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EMISSIONS AND PERFORMANCE OF A DIESEL ENGINE AFFECTED BY CRAMBE BIODIESEL BLENDS

Leonardo da S. Reis[1*], Reginaldo F. Santos[1], Cristiano F. Lewandoski[1], Evelyn T. C. Silva[1], Wilson A. de Oliveira[1]

[1*]Corresponding author. Universidade Estadual do Oeste do Paraná/Cascavel - PR, Brasil.
E-mail: leonardoreis183@gmail.com | ORCID ID: https://orcid.org/0000-0002-9239-6158

KEYWORDS

Crambe abyssinica Hoechst, oilseeds, crambe biodiesel.

ABSTRACT

Brazil has been facing a huge rise in fuel and diesel prices due to the rise in the international market and the war between Ukraine and Russia. The rise in electricity prices is also a problem that affects everyone in Brazil. This study aimed to evaluate the performance and emissions of a diesel engine for power generation that operates with crambe-based fuels with blends of 0% (control), B5, B10, B15, B20, B50, B70, and B90. The fuels were tested in an 8 kVA generator engine at a load of up to 6000 W. The biofuels were obtained from a mixture of diesel with crambe biodiesel at incremental levels from B0 to B90 in the fuel mixture. The increased proportion of crambe biodiesel resulted in lower specific consumption. Crambe biodiesel resulted in a reduction of CO, CO_2, and NO_2 emissions due to an increase in crambe biodiesel at the proportion. The results indicate that crambe biodiesel blends are viable technical solutions for the partial replacement of conventional diesel.

INTRODUCTION

Commercial production of vegetable oils is based on mechanical pressing and extraction. The mechanical extraction of oil from oilseeds is one of the most used methods to obtain their oil (Sriti et al., 2011, 2012; Kartika et al., 2010), highly effective in a single step and continuously (Evon et al., 2015). Mechanical pressing provides a simple means of processing small lots of seed. It helps the commercial establishment of these new oilseeds (Lewandoski et al., 2021).

Crambe seeds (*Crambe abyssinica* Hochst) have 35–45% oil, and up to 55–60% of this oil is composed of erucic acid, unsuitable for human consumption, but it has been gaining great space in other fields, such as the industrial manufacture of oils, lubricants, plastics, and biodiesel (Bassegio et al., 2016; Costa et al., 2019).

Oilseed crops that offer higher oil yields than soybeans have been studied in recent years, including crambe. Crambe (*Crambe abyssinica* Hochst) has the potential for the production of biodiesel, as its grains contain up to 45% industrial oil, with easy winter cultivation (Bassegio et al., 2016).

Biodiesel produced with oilseeds can replace diesel without major losses (Silva et al., 2012). In addition, combustion engines that operate with fuels derived from petroleum, such as diesel cycle engines, are responsible for the emission of particulate matter such as carbon dioxide (CO_2), nitrogen oxides (NO_2), carbon monoxide (CO), and aromatic hydrocarbons. Pollutant emissions decrease as biofuel concentrations in a blend with conventional fuel increase (Rizwanul et al., 2013). However, Mofijur et al. (2014) reported that, in general, the use of biodiesel increases NO_2 emissions. Sharma et al. (2009) and Murthy (2010) found a reduction in NO_2 emissions compared to diesel with the use of peanuts, cotton, and tobacco, whereas Puhan et al. (2009) and Ganapathy et al. (2011) reported an increase in NO_2 emissions with flaxseed and jatropha compared to diesel. It justifies the importance of evaluating different oilseeds regarding their performance and engine emissions.

Aligned with issues of environmental sustainability and social development, and based on the Brazilian

[1] Universidade Estadual do Oeste do Paraná/Cascavel - PR, Brasil.

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agricultural potential, this study aimed to evaluate the emissions and performance of a diesel engine operating with diesel with crambe biodiesel blends from 0 to 100%.

