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Effect of type of fuel and speed of engine on the performance of agricultural tractor

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Given the need for new alternatives to finite source of energy from fossil fuels, testing of alternative fuels has become quite important. Studies have been carried out using sets of tractor with equipment to evaluate the operational performance together with supplying diesel and biodiesel. Biodiesel is a feasible alternative as it waives adjustments in diesel cycle engines, unlike other clean fuels such as natural gas or biogas, for example. This study aimed at to assess the operational performance and smoke density of a tractor running on diesel and biodiesel, through the parameters of fuel type and engine speed. The assessed engine speeds were 1800, 1900, 2000, 2100, 2200, 2400 and 2600 rpm and the fuel types were diesel B S1800, diesel B S500, soyabean biodiesel and murumuru biodiesel. The results showed that there was an increase in the specific consumption for all fuel types with increasing engine speed, and 1900 and 2000 rpm, mainly for the use of biodiesel speed range that least interferes with the performance. The smoke density was reduced when using soyabean and murumuru biodiesels.

Key words: Biofuel, specific consumption, smoke density, operational performance, engine speeds.

INTRODUCTION

Diesel cycle engines are widely used in agriculture, transport and industry due to their combustion efficiency, reliability, adaptability and cost-effectiveness; however, increasing vehicle fleets have promoted a significant raise in carbon dioxide (CO_2) emissions (Dawody and Bhatti, 2014; Labeckas et al., 2014; Rashedul et al., 2014). Air quality detriment, especially in urban centers, has attracted scientists' attention with a view to proposing solutions and taking mitigation actions against atmospheric impacts. Brazilian researches on biofuels as energy sources have been assuming major proportions in the recent years (Schirmer and Gauer, 2012). However, most of these investigations are restricted to replacing gasoline and diesel in terms of production and energy equivalence. Thus, studies on biofuels and on greenhouse emission reductions have utter importance as preventive measure for environmental issues. Chemically, biodiesel is an oxygenated fuel consisting of

long-chain fatty acid which contain 10 to 15% oxygen by weight, deriving from renewable biomass for use in internal combustion engines with ignition by compression, thus being able to replace, partially or completely, petroleum-derived diesel fuel (Can, 2014; Sorate and Bhale, 2015).

A diverse number of raw materials are to be used in biodiesel production, such as vegetable oils and animal fats (Bunce et al., 2010; Lim and Teong, 2010). The oil extracted from peanut, corn, soyabean, palm, cotton, babassu, sunflower seed, castor bean, among many other seeds, almonds or pulps are likely to be considered suitable raw materials for biodiesel production (Tapanes et al., 2013). It is noteworthy that a molecular oxygen donated to the biodiesel constituting molecules confers the improved burning thereof. With a more efficient burning, lower levels of harmful pollutants are released into the environment, which may include particulate matter (PM), CO, CO_2, volatile organic compounds and total unburned hydrocarbons (Özener et al., 2014).

In addition to low sulphur contents, this fuel has a steadier density range (0.82 to 0.85 gcm^3) and higher cetane number (CN_{min} = 46). As vehicle benefits, one can mention improved cold starting, reduced engine deposits and less lubricant contamination, aside from lower environmental emissions of sulphur (up to 90%) and particulate matter (Silveira, 2013).

Performance of engine when running on biodiesel or blends with diesel largely depends on the combustion air turbulence, air-fuel mixture quality, injector pressure, actual start-of-combustion, among others. Furthermore, it may vary with biodiesel source quality and conditions, as well as engine operating parameters as speed, load, etc. Biodiesel use in agricultural tractors can be assessed by determining engine power, torque, fuel consumption and gas emissions (Harch et al., 2014). Nagi and Nagi (2008) tested a model of four-stroke diesel engine (DWE–47–50–HS–AV) fueled with palm biodiesel at a maximum torque of 3200 rpm. Testing was monitored at 650, 1000, 1350, 1700 and 2050 rpm measuring time spent to consume each 100 mL fuel. Based on that, the authors asserted that palm biodiesel consumption takes longer time and provided lower specific consumption if compared to diesel (16.8%). Therefore, it may be assumed that varied engine working speeds and types of fuel (diesel or biodiesel) can affect tractor operational performance and smoke opacity. Considering this scenario, this study aimed to assess the tractor performance, fuel consumption and smoke opacity of different engine speeds and fuel types.

