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Production of biodiesel from extra virgin chia oil by transesterification

Produção de biodiesel a partir do óleo extravirgem de chia por transesterificação

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Rogério Pereira dos Santos
State University of Western Paraná, Graduate Program in Agricultural Energy Engineering, Brazil
E-mail: rogerio.dosantos@ifpr.edu.br

Reginaldo Ferreira Santos
State University of Western Paraná, Graduate Program in Agricultural Energy Engineering, Brazil
E-mail: reginaldo.santos@unioeste.br

Samuel Nelson Melegari de Souza
State University of Western Paraná, Graduate Program in Agricultural Energy Engineering, Brazil
E-mail: ssouza@unioeste.br

ABSTRACT
Biodiesel is an alternative fuel obtained from natural and renewable sources, with several advantages over regular diesel. The objective of this work was to extract biodiesel from extra virgin Chia oil and analyze different diesel blends obtained. The method for carrying out this process was by transesterification of Chia extra virgin oil, with methanol and a catalyst (sodium hydroxide), at a temperature of 60°C, for 1 hour. Analysis of the biodiesel obtained. The results of the biodiesel obtained showed a chemical composition suitable for use as fuel. The most efficient mixture was the one containing 20% biodiesel and 80% ordinary diesel. In this sense, it is concluded that Chia extra virgin oil can be used as a source of biodiesel due to its suitable chemical composition. The blend of 20% biodiesel and 80% ordinary diesel was the most efficient in terms of emission of pollutant gases.

Keywords: Chia biodiesel, Biodiesel blends, Transesterification.

1 INTRODUCTION

Chia-based biodiesel is a renewable fuel produced from vegetable oils such as chia oil. It is a clean and efficient fuel that can be used in diesel vehicles with little or no modification. Chia-based biodiesel has been used as an alternative fuel for diesel vehicles because it is biodegradable, non-toxic, non-polluting and has a high calorific value. In addition, chia-based biodiesel is cheaper than regular diesel, which makes it an attractive option for drivers [11].

Chia-based biodiesel performs satisfactorily when used in blends with diesel. Studies show that blends of chia-based biodiesel and diesel can significantly improve engine performance by increasing power, fuel efficiency and fuel economy. In addition, blends of chia-based biodiesel and diesel have a lower environmental impact than regular diesel as they produce fewer greenhouse gas emissions [9].

According to the authors [2], incentives for biodiesel production can help reduce pollution caused by petroleum diesel. Biodiesel is a renewable fuel source that can be produced from natural sources such as vegetable oils, animal fats and algal oils. Biodiesel is biodegradable, contains no sulphur and produces fewer greenhouse gas emissions than petroleum diesel. In addition, biodiesel is cleaner and has less impact on human health. Therefore, incentives for biodiesel production can help reduce pollution caused by petroleum diesel.

The use of biodiesel blends in power generators can offer great environmental benefits. Biodiesel is a renewable fuel that is produced from natural sources such as vegetable oils, animal oils and fats. It is biodegradable, non-toxic and has a much smaller carbon footprint than fossil fuels. In addition, biodiesel is cleaner than fossil fuels as it produces fewer emissions of carbon dioxide, nitrogen oxides, hydrocarbons and particulate matter [12].

This means that the use of biodiesel blends in power generators can help reduce air pollution and contribute to a healthier environment. However, a thorough assessment of engine specifications should be carried out when higher blends of biodiesel are used in order to maximize these benefits and minimize the risks of engine damage [5].

Diesel engines are widely used in buses, trucks, agricultural machinery and generators, due to their high efficiency, power and fuel economy. The main advantage of diesel engines is that they are more efficient than gasoline engines as diesel is denser and contains more energy per unit volume than gasoline. This means that diesel engines can produce more power per unit of fuel consumed [3].

In addition, diesel engines are more durable and have less need for maintenance than gasoline engines. Another advantage of diesel engines is that they are more economical than gasoline engines. This means that they consume less fuel to produce the same amount of power. This makes diesel engines a more economical option for vehicles that need power, such as trucks and buses. In short, diesel engines are more efficient, durable and cost-effective than gasoline engines, making them an ideal choice for vehicles that need power [13].