MATERIAL AND METHODS

Characterization of the experimental area and raw material

The present study was carried out in the Laboratory of Sustainable Technology (LABTES) at the Western Paraná State University, Cascavel, PR, Brazil.

Automated mechanical extruder

A Z-1500 press manufactured by the company Galvão Insumos, with a general power supply at 220Vac three-phase, with a 0.5-hp motor for feeding SEW grains, and the main motor of 7.5 hp SEW, with a maximum rotation of 1800 rpm. The project was developed using the latest 4.0 automation technology, with a CLP Delta, an IHM DOP100, and two MS300 inverters. The equipment is on an Industrial Modbus network. This protocol allows a fast communication of commands between the extruder hardware and other external hardware if necessary (Cristiano et al., 2021).

The temperature measurement was performed with PT100 sensors ranging from –100 to +400 °C, model FSB-RTD-BRA-T60-U23-B03-C15-BF Novus. A Delta temperature indicator model transducer was used to convert the PT100 electrical signal to a 4–20 mA signal. The rotation variation (RPM) of the oil extraction spindle motor was possible with the installation of an MS300 frequency inverter. An HMI (Human Machine Interface) installed in the equipment was used to control and adjust the rotation and temperature of the experiment.

Oil and generator

The crambe oil used to produce crambe biodiesel was produced through a process of mechanical pressing of grains in the Zaamp Z1500 extruder.

The motor-generator set used in the tests was a Branco DB-8000E3. It has an electric start, is air-cooled, single-cylinder, and has a diesel cycle. The motor-generator set did not undergo mechanical adjustments and its originality was maintained during the tests.

Biodiesel

Crambe oil was transformed into biodiesel at LABTES. Biodiesel was obtained by a transesterification reaction with potassium hydroxide (KOH) as catalyst (1% of oil weight) and methanol (CH_3OH) as alcohol (25% of oil volume). First, methanol and potassium were mixed vigorously for 10 to 20 minutes. Second, the formed potassium methoxide was mixed with oil in a round bottom flask, stirred continuously using a magnetic stirrer, and maintained at a temperature of 60 °C. At the end of the reaction time, the content was transferred to a separatory funnel and remained in it for 24 h to be separated into two layers. After separation, the biodiesel was subjected to a washing process with warm distilled water. Finally, the biodiesel was placed in an oven to remove excess water at 105 °C for 24 hours (Rosa et al., 2014; Leite et al., 2019).

Biodiesel-diesel blend

The tests were conducted in a completely randomized experimental design with resistive electrical load demands of 1000, 1500, 4500, and 6000 W and seven different fuel concentrations: crambe B5 (5% crambe biodiesel and 95% diesel), crambe B10 (10% crambe biodiesel and 90% diesel), crambe B15 (15% crambe biodiesel and 85% diesel), crambe B20 (20% crambe biodiesel and 80% diesel), crambe B50 (50% crambe biodiesel and 50% diesel), crambe B70 (70% crambe biodiesel and 30% diesel), and crambe B90 (90% crambe biodiesel and 10% diesel). The blend choices were driven by the mandatory Brazilian B10 biodiesel-diesel blend, the B15 target for 2023, doubling the B30 target, and achieving B100.

Biodiesel characteristics

Table 1 below shows the biodiesel characteristics.

TABLE 1. Features of Biodiesel.