MATERIALS AND METHODS

The study was conducted at the Department of Agricultural Engineering, Biofuels and Machine Tests (BIOEM) of the Faculty of Agricultural and Veterinary Sciences (FCAV), São Paulo State University (UNESP), campus in Jaboticabal, SP, Brazil. The area is located laterally to the road path *Via de Acesso Prof. Paulo Donato*

Castellane, km 5, at the geographical coordinates of 21° 15' S and 48° 18'W, with an average altitude of 570 m. The area has an average annual temperature of 22.2°C, average annual rainfall of 1425 mm, average relative humidity of 71% and atmospheric pressure of 94.3 kPa. According to Köppen, local climate is classified as *Aw* type, which stands for tropical humid with rainy summers and dry winters (UNESP, 2015).

Local soil was classified as a typical eutro ferric Red Latosol (Oxisol) on a flat to gently wavy relief (3% slope), according to the Brazilian System of Soil Classification (Nagi and Nagi, 2008). Soil moisture contents during chisel-plow pilot testing, measured by standard gravimetric method, at the depth ranges of 0 to 15 cm and 15 to 30 cm were 11.2 and 13.4%, respectively. The particle size analysis of soil samples taken from 0 to 20 cm depth range showed rates of 51, 29, 10 and 10% for clay, silt, fine sand and coarse sand, respectively, that is, a clayey textured soil.

Two types of biodiesel were used: refined soybean (*Glicinemax* L.) and refined murumuru (*Astrocaryum murumuru* MART). Biofuels were produced and supplied by our partner LADETEL (Laboratory of Clean Technology Development), São Paulo University (USP), campus in Ribeirão Preto - SP, Brazil. The fossil diesels used were B S1800 and B S500, being respectively purchased in Jaboticabal - SP and São Paulo - SP, Brazil, with maximum total sulphur of 1800 and 500 mg kg^{-1}, and specific masses of 860 and 840 kg m^{-3}, respectively, according to ANP resolution n° 42/ 2009 (ANP, 2009).

The testing tractor was a Valtra, model BM 125i, 4×2 with front wheel assist (FWA), maximum engine power of 91.9 kW (125 hp) at 2300 rpm (ISO1585). The tractor was equipped with turbo charger and intercooler, total mass of 7000 kg, distributed 40% and 60% in the front and rear axles, respectively, mass/power ratio of 76 kgkW^{-1} (56 kghp^{-1}), and 14.9–26 front tires and 23.1–30 rear tires, calibrated according to the manufacturer's recommendation. The braking tractor was a Valmet, model 118–4, 4×2 with front wheel assist (FWA), engine power of 82.43 kW (112 hp) at 2400 rpm, total mass of 7310 kg, distributed 40 and 60% respectively in the front and rear axles, and equipped with 14.9–28 front tires and 23.1–30 rear tires.

Performance was analyzed with a testing tractor Valtra BM 125i instrumented with load cell, slippage meter, radar unit, data acquisition system and a prototype meter of fuel consumption containing three auxiliary tanks for biodiesel, as described by Lopes (2006). From test to another, unconsumed biodiesel was drained from tanks, filters and pipes, in order to avoid contamination of the next test.

The study was divided into two stages. The first one consisted of a dynamic test carried out under field conditions to assess tractor performance, allotted in a completely randomized design, arranged in a 4 × 7 factorial scheme and with three replications, totaling 84 observations. The second composed a static test with the vehicle at rest, aiming to assess its engine smoke opacity, which was carried in a completely randomized design, with 4 types of fuels and 12 replications, totaling 48 observations. The fuels used were soybean and murumuru biodiesel (B100) and diesel B S1800 and B S500 (B0), in addition to seven engine speeds (1800, 1900, 2000, 2100, 2200, 2400 and 2600 rpm). For the performance test, each plot had 40 m in length and from one to another plot, at the longitudinal direction, there was a space of 15 m for conducting maneuvers, machinery traffic and stabilization of the moto-mechanization set in each treatment.

The braking tractor was coupled to the test tractor by means of a steel wire, forming a train. Preliminary testing, so-called pilot, was developed to set the maximum loading technically feasible to be pulled by the test tractor. To achieve that, gear combinations were tried in the braking tractor, thus reaching a workforce of nearly 25 kN. This tractor remained powered off and geared since its only function was to provide a uniform load to the tractor drawbar. The working speed was achieved with a gear combination in fourth L.