According to [4], soy-based biodiesel is a renewable fuel that is produced from soybeans. It is also produced through a transesterification process, which involves mixing alcohol (usually methanol) with soybean oil and a catalyst. The result is a mixture of alcohol and oil, known as biodiesel. Soy-based biodiesel can be used in diesel engines as an alternative fuel. Engine tests show that soy-based biodiesel can improve engine performance by reducing pollutant emissions and increasing fuel efficiency.

In addition, soy-based biodiesel is biodegradable and does not contain heavy metals, which makes it safer for the environment. However, soy-based biodiesel also has some disadvantages. For example, it can have a higher production cost than regular diesel, and it can be more difficult to store and transport due to its high viscosity. In addition, soy-based biodiesel may contain impurities that can damage the engine. For these reasons, it is important that engines are properly calibrated to use soy-based biodiesel [14].

Transesterification is a chemical process that allows the production of biodiesel from vegetable or animal oils. The process involves the reaction of an alcohol (usually methanol or ethanol) with fatty acids to produce esters, which are the main components of biodiesel. The transesterification process improves the properties of biodiesel both in performance and pollutant emissions [15].

Biodiesel produced by transesterification has better combustion, which results in lower emissions of polluting gases. In addition, biodiesel produced by transesterification has greater stability, which means that it can be stored for longer without deteriorating. Finally, biodiesel produced by transesterification has higher lubricating power, which means that it can be used in older engines without problems [6].

The advantages of using biodiesel over conventional diesel can range from higher energy efficiency: Biodiesel has a higher energy efficiency than conventional diesel, which means that less fuel is needed to produce the same amount of energy. Lower emission of polluting gases: Biodiesel has lower emissions of polluting gases than conventional diesel, which means it is more environmentally friendly. Increased engine longevity: Biodiesel has fewer impurities than conventional diesel, which means it can help extend engine life. Improved safety: Biodiesel is less flammable than conventional diesel, which means it is safer to use. Greater availability: Biodiesel is easier to find than conventional diesel as it is produced from renewable sources such as used cooking oil [1].

Studies on different blends of chia biodiesel have focused on evaluating the performance of the fuel relative to conventional diesel oil. The results show that chia biodiesel performs similarly to conventional diesel oil but with some advantages [16].

For example, chia biodiesel has a higher oxidation stability, which means it can be stored for longer without deteriorating. In addition, chia biodiesel has a higher cleaning power, which means it can help reduce air pollution. Studies also show that chia biodiesel has a lower flash point, which means it is less likely to explode in case of accidents [10].

Given this context, this work aims to extract biodiesel from extra virgin Chia oil, through transesterification and analyze the different diesel blends obtained. Finally, to provide scientific evidence for the use of chia-based blends as renewable fuel. This study offers approaches to determine the effectiveness of blending biofuels with diesel and biodiesel derived from chia vegetable oil, in pursuit of achieving better engine performance. While many types of research are directed towards alternative products, this study approaches from a different perspective, a product (chia) that is little known and also has a high level of potential among other seed varieties. It focuses on evaluating the performance effects on a fuel type diesel engine prepared by blending chia biodiesel at a constant rate in mixture with diesel.

To this end, the paper was divided into three sections, in addition to this introduction and the concluding remarks. In this paper, Section 2 presents the materials and methods used in this research work. Section 3 presents the results and discussions of this research. Finally, Section 4 presents the final considerations and future work.

2 MATERIALS AND METHODS

The experiment was conducted in the Multiuser Laboratory of Sustainable Technologies (LABTES), linked to the Graduate Program in Agricultural Energy Engineering (PPGEA), Unioeste Campus of Cascavel. Associated with the laboratory is the CDTER - Center for Development and Technology of Renewable Energies, located at the Foundation for Scientific and Technological Development - FUNDETEC, in Cascavel-PR and the Center for Automotive Technology - CTA.

The development of this work is presented in three main stages. In the first moment, a physicochemical analysis of chia oil is carried out, as presented in Table 1, the results are presented. The physicochemical analysis of chia oil involves the evaluation of various parameters such as color, odor, acidity, fatty acid content, oxidative stability, viscosity, density, solubility, refraction, fluorescence, polarity, solubility in water, solubility in organic solvents, solubility in inorganic solvents, solubility in alcohols, solubility in acids, solubility in bases. The analysis was carried out by the Pool-Lab fuel laboratory in Itajaí - SC on June 22, 2022 as a scientific research.