	Unit	Method	Specification	B5	B10	B15	B20	B50	B70	B90	B100 (control)
Aspect	-	Visual	CFI	CFI	CFI	CFI	CFI	CFI	CFI	CFI	CFI
Visual color	-	Visual	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Specific weight (20 °C)	Kg/m³	ASTM D 4052	820 to 853.0	836.2	838	838.7	841.9	854.3	863	869.4	833.6
Flash point	°C	ASTM D 93	38 °C min	57	56	57	58	63	71.5	103	58
Water sediments – BSW	%	ASTM D 1796	0.05 max	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent
Biodiesel content	%	Infra-red	9.5 to 10.5	4.03	8.08	10.9	16.58	44.05	78.94	93.6	0.25
Freezing point	°C	ASTM D 97	NA	< - 8	< - 7	-5	-4	-4	-3	0	< -9
Viscosity (40 °C)	cSt	ASTM D 445	1.5 to 6.0	2.299	2.427	2.555	2.555	3.449	4.343	5.237	2.427
Total aromatics	%	Infra-red	NA	3.6	3.1	2.72	2.03	0	0	0	4.14
Total olefins	%	Infra-red	NA	4.23	4.99	5.57	6.64	12.49	17.03	20.97	3.62
Benzene	%	Infra-red	NA	0.06	0.05	0.06	0.05	0.03	0.02	0.02	0.06
Toluene	%	Infra-red	NA	2.31	2.82	3.16	3.83	7.05	9.46	11.39	1.81
Corrosivity to copper	-	ASTM D 130	NA	1A	1A	1A	1A	1A	1A	1A	1A
Water by Karl Fischer	PPM	ASTM D 6304	200.0 max	77.1	99	117.68	152.46	340.38	483.21	597.46	48.97
NA – Not applicable											
CFI – Clear and free of impurities											

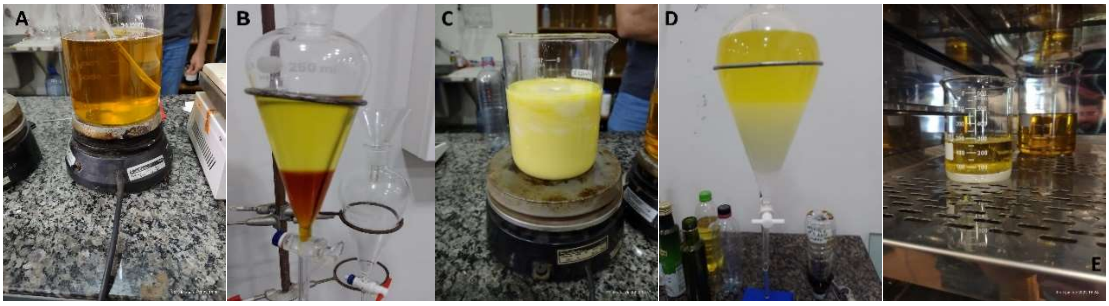


FIGURE 1. Crambe oil and methyl alcohol mixing process (A), separation of glycerin from crambe biodiesel (B), crambe biodiesel washing process (C), biodiesel washing separation (D), biodiesel drying in the greenhouse (E).

Engine tests

The operating performance parameters were evaluated under different loads fed by a 6000 W power generator set (Table 2). The motor-generator set was operated at four load levels: 1000, 1500, 4500, and 6000 W (Fig. 2).

$$SFC = (m_i - m_f) / P_e \times t \quad (1)$$

Where:

SFC is the specific fuel consumption (g kW^{-1} h^{-1});

m_i is the fuel mass at the beginning of the test (g);

m_f is the fuel mass at the end of the test (g);

P_e is the engine power (kW), and

t is the consumption time in hours of operation of the generator engine.

Emissions and exhaust gas temperature

Gas analysis was performed on benchtop combustion analysis equipment (Infralyt ELD, SAXON) (Klajn et al., 2018; Leite et al., 2019). Table 3 shows the measurement ranges and accuracy.

RESULTS AND DISCUSSION

TABLE 2. CO_2 data sample.