In all plots, test tractor started moving 15 m before the first pole

marking the beginning of measurements, aiming at assessment standardization. Data acquisition system was activated at the time when the rear wheel center (referential) overlapped the first pole, being switched off as tractor went through 40 m along the experimental plot, at which rear wheel center overlapped the second pole.

Fuel consumption was measured in each plot in terms of volume spent (mL), obtaining the total volume supplied to the inlet pump injection and the total volume returned. The fuel consumed was measured by the difference between these two measurements.

Based on consumed volume and driving time in each plot, hourly consumption was determined according to Equation 1:

$$HC = \left(\frac{Sv - Rv}{t}\right) \times 3.6 \tag{1}$$

Wherein: HC is the hourly consumption (L h^{-1}), Sv is the supplied volume (mL), Rv is the returned volume (mL), t is the driving time in the plot (s) and 3.6 is a conversion factor.

The time-weighted hourly consumption was calculated considering the supplied and the return fuel densities at the testing time, according to Equation 2:

$$HC_w = \left(\frac{Sv \times Dsf - Rv \times Drf}{t}\right) \times 0.0036 \tag{2}$$

Wherein: HC_w is the time-weighted hourly consumption (kg h^{-1}), Sv is the fuel supply volume (mL), Dsf is the supply fuel density (kg m^{-3}), Rv is the fuel returned volume (mL), Drf is the returned fuel density (kg m^{-3}), t is the driving time in the plot (s) and 0.0036 is a conversion factor.

The specific consumption, which is the fuel consumption expressed in mass unit per power unit required in the drawbar, was calculated according to Equation 3:

$$SC = \frac{WHC}{PD} \times 1000 \tag{3}$$

Wherein: SC is the specific consumption (g kW h^{-1}), HC_w is the weighted hourly consumption (kg h^{-1}), PD is the power on drawbar (kW) and 1000 is a conversion factor.

The smoke opacity test was performed by applying a snap idle test, in which engine rotation speed reaches a full-throttle acceleration, and developed power is absorbed only by the inertia of the mechanical engine components (clutch, gearbox primary shaft), since vehicle is parked (SAE, 1996). Measurements were determined in the BM125i Valtra testing tractor, and results were given in K, which is the light absorption coefficient in m^{-1}, as the manufacturer's manual (Tecnomotor). At the end of each determination, supply system was fully drained out to avoid contamination of incoming tests. Moreover, after refueling, engine had operated for ten minutes prior to each test started.

The data underwent variance analysis and means were compared by the Tukey's test at 5% probability, as recommended by Banzatto and Kronka (2006). A most suitable regression adjustment model was set for fuel specific consumption. Moreover, a response surface model was adjusted to explain fuel density as a function of temperature and fuel type. The variance analysis (F-test) was applied to select an equation model with higher significant exponent.

RESULTS AND DISCUSSION

There was no interaction between fuel type and engine speed for volumetric fuel consumption (Table 1). However, for fuel type, the soybean biodiesel presented a higher consumption, which increased 15.4% when compared to the diesel B S500. This increase is due to the lower calorific value of biodiesel compared to diesel, i.e., it is necessary a higher fuel supply to accomplish the same amount of work. These above-cited results are similar to those found by Lima et al. (2012), who evaluated a tractor engine (Valtra BM110) equipped with turbo charger, running with diesel at total sulphur level of 1800 mg kg^{-1}, and with palm and tucuman biodiesels. They observed an HC increase of 23.0% from biodiesel B100 to B0 that was related to the lower calorific power of palm- and tucuman-produced biodiesels against diesel, which could require more petrol to accomplish the same amount of work. According to Uzun (2010) and Neves et al. (2013), a turbocharger intercooler engine helped diminishing diesel consumption from reduction rates of 3 to 12%, which could also be used for biodiesel owning to their chemical and physical similarities. Analysis of Table 1 highlights that weighted consumption and specific consumption interaction was significant; therefore, these variables were further assessed using two complementary tables of breakdown of interactions (Tables 2 and 3). It is noted that, for the factor fuel type (in the line), the weighted consumption was lower at 1800 rpm for diesel B S1800 and B S500, but did not differ from results at 1900 rpm. On the other hand, soybean and murumuru biodiesel consumptions had no difference at 1900 and 2000 rpm (Table 2), although the lowest weighted consumption was observed at 1800 rpm.