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Table 1 - Properties of chia oil used in the transesterification process

Tests	Unit	Method	Specification	Results
Aspect	-	Visual	LII	LII
Visual Color	-	Visual	Yellow	YELLOW
Specific mass at 20 °C	kg.m-3	ASTM D 4052	820.0 to 853.0	887.7
Flash point	ºC	ASTM D 93	Min 38.0	>200
Water Sediments % (BSW)	%	ASTM D 1796	Max 0.05	ABSENT
Freezing point	ºC	ASTM D 97	NA	<-4
Kinematic Viscosity at 40ºC	cSt	ASTM D 445	1.5 to 6.0	3.832
Ester	%	Infra-red	NA	25.323
Total Aromatics	%	Infra-red	NA	0.80
Total Olefins	%	Infra-red	NA	19.56
Benzene	%	Infra-red	NA	0.03
Toluene	%	Infra-red	NA	11.81
Glycerol	%	Infra-red	NA	5.42
Corrosivity to copper	-	ASTM D 130	NA	1A
Water by Karl Fischer	PPM	ASTM D 6304	Max 200.00	874.2
LII - Clean and Free from Impurities e NA - Not applicable				

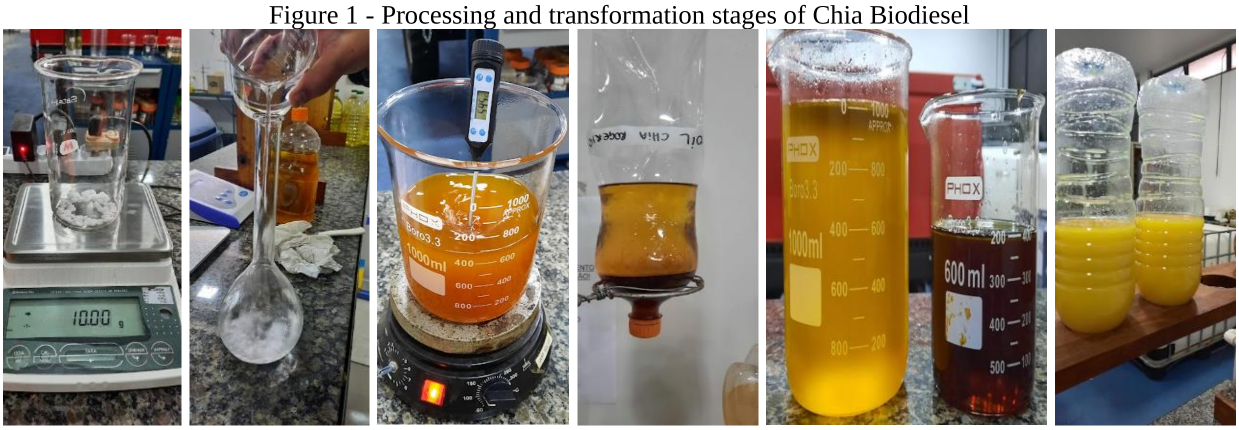
Secondly, the processing and compounding of chia biodiesel takes place. The process is divided into three main steps:

1. **Pre-treatment:** In this step, the chia seed is crushed and subjected to an extraction process to obtain the crude oil. In this research it is not applied, it was used from the extra virgin chia oil.
2. **Processing:** The crude oil is then subjected to a transesterification process, which is a chemical process that converts the oil into biodiesel.
3. **Refining:** Lastly, the biodiesel is refined to remove impurities and improve its quality. After refining, the biodiesel is ready for use.

For the preparation of the catalysts and the respective transesterification reactions, we used potassium hydroxide (KOH), methanol (CH_3 OH) and extra virgin chia vegetable oil as precursors. First, KOH was dissolved in methanol to form a catalyst solution. This solution was then added to the chia oil to initiate the transesterification reaction. This chemical reaction converts the triglycerides present in the oil into methyl esters, which are the main components of biodiesel. During the reaction, methanol is converted into methyl alcohol, which is one of the main components of biodiesel. The transesterification reaction is carried out under controlled temperature and pressure conditions, to ensure that the reaction takes place efficiently. After the reaction, the biodiesel is separated from the residual liquid, which is mainly composed of water and methanol. The resulting biodiesel is then filtered and stored for future use.

