorphous form of silicon dioxide (SiO_2), which is a substance composed of silicon and oxygen), it absorbs all remaining impurities from filtration.

CALCULATION OF THE ACID VALUE OF THE BIOFUEL PRODUCED

In this test, four samples of biofuels extracted from the seed oil of *Hymenaea sp.* Each sample, consisting of 200 ml, was divided into distinct containers (Beques), allowing the observation of the different resulting stains.

Subsequently, the biofuels underwent pH analysis, following the application of the following formula:



Where:

$$pH = -\log[H^+]$$

$$pOH = -\log[OH^-]$$

CALCULATION TO EVALUATE THE PERCENTAGE OF CATALYZED FUEL, SULFUR INDEX AND IODINE INDEX PRESENT IN THE SAMPLES

To evaluate the catalyzation process, 150 ml of fuel, 20 ml of calcium carbonate (CaCO3) and 30 ml of calcium oxide (CaO) were used. To perform this calculation, the following formula was applied:

$$\begin{matrix} A & \text{—} & B \\ C & \text{—} & X \end{matrix} \qquad X = \frac{B\,x\,C}{A}$$

Where:

X = Catalyzed Perceptual to be found

A = Amount of ml applied in the experiment.

B = Percentage constant applied in percentage calculation (100%).

C = Amount of CaCO3 + CaO, used in the experiment.

For the sulfur index, 325 ml of fuel, 64g of SO2 titration sample, 32g of sulfur sample (S) were used and the following formula was applied.

$$Is = \left[\frac{mLc}{SO2}\right] x \left[\frac{S(g)}{100\%}\right]$$

Where:

Is = índice de enxofre

mlc = Amount of fuel applied in the experiment.

SO2(g) = Titration sample (64g).

S(g) = Sulfur Sample.

100% = The percentage factor applied in the international standard.

To calculate the iodine index, sodium thiosulfate (Na2S2O3) and filter paper were used to obtain the residues.

$$I = \left[\frac{Vs-Va}{m}\right] x\ m\ x\ 12{,}68$$

Where:

I = Índice de iodo.

Vs = Na2S2O3 volume spent on white titration.

Va = Na2S2O3 volume spent on sample titration.

M = Concentration of (mol/l) of Na2S2O3.

To calculate the lead index, filter paper was used after heating the samples. This is possible because the cellulose nanocrystals found in plastic wrap retain lead impurities.

$$\begin{array}{l} A \text{ --- } B \\ C \text{ --- } X \end{array} \qquad X = \frac{B x C}{A}$$

Where:

X = Catalyzed Perceptual to be found

A = Amount of ml applied in the experiment.

B = Percentage constant applied in percentage calculation (100%).

C = Amount of CaCO3 + CaO, used in the experiment.

TEST OF BI-FUEL IN MODEL AIRPLANE

To evaluate the effectiveness of the green fuel produced in the laboratory in an experimental way, using the oil of *Hymenaea sp* and the CaO catalyst derived from the eggshell, 5 tests were carried out using the Trainer Classic 40 Kit ARF aeromodel from Phoenix Model. These tests were accompanied by the advisor and by a specialist in aeromodelling.

RESULTS

BIOFUEL PRODUCTION

The production of biofuel from *Hymenaea sp* oil proved to be highly favorable, with a use of 96.67% of the seed oil. This means that to produce 100 ml of biofuel, 50 ml of *Hymenaea sp's oil,* 150 ml of methanol and 100g of Ca are needed. The total time of 6 hours for all production steps is considered reasonable and feasible.

An analysis of the stains resulting from the hexane solution on the filter paper, using the catalysts mentioned and presented in Table 01, revealed the exclusive presence of ethyl esters. This finding reinforces the efficacy of the complete conversion of fatty acids into ethyl esters through the procedure adopted in this study. It is important to note that the CaO catalyst technique from eggshells is simple, but highly effective to qualitatively verify the complete conversion into ethyl esters, thus evidencing the successful production of the biofuel.