Regarding engine speed in the column of Table 2 it was shown that weighted consumption was lower for B S500 diesel in comparison to soybean biodiesel at all assessed speeds, with the lowest consumption observed at 1800 rpm (21.1%). According to Murugesan et al. (2009) and Tabile et al. (2009), such an outcome can be explained by the lower calorific power and increased biodiesel density compared to the diesel. This measure is relevant for workers when performing fuel distribution, because the amount of mass leaving origin should be the same reaching its destination. Table 3 displays an increasing specific consumption for all fuel types (in the line) as engine speed increased; however, the lowest one was reached at 1800 rpm, using B S1800 and B S500 diesels (30.7 and 35.6%, respectively) whether compared to 2600 rpm speed. Concerning biodiesel use, consumptions were least at 2000, 1900 and 1800 rpm for soybean biodiesel, not differing from each other, and at 1900 and 1800 rpm for murumuru, not differing from each other (Table 3). By observing engine speed in the same Table (in the column), one can verify low specific consumption for B S500 diesel at all studied speeds; emphasizing 1800 rpm, which had a reduction of 27.8% compared to soybean biodiesel. Conversely, at 2100, 2000 and 1900 rpm, this diesel type consumption did not differ from the murumuru biodiesel (Table 3).

Table 1. Means of volumetric hourly consumption (HC), weighted hourly consumption (HC_w) and specific consumption (SC) for four types of fuel and seven engine speed rates.

Factors	HC $L\ h^{-1}$	HC_w $kg\ h^{-1}$	SC $g\ kWh^{-1}$
Fuel type (FT)			
Diesel B S1800	14.4 [a]	12.4	311
Diesel B S500	12.6 [c]	10.9	259
Soybean biodiesel	14.9 [a]	13.2	332
Murumuru biodiesel	13.4 [b]	11.8	272
Engine speed (ES)			
1800 rpm	9.7 [a]	8.5	250
1900 rpm	10.7 [ab]	9.4	262
2000 rpm	11.7 [bc]	10.2	271
2100 rpm	12.7 [c]	11.1	281
2200 rpm	14.0 [d]	12.2	240
2400 rpm	17.1 [e]	14.7	329
2600 rpm	21.0 [f]	18.4	366
F-TEST			
FT	24.9**	43.3**	827.2**
ES	222.4**	302.4**	698.2**
FT × ES	1.6[NS]	2.5**	11.5**
CV (%)	6.7	5.7	1.8

Means followed by the same letter in the columns do not differ from each other by the Tukey's test at 5% probability. **: Significant at 1% ($p < 0.01$); *: Significant at 5% ($p < 0.05$); NS: non-significant; CV: coefficient of variation.

Table 2. Breakdown of the interactions between fuel type and engine speed for weighted hourly consumption ($kg\ h^{-1}$).

Fuel type	Engine speed (rpm)						
	1800	1900	2000	2100	2200	2400	2600
Diesel B S1800	8.5 [ABa]	9.5 [ABab]	10.8 [ABbc]	11.8 [Acd]	13.2 [Ad]	15.7 [Ae]	17.3 [Be]
Diesel B S500	7.1 [Ba]	8.7 [Bab]	9.3 [Bbc]	10.1 [Bbc]	10.9 [Bc]	13.1 [Bd]	16.9 [Be]
Soybean	9.0 [Aa]	10.3 [Aab]	11.0 [Aab]	12.0 [Abc]	13.2 [Ac]	16.0 [Ad]	20.2 [Ae]
Murumuru	8.5 [ABa]	9.0 [ABab]	9.7 [ABab]	10.6 [ABbc]	11.6 [Bc]	13.9 [Bd]	19.4 [Ae]

Means followed by the same uppercase letter in the columns and lowercase letter in the rows do not differ from each other by the Tukey's test at 5% probability.

Table 3. Breakdown of the interactions between fuel type and engine speed for specific hourly consumption ($g\ kWh^{-1}$).

Fuel type	Engine speed (rpm)						
	1800	1900	2000	2100	2200	2400	2600
Diesel B S1800	255 [Ba]	271 [Ab]	286 [Bc]	307 [Ad]	320 [Ad]	368 [Ae]	367 [Be]
Diesel B S500	213 [Da]	234 [Cb]	242 [Cc]	250 [Bcd]	258 [Cd]	285 [Ce]	331 [Df]
Soybean	295 [Aa]	304 [Aab]	304 [Aab]	310 [Ab]	324 [Ac]	366 [Ad]	418 [Ae]
Murumuru	237 [Ca]	243 [Cab]	252 [Cb]	256 [Bb]	273 [Bc]	297 [Bd]	347 [Ce]

Means followed by the same uppercase letter in the columns and lowercase letter in the rows do not differ from each other by the Tukey's test at 5% probability.