The recipe applied was, for each 500ml of Chia oil, 150ml of Methanol and 10g of Potassium Hydroxide was used. To carry out the transesterification reaction, a known homogeneous catalyst (potassium hydroxide) is used.

Figure 1 - Processing and transformation stages of Chia Biodiesel



In this reaction, as shown in Figure 1, Chia oil, Methanol and Potassium Hydroxide were mixed in a vessel. Then it was necessary to heat the mixture to the reaction temperature (usually between 60 and 70°C). When the temperature is reached, the catalyst (potassium hydroxide) is added to the mixture and the transesterification reaction is started. After the reaction, it was necessary to separate the mixture into two phases: a liquid phase (containing the biodiesel) and a solid phase (containing the catalyst). The liquid phase is then distilled to remove the methanol and any other residual solvent.

Finally, the resulting biodiesel is filtered to remove any impurities and stored in a clean, dry container. Finally, drying was carried out in an oven by leaving the washed biodiesel in a beaker for a period of 24h at 105^0 C in order to remove any water that may have remained in the biodiesel during washing. After drying, the biodiesel was stored in a clean and dry container, to be used later for testing.

The last stage of this study used three chia-biodiesel blends with different proportions of chia-biodiesel blend to premium diesel: premium diesel fuel (B0), B10 (10 vol% chia-biodiesel+90 vol% B0), B20 (20 vol% chia-biodiesel+80 vol% B0), B40 (40 vol% chia-biodiesel+60 vol% B0) and finally 100 vol% chia-biodiesel (B100).

The methodology of [7] was followed, using the equipment shown in Figure 2. The tests of were carried out at two different loads of 1.5k/w and 4.5kw, on a diesel generator and fed with four types of biofuel blends.

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Figure 2 - Engine generator as specified, load cell, resistor bank, multifunction meter and fuel consumption indicator

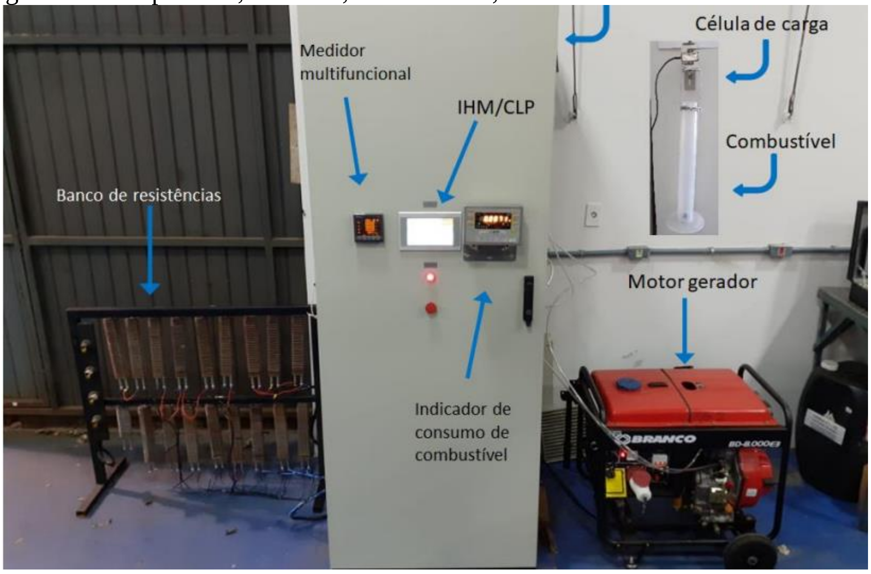


Table 2: White BD-8000 E3 Generator Engine Specifications.

Feature	Specification
Maximum power	8.0 kVA
Continuous Power	7.5 kVA
Output voltage	220 V
Phases	Three-phasic
Voltage Control	AVR / With brush
Tank capacity	10 L
Autonomy	5.0 h
Dimensions (L x W x H)	690mm x 450mm x 550mm
Weight	110 kg

The aim is to evaluate the stability of diesel blends with biodiesel produced with chia oil, according to the contents of B0, B10, B20, B40 and B100. The stability of diesel blends with biodiesel produced with chia oil will depend on the pre-defined B0, B10, B20, B40 and B100 contents. The higher the biodiesel content, the higher the stability of the blend. For example, a B10 blend is more stable than a B0 blend, while a B20 blend is more stable than a B10 blend. Also, B40 and B100 blends are more stable than B20 blends. However, it is important to note that chia oil may have different properties than other vegetable oils, so it is important to evaluate the stability of blends according to specific biodiesel contents.