Power	DIESEL	B5	B10	B15	B20	B50	B70	B90
P500	3.95	3.68	3.75	3.55	3.45	3.56	3.52	3.6
P500	3.95	3.71	3.68	3.61	3.48	3.37	3.53	3.42
P500	3.99	3.66	3.56	3.46	3.41	3.4	3.54	3.38
P1500	5.67	7.88	3.39	5.21	5.16	5.02	3.68	5.01
P1500	5.67	8.52	7.99	5.24	5.17	5.01	3.69	4.99
P1500	5.66	8.66	8.14	5.24	5.15	4.67	3.7	7
P4500	8.86	8.61	9.11	6.75	5.16	7.97	3.73	8
P4500	8.84	9.93	9.67	6.65	5.16	8.11	3.74	8.01
P4500	8.86	10.24	9.91	6.48	7.12	8.14	3.75	7.95
P6000	10.1	10.32	10.01	6.38	7.86	8.71	3.76	8.69
P6000	10.46	10.38	10.11	7.98	8.02	9.21	3.77	9.17
P6000	10.64	10.39	10.2	9.03	8.06	9.43	3.78	9.38

TABLE 3. CO_2 normality test.

Variable	Observation	Observation with missing data	Observation without missing data	Minimum	Maximum	Mean	Standard deviation
DIESEL	12	0	12	3.950	10.640	7.221	2.655
B5	12	0	12	3.660	10.390	7.998	2.739
B10	12	0	12	3.390	10.200	7.460	2.942
B15	12	0	12	3.460	9.030	5.798	1.756
B20	12	0	12	3.410	8.060	5.600	1.763
B50	12	0	12	3.370	9.430	6.383	2.410
B70	12	0	12	3.520	3.780	3.683	0.097
B90	12	0	12	3.380	9.380	6.550	2.320

Shapiro-Wilk test (B20 | P1500):