Interestingly soybean biodiesel had an increased specific consumption at all assessed speeds, except for
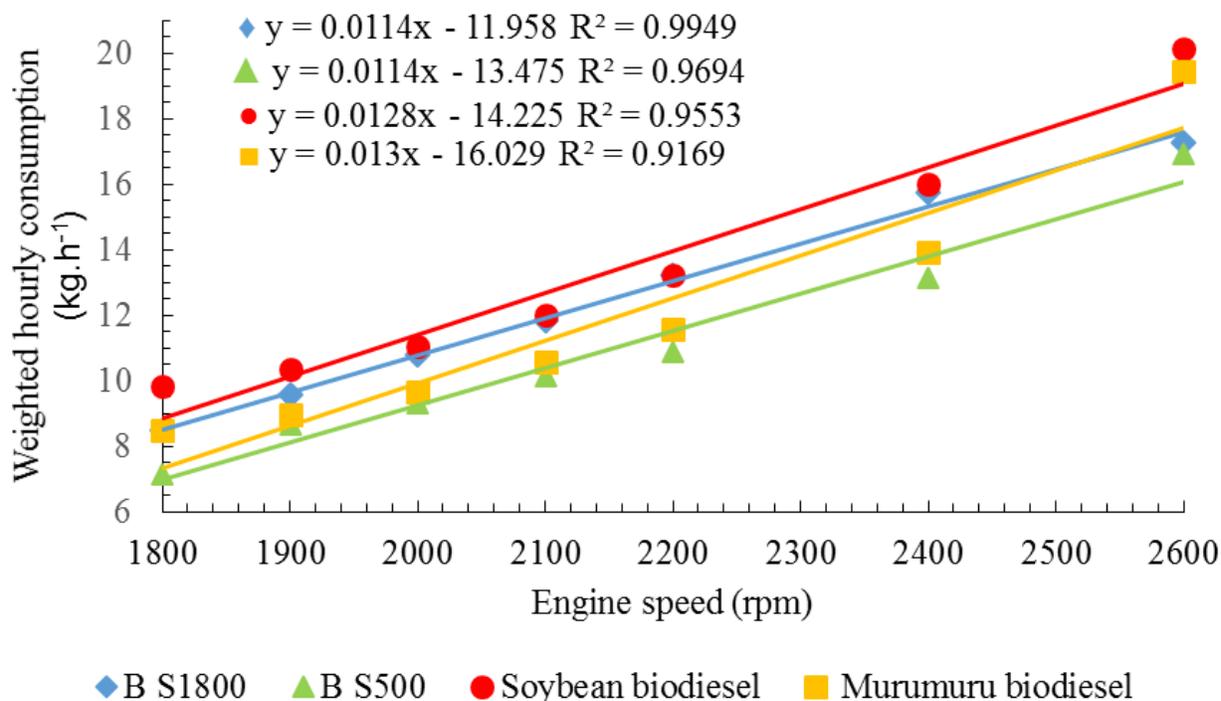
Figure 1. Weighted hourly consumption as a function of engine speeds and fuel types.

2400, 2200 and 2100 rpm, not differing from B S1800 diesel. It might have been due to both higher density and lower calorific power of biodiesel. The outcomes evidenced a rising specific consumption as engine speed was increased, for all fuel types; nonetheless, less performance interference was noted at 1900 and 2000 rpm, mainly when using biodiesel. Almeida et al. (2010), studying energy performance of a tractor-precision seeder system under different gears and engine speeds, also found similar results of fuel consumption as the ones presented here. These authors concluded fuel consumption is lower at low engine and driving speeds, and a maximum specific consumption was achieved at 2200 rpm using fourth gear.

Studying a tractor-seeder-fertilizer energy demand in no-till system as a function of driving and engine speeds (2100, 1800 and 1500 rpm), Silveira et al. (2013) concluded that the lowest specific fuel consumption was obtained at higher operating speeds and at a low engine speed (1500 rpm).

In contrast, Correia et al. (2015), assessing the operational performance of a tractor harrowing a clayey soil at diverse engine working speeds, observed that the highest working speed (2100 rpm) provided lower fuel consumptions and higher field capacity.