The tests take place in two stages and different loads, in a total of six collections for each of these stages. The reading and data collection are presented as shown in Table 4, with interspersed times from minute to minute, two loads of 1.5 and 4.5 k/w, voltage (V), current (A), power (W), energy (KWh) and fuel mass (Kg). In this sense, it is expected to understand the energy generated (KWh), fuel consumption (L) and yield (KWh/L).

In this sense, for the characterization, the different blends of B10, B20, B40 and B100 were used in incremental steps in volume with diesel. As an example, B10 with a mixture of 50ml of biodiesel in addition to 450ml of diesel, B20 with 100ml of biodiesel and a complement of 400ml of diesel, B40 with 200ml of biodiesel and a complement of 300ml of diesel and finally, B100 with pure chia biodiesel.

3 RESULTS AND DISCUSSION

In this step will be demonstrated in detail the data collected during the research will be presented in the form of tables, with the information organized in a clear and objective way. The results will be presented in the form of graphs, with the data organized in a way that facilitates the understanding of the results. The graphs will be accompanied by a detailed explanation of the results, so that readers can better understand the data collected.

Regarding the blends made with biodiesel and pure diesel, Table 3 presents the estimated specific mass corresponding to the blends, by means of the biodiesel/diesel ratio, for the blends used in the fuel burning efficiency tests (B10, B20, B40 and B100).

Table 3 - Mass Specification Properties of Biodiesel, Diesel and the Blends

Specific mass							
Blends	10%	Biodiesel (kg/m³)	887,70	Diesel (kg/m³)	833,60	Blend (kg/m³)	839,01
	20%					Blend (kg/m³)	844,42
	40%					Blend (kg/m³)	855,24
	100%					Blend (kg/m³)	887,70

For the power generation efficiency test, the fuel consumption and power generated for each of the blends b0, b10, b20, b40, b60 and b100 were evaluated. The results showed that blend b0 (no biodiesel added) generated the least amount of energy, while blend b100 generated the highest amount of energy. In addition, blend b100 also consumed less fuel than the other blends. This indicates that the addition of biodiesel to diesel fuel increases the power generation efficiency. Table 4, 5 and 6 show the average values resulting from the respective blends in B10, B20 and B40.

Table 4 - Average fuel consumption in (kg) and (L) and energy yield generated for the respective blends in B10

Charge	Voltage (V)	Current (A)	Power (W)	Reading Energy (KWh)	Energy generated (KWh)	Fuel mass (kg)	Fuel Consumption (kg)	Fuel Consumption (L)	Yield (KWh/L)
4,5	232,16	11,58	4655,90	123,56	-	0,247	-	-	-
	232,16	11,55	4643,60	123,63	0,0700	0,222	0,0250	0,0298	2,3492
	232,17	11,54	4639,70	123,69	0,0600	0,198	0,0240	0,0286	2,0975
	232,21	11,53	4636,50	123,76	0,0700	0,167	0,0310	0,0369	1,8945
	232,21	11,52	4632,40	123,84	0,0800	0,137	0,0300	0,0358	2,2374
	232,23	11,51	4629,00	123,91	0,0700	0,108	0,0290	0,0346	2,0252
1,5	232,00	3,990	1597,80	123,91	-	0,106	-	-	-
	232,09	3,990	1598,70	123,94	0,0300	0,090	0,0160	0,0191	1,5731
	232,10	3,990	1597,50	123,96	0,0200	0,078	0,0120	0,0143	1,3983
	232,05	3,990	1597,80	123,99	0,0300	0,061	0,0170	0,0203	1,4806
	232,09	3,990	1597,20	124,02	0,0300	0,043	0,0180	0,0215	1,3984
	232,00	3,990	1596,70	124,05	0,0300	0,028	0,0150	0,0179	1,6780

Table 5 - Average fuel consumption in (kg) and (L) and yield energy generated for the respective blends in B20