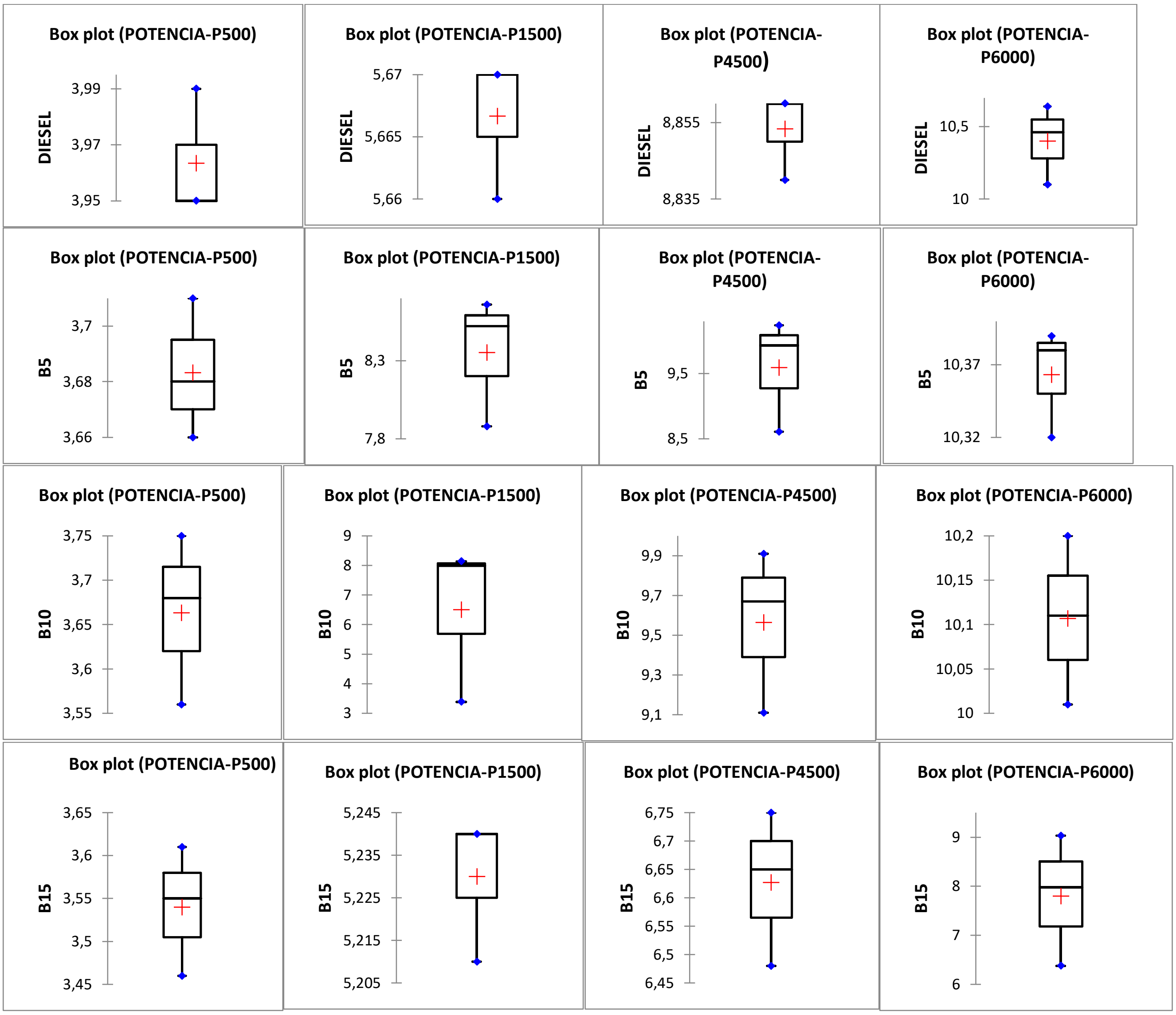
W	1.000
p-value	1.000
alpha	0.05

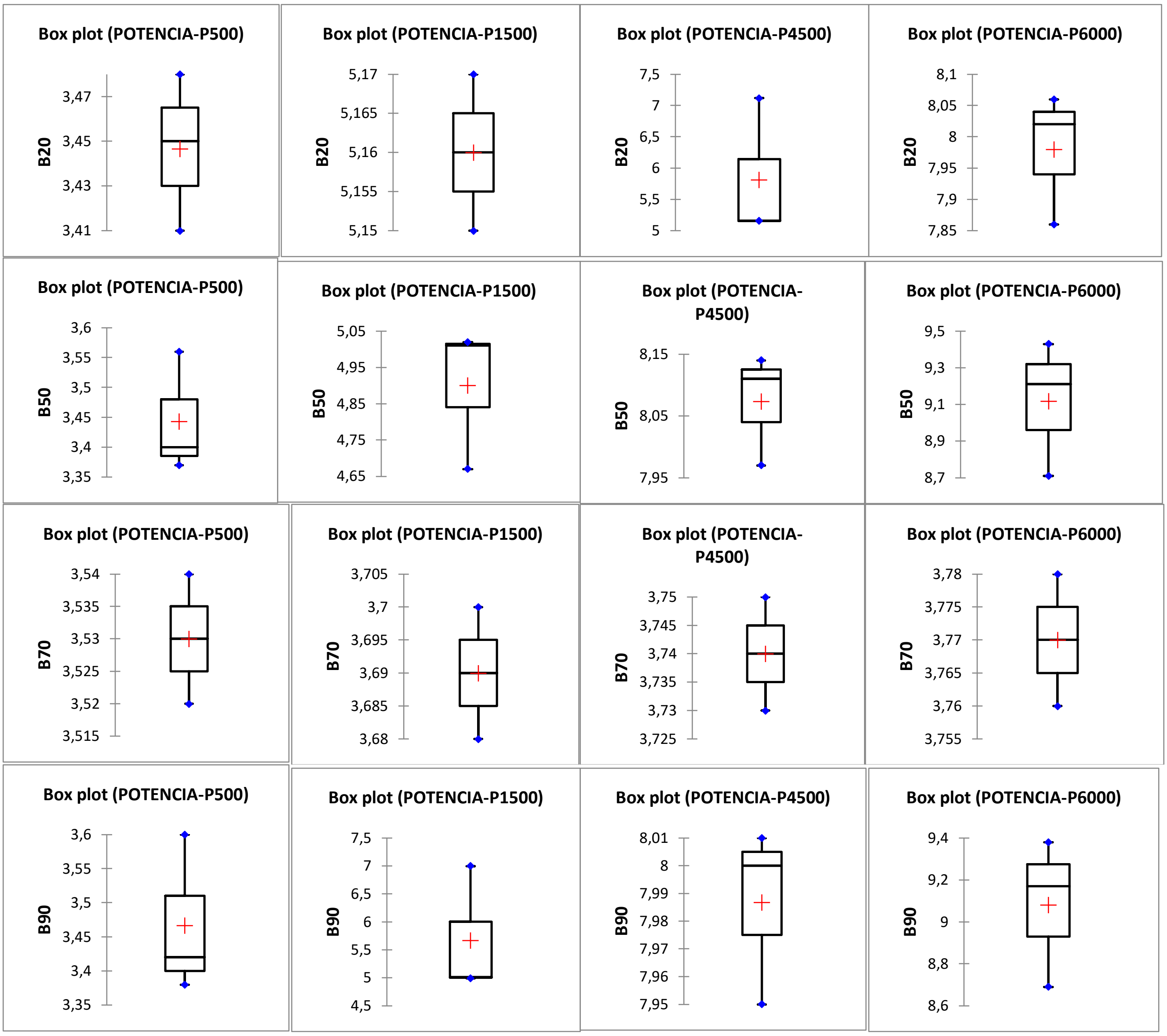
Test interpretation:
H0: The variable from which the sample was taken follows a normal distribution.
Ha: The variable from which the sample was taken does not follow a Normal distribution.