Table 01: Reference standards and sample of bifuel obtained from 310 ml of roasted seed oil from

Compound	References%
Hymenaea sp oil bi-fuel	75.71±3.67
Fatty acid esters	10.69±2.21
Triglycerides	8.15±1.25
Fatty Acids	5.45±0.35

± Variation more or less. / Source: Authors

In the mass balance tests, the results of the transesterification reaction showed that 56.22% of biofuel, 21.27% of glycerin, 12.02% of recovered ethanol and 10.44% of losses were obtained, in terms of mass. These values are detailed in table 02. It is important to note that these percentages reflect the average yield of 13 kilograms of seeds that were transformed into oil

Table 01: Reference standards and sample of bifuel obtained from 310 ml of roasted seed oil from

Products found	Yield %
Biofuel	56.22 ±3.61
Glycerine	21.27±2.21
Ethanol	12.02±2.76
Losses	10.44±2.75

Source: Authors

In the decantation tests, which consist of mixing water with the fuel and allowing the separation of the phases to occur, it was observed that the maximization occurred in accordance with ANP standards.

In the characterization of the maximized biofuel, it was observed the low presence of free glycerol in the ester obtained and the absence of impurities, as indicated in table 03. In this case, it can be stated that the glycerol removal process was successful.

The elements lead, sulfur and carbon showed low levels, which suggests that the purification stage was adequate for the test to obtain aviation biofuel, following the Brazilian standards of the National Petroleum Agency (ANP) of 2019 and the methodologies of Ferrari et al. (2005).

Table 03: Characteristics of the quality of biofuel from Hymenaea sp seed (jatobá mirim) compared with some specifications for diesel marketed in Brazil according to ANP Ordinance 310/01/2001 and biodiesel according to E-DIN 51606. Source**:** Authors (Biochemistry Laboratory of UEMASUL).

Characteristics	Diesel/Petrobras Specification		Biofuel from *Hymenaea sp*/author
Aspect	Limpido, insento of impurity		Limpido, insento of impurity
Color, maximum	3,0		1,0
Total sulfur, maximum	0,35%		< 0,066%
Specific mass at 20°C	820 to 880 kgm^3		874.3kg/m^3
Max Carbon Residue	0,25%		<0.12%
Acid value	0.8mgKOH/g		0.4mg KOH/g
Iodine Index	120.31gl/100g		101.28 gl/100g
% free glycerol	-		-
Prickly pear residue (g)	1,243g		<0.034g
Hydrocarbonet residue	1.23gl		0.064g/l
Branched hodrocarbonet residue	1.034g/l		<0.214g/l
Aromatic hydrocarbon residue	1.067g/l		0.153g/l

ANALYSES OF THE COMPARATIVE RESULTS OF FILTRATION AND PURIFICATION OF FUELS

The comparative analysis of the results between the filtration and purification processes of the four fuels was of paramount importance to evaluate the effectiveness of these procedures in removing impurities and obtaining purer and better quality products.

By evaluating the amount and nature of impurities removed in each process, it was possible to compare the decrease in visible impurities and the improvement in fuel clarification after the first filtration and purification. The residues found showed characteristics of lead (Pb), sulfur (S) and iodine (I), common in fuels used in aviation.

The amount of residues retained in the filters used during the filtration process was measured by comparing the amount and nature of the residues retained between different fuel samples. It was identified that there were significant differences.

Evaluation of the visual purity and clarity of the fuels after purification, compared to the unpurified samples, revealed that the process resulted in a clearer and more transparent fuel. However, it did not reach the same level of clarity as the fuel produced from the seed of *Hymenaea sp* (jatobá mirim).

After analyzing the filters used in the filtration process, the presence of metals in the fuels purchased in the market became evident. On the other hand, the fuel produced from the seed of *Hymenaea sp* did not present residues or sludge after the first and second filtration. In addition, traces of metals were practically non-existent (see Table 04).

The fuel resulting from this research, after its filtration and purification, exhibited a clear and translucent color, without the presence of residues

Table 05 provides a comparative view of the filtration and purification characteristics between the market fuel samples and the biofuel from *Hymenaea sp* seed oil, including volume, presence of residues and traces of metals. Volume units can be specified (ml or % percentage volume).