Charge	Voltage (V)	Current (A)	Power (W)	Reading Energy (KWh)	Energy generated (KWh)	Fuel mass (kg)	Fuel Consumption (kg)	Fuel Consumption (L)	Yield (KWh/L)
4,5	232,28	11,57	4653,70	124,33	-	0,292	-	-	-
	232,23	11,54	4641,50	124,41	0,0800	0,263	0,0290	0,0343	2,3294
	232,32	11,52	4634,50	124,48	0,0700	0,237	0,0260	0,0308	2,2734
	232,31	11,52	4635,20	124,56	0,0800	0,209	0,0280	0,0332	2,4126
	232,32	11,52	4635,10	124,65	0,0900	0,181	0,0280	0,0332	2,7142
	232,32	11,52	4635,00	124,72	0,0700	0,154	0,0270	0,0320	2,1892
1,5	232,23	4,000	1600,90	124,73	-	0,150	-	-	-
	232,19	3,990	1600,10	124,75	0,0200	0,135	0,0150	0,0178	1,1259
	232,19	3,990	1599,00	124,78	0,0300	0,120	0,0150	0,0178	1,6888
	232,19	4,000	1599,90	124,81	0,0300	0,100	0,0200	0,0237	1,2666
	232,16	3,990	1598,20	124,83	0,0200	0,085	0,0150	0,0178	1,1259
	232,15	3,990	1598,00	124,85	0,0200	0,068	0,0170	0,0201	0,9934

Table 6 - Average fuel consumption in (kg) and (L) and yield energy generated for the respective blends in B40

Charge	Voltage (V)	Current (A)	Power (W)	Reading Energy (KWh)	Energy generated (KWh)	Fuel mass (kg)	Fuel Consumption (kg)	Fuel Consumption (L)	Yield (KWh/L)
4,5	232,35	11,55	4647,10	125,15	-	0,252	-	-	-
	232,35	11,54	4643,80	125,23	0,0800	0,225	0,0270	0,0316	2,5340
	232,34	11,53	4639,10	125,30	0,0700	0,201	0,0240	0,0281	2,4944
	232,36	11,52	4635,70	125,37	0,0700	0,176	0,0250	0,0292	2,3947
	232,36	11,52	4636,00	125,44	0,0700	0,149	0,0270	0,0316	2,2173
	232,38	11,52	4635,80	125,51	0,0700	0,123	0,0260	0,0304	2,3026
1,5	232,25	4,000	1601,60	125,52	-	0,119	-	-	-
	232,06	4,000	1601,10	125,56	0,0400	0,100	0,0190	0,0222	1,8005
	232,19	3,990	1599,60	125,58	0,0200	0,085	0,0150	0,0175	1,1403
	232,20	4,000	1600,40	125,61	0,0300	0,069	0,0160	0,0187	1,6036
	232,16	4,000	1599,50	125,62	0,0100	0,058	0,0110	0,0129	0,7775
	232,14	3,990	1599,10	125,65	0,0300	0,038	0,0200	0,0234	1,2829

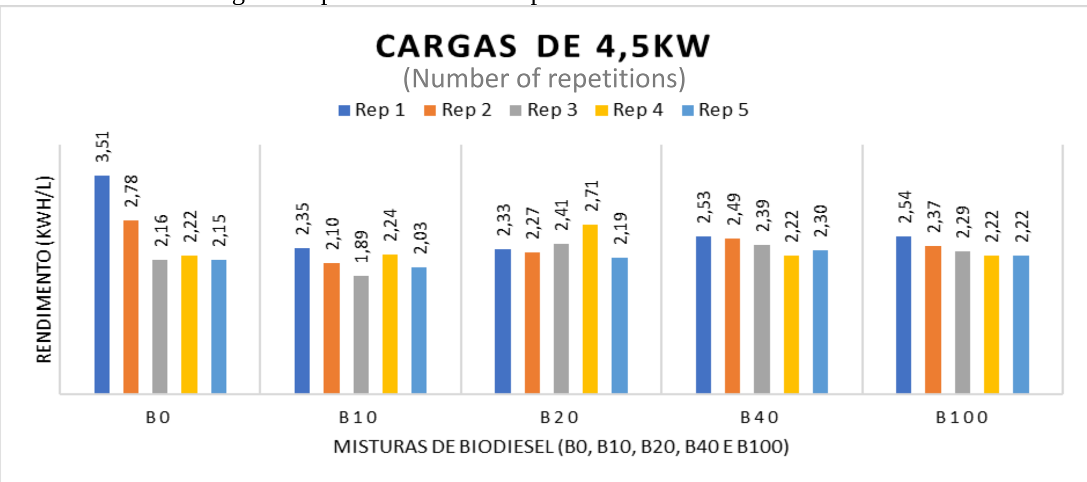
It can be observed in Tables 4, 5 and 6 that the resistive load of 4.5kW, presents a difference for both the energy generated and the fuel consumed by the Tukey test at 5% of variance, which does not occur with the load of 1.5kW in both mixtures occurred.

