STATTIONARY ENGINE PERFORMANCE USING MIXTURE OF SOYBEAN AND CASTOR BEAN BIODIESEL TO DIESEL OIL

Jorge W. Cortez[1*], Camila C. Guimarães[2], Vivianni M. L. dos Santos[3]

[1*]Corresponding author. Universidade Federal da Grande/ Dourados - MS, Brasil. E-mail: jorgecortez@ufgd.edu.br

ABSTRACT

The use of alternative fuels in diesel engines has been the subject of research that seeks new fuels to expand the energy matrix. The aim of this study was to evaluate the performance of the stationary engine with the use of mixtures of biodiesel from soybean and castor bean added to diesel (S500) in two proportions (25% and 40%), evaluating the torque, effective power observed and specific consumption. The five biodiesel mixtures of soybean (S) and castor bean (C) analyzed were: S100C0, S75C25, S50C50, S25C75 and S0C100, which were added to the diesel in proportions B25 and B40, totaling ten treatments, plus the control with diesel S500 (B7). The stationary engine was subjected to the rotations of 3000, 2700, 2400, 2100, 1800 and 1500 rpm. The performance of the engine was similar for all biodiesel mixtures of soybean and castor bean, and commercial diesel (B7). The B40 S100C0 and B40 S75C25 provide better performance in terms of effective power observed and torque at 2700 rpm. The highest effective maximum power (3000 rpm) was obtained with the use of B7 diesel. In the lower rotations, it was possible to identify a similar performance result of the biodiesel mixtures with the B7, in addition to providing better torque and consumption performance compared to the commercial diesel.

INTRODUCTION

Most machines, currently used in agriculture, for mobility or power generation, are equipped with diesel cycle engines because of the efficiency they present. However, the unavailability prediction of long-term of fossil fuels and the emission of pollutants has stimulated research on biofuels (Perin et al., 2015), mainly with respect to environmental, economic, political, cultural and technical aspects for agriculture (Ballesteros et al., 2014).

Among the biofuels, the biodiesel is an attractive option for use in diesel engines, and can be produced from oil sources, with the characteristic of being biodegradable, renewable, non-toxic (Selvam & Vadivel, 2013), presenting high energy density, compatibility with existing engines, low NOx and SOx emissions after combustion (Rashid et al., 2014) and less impact on CO_2 emissions in relation to fossil derivatives (Chauhan et al., 2013; Zhou et al., 2014).

The biodiesel has been used in diesel cycle engine in combination with diesel, with soybean being the main source used for its production, a factor that has stimulated the investigation of the effects of the use of biodiesel from other sources and percentages. Castellanelli et al. (2008), for example, found that torque, power and specific consumption were similar between B0 (diesel), B2, B5 and B10, and the best engine performance occurred with B20 and the worst with soybean B100. Nietiedt et al. (2011) identified better potency and consumption with the use of B10 and the worse with B100 compared to B5 and B20.

The biodiesel from soybean is one of the most susceptible to oxidation, unlike castor bean biodiesel that presents greater stability and, in mixture with the soybean, promotes an increase in the resistance time to oxidative factors (Carvalho et al., 2013). However, particular physical-chemical characteristics of castor bean biodiesel, such as high viscosity, make difficult to use this biodiesel, and necessary to investigate the effects of this fuel on the performance of internal combustion engines (Monteiro et al., 2013).

Faced the need to reduce the dependence on the use of raw material, currently concentrated in soybeans, and to promote adequate insertion of oleaginous sources that present restrictions on the mechanical performance of the engine, as it is the case of castor bean biodiesel. The aim of this study was to evaluate the performance of the

stationary engine with the use of mixtures of biodiesel from soybean and castor bean oil added to diesel (S500) in two proportions (25% and 40%), evaluating the torque, effective power observed and specific consumption.

MATERIAL AND METHODS

The study was conducted in a laboratory at the Federal University of the São Francisco Valley (UNIVASF), in Juazeiro (BA), located at an altitude of 368 m, which temperature of the test site was on average 27°C, in a controlled condition.