The null hypothesis H0 is not rejected because the calculated p-value is higher than the alpha=0.05 significance level.

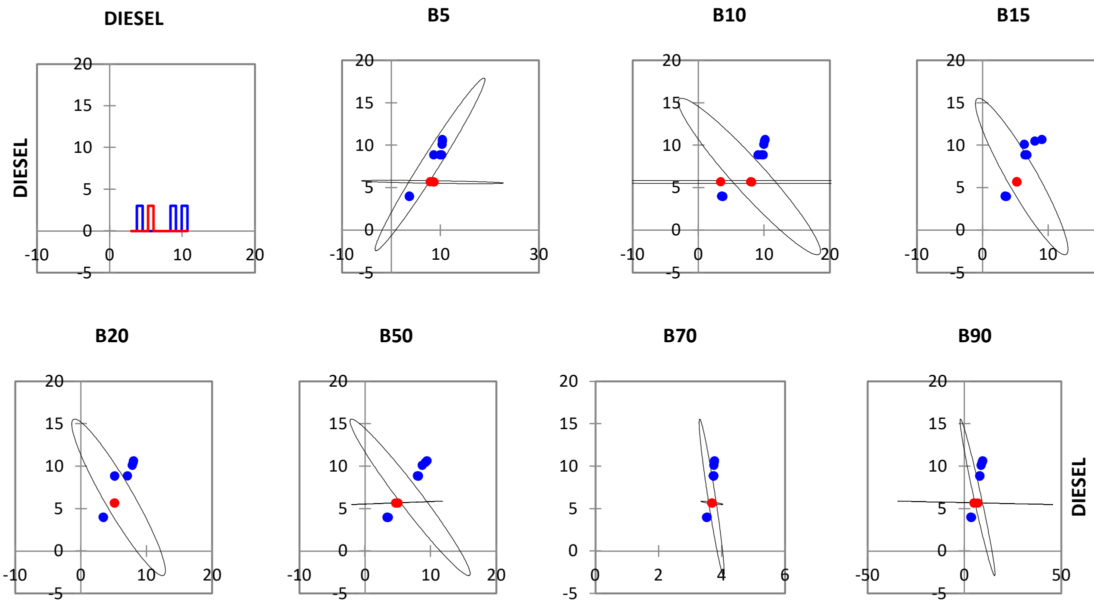
The risk of rejecting the null hypothesis H0 when it is true is 100.00%.