The difference in power generated and fuel consumed is due to the higher resistive load of 4.5kW. As the load is higher, the engine needs more fuel to generate the same amount of power. This means that for the same amount of fuel, the 4.5kW engine will generate less power than the 1.5kW engine. In addition, the 4.5kW load also consumes more fuel than the 1.5kW load. Therefore, the difference in power generated and fuel consumed between the two loads is significant.

The behavior of the engine specific consumption as a function of the load variation of 4.5kw applied to the engine generator can be observed in Figure 3.

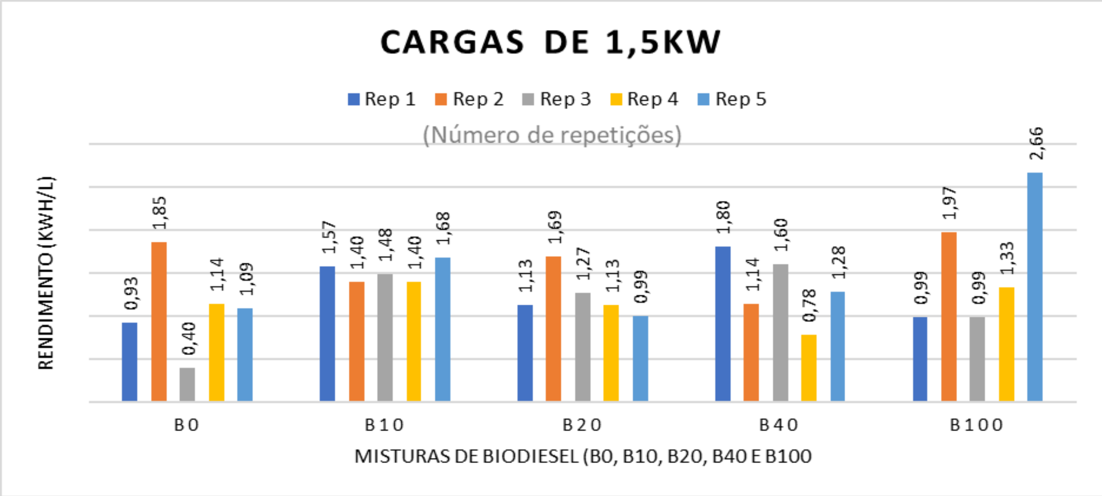
And with regard to fuel consumption, there was a significant difference between pure diesel (B0) and the blends tested. On the other hand, the burning of pure biodiesel (B100) did not differ statistically from any of the others and an increase in the average was observed. In addition, the B20 blend presented in the first and second repetition a lower fuel consumption than pure diesel (B0). These results suggest that the B20 blend may be a viable alternative to reduce fuel consumption.

Figure 3 Specific fuel consumption for the 4.5KW loads tested



Then the behavior of the engine specific consumption as a function of the load variation of 1.5kw applied to the engine generator can be observed by means of the engine power curve. This curve shows how the engine power varies with the applied load, and can be used to determine the specific engine consumption. The engine power curve is usually obtained through performance tests carried out on a test bench as shown in Figure 4.

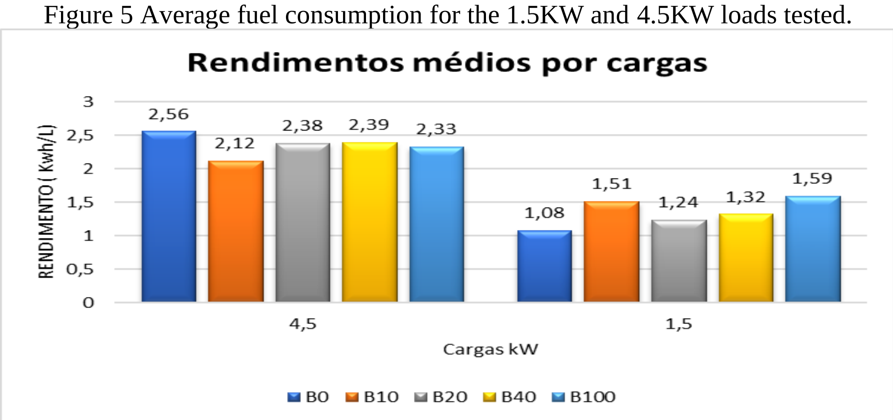
Figure 4 - Specific fuel consumption for the 1.5KW loads tested