Samples	Residue	Initial V./ml	V. final/ml	Loss/ml//%	Colouring
01 Market	Yes	400	310	80ml/20	Reddish
02 Market	Yes	380	300	80ml/30.4	Greenish
03 Market	Yes	400	300	100ml/	Cloudy yellow
04 Market	Yes	400	300	100ml/25	Purple
01 *Hymenaea*	No	300	298	2ml/1.5	Light yellow
02 *Hymenaea*	No	300	299	1ml/0,33	Light yellow

APPLYING BIOFUEL IN MODEL AIRPLANE

By analyzing the technical issues, it was possible to observe that the maximized biofuel from the seed of the jatobá mirim presented a high performance. In addition, its octane, which is the power of explosion, proved to be ideal for air engines. It is worth mentioning that this biofuel did not present sludge formation, which reduces the need for periodic maintenance. Another point to highlight is the low alcohol content in its composition, practically close to zero, and also the low presence of sulfur, carbon, lead, hydrocarbons and alcohol, when compared to the conventional fuel used in commercial aviation.

During the tests using the model aircraft engine identification T2 164, it was possible to observe that the engine maintained a high temperature during the flight. This observation is relevant, considering that large aircraft operate at high altitudes with often negative temperatures, which contrasts with model airplanes that fly at lower altitudes. However, this temperature rise did not affect the performance of the model airplane. This phenomenon can be explained by the fact that the fuel used was more homogeneous and free of impurities. In addition, there was a low variation in engine regulation, and the increase in aircraft power was remarkable.

The sustainable production and use of biofuels brings environmental benefits, job creation, stimulation of the economy and reinforcement of energy security. However, to reduce the CO2 emissions generated by the sector, it is essential that sustainable biofuels meet the technical requirements of aviation. The use of biofuels allows for a carbon cycle, where CO2 is absorbed during plant growth and released when the biofuel is burned, resulting in reduced net CO2 emissions. Additionally, replacing traditional fuels with biofuels reduces emissions of sulfur, particulate matter, and nitrogen oxide.

In the context of the production of maximized biofuel from Hymenaea sp seed oil (wild jatobá), its viability is highlighted by the considerable cost reduction compared to conventional aviation kerosene.

CONCLUSION

At the conclusion of this stage of the research, it becomes evident that the advantages of producing biofuels from *Hymenaea sp* (jatobá mirim) are significant. In addition to promoting the incentive to regional agriculture in the Brazilian cerrado, with the potential for global impact, the production of biofuels provides economic development for the communities involved. The reduction of dependence on imported fossil fuels for use in aviation is a clear benefit, along with positive environmental impacts, since the emission of polluting gases into the atmosphere is reduced.

Biokerosene, derived from renewable biomass, can be used in aeronautical turboprop engines. The results of the tests with model airplanes demonstrated satisfactory levels of performance and environmental characteristics, however, they highlighted challenges to be overcome. One of the main difficulties lies in the production of raw material, requiring investments in research, especially with regard to the viability of the raw material. In addition, the implementation of appropriate policies for efficient land use is essential, aiming at sustainable production growth. The production chain as a whole must be considered sustainable, going beyond the name of biofuel. Improvements in the national logistics infrastructure, for example, could involve the use of trains to replace trucks on highways, facilitating the sustainable transport of raw materials to production sites.

It is also imperative to establish public policies that include smallholder farmers in the production chain of raw materials for sustainable biofuels. Sustainability encompasses not only the environmental impact, but also the socioeconomic inclusion of all those involved in the production chain.

The environmental gains from the production of biokerosene from the seeds of *Hymenaea sp* (jatobá mirim) proved to be highly viable. The waste generated during the process can be reused as natural fertilizers, contributing to a number of environmental advantages.

In conclusion, this stage of the research is in line with the 17 Sustainable Development Goals (SDGs) proposed by the UN, demonstrating the potential to contribute to a more sustainable and harmonious future. The production of biofuels from the seed oil of *Hymenaea sp* (jatobá mirim) offers a promising alternative to aviation and the reduction of its environmental impact.

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