GRAPH 1. Box plot test for CO_2.





GRAPH 2. Pearson correlation for CO_2.



Biodiesel density increased linearly as a function of an increase in vegetable oil in biodiesel blends, regardless of the oilseed plant. The density increased from 0.84 to 0.89 g cm^3 for soybean biodiesel, 0.84 to 0.90 g cm^3 for linseed biodiesel, and 0.84 to 0.88 g cm^3 for crambe biodiesel for B10 and B70 blends, respectively. Leite et al. (2019) reported a diesel density of 0.83. Mofijur et al. (2014) reported that the power reduction when using palm (B10) and moringa biodiesel (B10) can be caused by the high oil viscosity. Furthermore, the presence of oxygen in biodiesel can cause a decrease in the calorific value (Dorado et al., 2003; Erdogan et al., 2019). Yesilyurt & Cesur (2020) reported that researchers generally found a reduction in power with the use of safflower biodiesel blends, observed with other raw materials and oilseeds. İlkiliç & Yücesu (2008) observed that the power of a diesel engine was higher than that of an engine using biodiesel blends. However, according to İlkiliç & Yücesu (2008), the engine power with lower loads using crambe and diesel biodiesel blends was approximately the same (Graph 2). It might be attributed to the test engine's higher efficiency temperature using biodiesel blends. Biodiesel fuels have enough time to be completely burned at lower speeds and the conversion of the fuel into energy is sufficient (İlkiliç & Yücesu, 2008).

The specific consumption of crambe biodiesel compared to pure S10 diesel was similar to that of blends and engine loads. Specific fuel consumption is higher for crambe biodiesel (Table 2) and commercial pure S10 diesel (Graphs 1 and 2) than for diesel, especially at low loads. The use of biodiesel blends increased the amount of fuel needed to obtain the same amount of engine braking power because an increase in biodiesel content reduced calorific value.

Effect on emissions

CO_2 emissions were different for crambe biodiesel compared to commercial diesel at low loads (Table 2). According to Simsek (2020), CO_2 values started to differ after the motor load reached 3000 W. CO_2 emission decreased for pure S10 diesel compared to B20 crambe biodiesel. Simsek (2020) observed that the highest CO_2 emission at loads of 3000 W was achieved with B5, while the lowest CO_2 emission value was reached with B20. The oxygen present in biodiesel enhances the burning of carbon molecules leading to more complete combustion (Aydın & Bayindir, 2010). The use of biodiesel results in more efficient performance with higher engine loads and higher combustion temperatures, generating fewer CO emissions (Kivevele et al., 2011). CO_2 emission decreased with increasing biodiesel concentration, especially under high loads for crambe biodiesel and commercial S10 diesel (Table 2 and Graph 21). CO_2 emission from the exhaust represents a loss of chemical energy during combustion due to incomplete diesel burning (Kalam et al., 2003; Deheri et al., 2020). A high cetane index is a parameter that improves combustion in diesel engines. The incomplete combustion rate decreases with the use of high-cetane fuels, and the total amount of combustion increases (Simsek, 2020; Leite et al., 2019).

CONCLUSIONS

The emissions and performance of a motor-generator using crambe biodiesel blends were compared with those of an engine using commercial S10 biodiesel. Although crambe does not meet the commercial demand for biodiesel in Brazil, detailed studies such as the present research are needed for diversifying with unknown species, given the increase in blends and demand for biodiesel. Generally, crambe biodiesel characteristics and its blends are similar to those of commercial diesel. Regarding engine performance, the specific consumption of crambe biodiesel and commercial diesel was similar. Despite this, crambe B15 reduced the specific consumption by 2% compared to diesel (S10) at a load of 6000 W. Crambe B20 biodiesel showed lower CO_2, CO, and NO_2 emissions compared to commercial diesel in high engine loads. Therefore, the crambe B20 biodiesel blend is a viable alternative for the partial replacement of conventional diesel.

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