Through repetitions at different loads, the specific consumption of each of the mixtures can be determined, as shown in the graphs in Figures 3 and 4. The specific consumption is the amount of fuel required to produce one unit of energy. For example, if a fuel mixture is used to generate 100 units of energy, and if the fuel consumed is 10 liters, then the specific consumption is 0.1 liter per unit of energy. This information can be used to compare the efficiency of different fuel blends.

Tukey's Test is a statistical test used to compare multiple groups at the same time. It is used to determine if there are significant differences between the groups. The test was developed by American statistician John Tukey in 1953. The test is based on the comparison of all pairs of groups and uses a significance level to determine if there are significant differences between the groups. The test was used to assess whether there are significant differences between groups on a response variable. The test is used to test hypotheses about the equality of means between groups. Tukey's test for the resistive load of 1.5 kW found that there is a significant difference in the specific consumption of diesel (B0) compared to the other blends, except pure biodiesel (B100) which in turn showed no statistical difference compared to the other blends.

Figure 5 Average fuel consumption for the 1.5KW and 4.5KW loads tested.



It can be observed from the graph presented in Figure 5, and the Tukey test at 5% indicates that diesel had higher specific consumption at the 4.5 kW load than the biodiesel blends tested. This means that diesel was more efficient than the biodiesel blends, which means that diesel is a more efficient option for use in diesel engines.

4 FINAL CONSIDERATIONS

This work enabled the production of biodiesel from extra virgin chia oil by transesterification method. The transesterification process is a chemical method used to convert vegetable oils into biodiesel. The process involves the reaction of alcohols, such as methanol or ethanol, with vegetable oils to produce methyl esters, which are the main components of biodiesel.

To produce biodiesel from chia oil, the oil must be heated and mixed with an alcohol, such as methanol or ethanol. A base, such as sodium hydroxide, is added to the mixture to speed up the reaction. The alcohol reacts with the fatty acids in the oil, forming methyl esters and glycerin. The glycerin is separated from the biodiesel, which is then filtered to remove impurities.

Biodiesel produced from chia oil has several advantages. It is biodegradable and does not pollute the environment. In addition, it is more efficient than fossil fuels as it has a high energy yield. Biodiesel is also safer than fossil fuels as it does not contain carcinogenic compounds. Therefore, the production of biodiesel from chia oil by transesterification method is a viable alternative for the production of clean and efficient fuels.

Furthermore, after the transesterification reactions, the catalyst was recovered and continued to show catalytic activity, i.e. it could be used again. The recovery of the catalyst is possible due to the chemical characteristics of phosphoric acid, which is a strong acid, meaning that it does not bind to the catalyst atoms, but to the oil molecules. Thus, when the phosphoric acid is removed, the catalyst is released and can be reused.

As a result of the tests, the addition of chia biodiesel to diesel increased the energy efficiency of the generator, with the highest increase recorded when using B20 (average increase of 0.87%). In addition, it was observed that the use of chia biodiesel significantly reduced greenhouse gas emissions, with average reductions of up to 20.4% for B20. The results also showed that the use of chia biodiesel did not affect fuel quality as there were no significant differences in fuel quality parameters.

As future work, it is suggested to evaluate the levels of gases expelled during combustion by the engine, since the mixtures did not show a difference in consumption between them. Finally, to perform tests with other methods of extraction of biodiesel. In addition, it would be interesting to carry out performance tests on diesel engines with biodiesel and diesel blends, evaluating power, torque, fuel consumption and polluting gas emissions. These tests could be carried out under different operating conditions, such as acceleration, constant speed, hill climbing, etc. Another possibility would be to evaluate the effects of the biodiesel and diesel mixture in comparisons to gasoline engines. Finally, it would be interesting to carry out cost-benefit studies to assess the economic viability of biodiesel production and use.

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