Science community has widely used the specific consumption as a measure to compare treatments, once it takes into account the amount of fuel consumed, developed power and product density. Figures 1 and 2

clearly demonstrates that time-weighted hourly consumption and specific consumption means had a linear behavior with regards to the four fuel types and at all engine speeds. It is noteworthy mention that soybean and murumuru biodiesels provided a smoke opacity reduction of 37 and 60%, respectively, if compared to B S1800 and B S500 diesels (which did not differ from each other) (Table 4). Smoke opacity reduction is representative and friendly to the use of biodiesel, which is partially explained by the absence of sulphur in its composition. Moreover, the presence of free oxygen in biodiesel molecule (reduced fuel-rich zones inside combustion chamber and increased yield during diffusive combustion), increasing combustion efficiency and reducing considerably the production of particulate matter (Sahoo et al., 2009; Chauhan et al., 2012). Biodiesel burning in diesel engines significantly reduces the emissions of particulate matter compared to diesel (Bora and Baruah, 2012).

Conclusions

1) Biodiesel from soybean and murumuru oils had no effect on engine performance during the tests.
2) Soybean biodiesel showed an increased volumetric fuel consumption of 15.4% if compared to B S500 diesel.
3) Weighted consumption for B S500 diesel was lower than that observed for soybean biodiesel, at all the
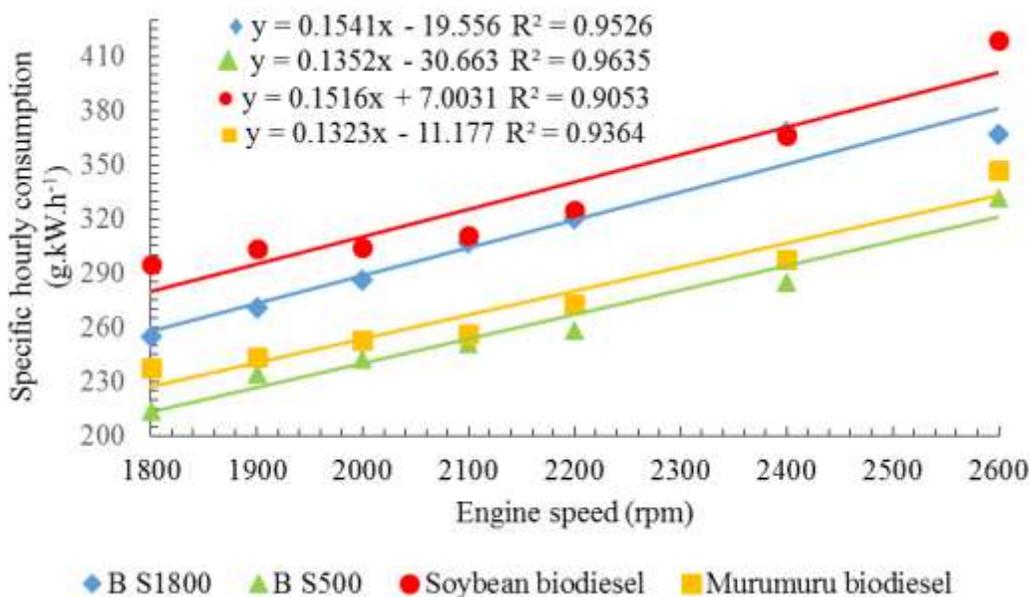
Figure 2. Specific consumption as a function of engine speeds and fuel types.

Table 4. Summary of the analysis of variance and mean test for smoke opacity.

Fuel type (FT)	Opacity (m^{-1})
Diesel B S1800	2.65 [a]
Diesel B S500	2.56 [a]
Soybean biodiesel	1.67 [b]
Murumuru biodiesel	1.05 [c]

F-TEST	
FT	975.74 **
CV (%)	2.13

Means followed by the same letter do not differ from each other by the Tukey's test at 5% probability. **: Significant at 1% ($p < 0.01$); *: Significant at 5% ($p < 0.05$); NS: not significant; CV: coefficient of variation.

assessed speeds, with the lowest value reached at 1800 rpm (21.1%).

4) Growing specific consumption was observed, for all fuel types, as engine speed was increased, especially for B S500 diesel at 1800 rpm, which had a 27.8% reduction whether compared to soybean biodiesel.

5) Smoke opacity was reduced by 37 and 60% using soybean and murumuru biodiesels, respectively, when contrasted with B S1800 and B S500 diesels.

Conflict of Interests

The authors have not declared any conflict of interests.

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