The biodiesel from soybean, obtained by methanol transesterification with alkaline catalysis, used to evaluate the performance of the engine in terms of effective power observed, specific consumption and torque, was provided by Granol (GO), while the castor biodiesel was transesterified with the support of the Experimental Biodiesel Plant of Caetés (PE).

The experiment was set up in a completely randomized design, with six replicates, with one control. The five mixtures analyzed resulted from combinations of biodiesel from soybean and castor bean, being designated by the symbol "SyCx", where "S" corresponds to soybean biodiesel and "C" to castor biodiesel, whose concentrations (%) are equivalent to "y" and "x" respectively. Thus, the mixtures S100C0, S75C25, S50C50, S25C75 and S0C100 were added to the commercial diesel S500 (currently with 7% biodiesel, B7) to obtain proportions with 25% (B25) and 40% biodiesel (B40), totaling ten treatments, plus the control (B7).

The BX/SyCx mixtures were subjected to 3000, 2700, 2400, 2100, 1800 and 1500 rpm rotations for stationary engine analysis. The quality control parameters of the fuels used are shown in Table 1, as well as the limits established by the National Petroleum Agency, Natural Gas and Biofuels according to ANP Resolution n° 45 (2014).

TABLE 1. Specification of the fuel quality in terms of kinematic viscosity, oxidation stability and specific mass.

Mixtures (SyCx)	Kinematic viscosity at 40°C [3-6 mm² s⁻¹] (mm² s⁻¹)		Stability to oxidation [6 h] (h)		Specific mass at 20 °C [850 - 900 kg m⁻³] (kg m⁻³)	
	B25	B40	B25	B40	B25	B40
S100C0	3.19	3.35	10.6	8.0	843	858
S75C25	3.31	3.70	7.6	6.5	853	863
S50C50	3.38	4.17	11.0	10.9	853	869
S25C75	3.49	4.66	19.2	17.3	860	871
S0C100	3.84	5.26	31.0	25.0	857	873
B7	3.03		35.0		838	

For the tests of the engine performance, in terms of effective power observed, specific consumption and torque, an electric dynamometer was used, consisting of a three-phase Negrini generator, with 36 kVA of power, 1800 rpm and 220 volts and a three-phase resistive bench, in which a stationary diesel engine was tested, BD 10.0 model of the Branco brand, mono-cylindrical, 4-stroke, direct injection of fuel and nominal power of 5.7 kW at 3000 rpm and 6.7 kW at 3600 rpm.

Triggered by the machine in test (engine), the generator produced electric energy that was consumed by 8.64 kW three-phase resistive bench, connected to the output of the generator, which allowed to determine the power through the generated voltage and current.

The test procedure consisted of inserting the BX/SyCx mixtures into the engine fuel tank, which remained initially for 5 minutes at low speed for heating and lubricating of the engine. After the heating, the engine was subjected to maximum rotation of 3600 rpm, condition in which it remained for 30 minutes. Then, the resistive bench was connected and after 15 minutes of stabilization the rotation (stabilized at 3000 rpm) was measured with a digital tachometer ICEL TC 5030 (accuracy: ± 0.05 + 1D); the voltage, with digital Minipa Meter ET-2907 (precision: ± (0.3% + 10D); and the generated current, with Minipa ET-3200A ammeter (accuracy: ± (2.0% + 5D).

The volumetric consumption of the mixtures was obtained with a volumetric meter, constituted by a graduated burette, coupled to the power line of the motor through a hose, according to Reis et al. (2013). The fuel consumption time was measured with the KENKO KK 2808 digital timer.

After the measurements, the rotation was reduced to 2700 rpm, repeating the procedure described above for the measurement of rotation, voltage, current and consumption, and so on for rotations of 2400, 2100, 1800 and 1500 rpm. The test was repeated six times for each mixture, removing all tested fuel contained in the engine reservoir at the end of each test.

Based on the current and voltage data, the effective power observed produced by the engine was determined under the atmospheric conditions (Equation 1), according to Kosow (1982).

$$EP_{observed} = \sqrt{3} * V * I \qquad (1)$$

That,

EP (observed) - Power (Watts);

V- Voltage output, and

I - Output current (Ampere).

It is worth noting that according to the engine manufacturer's catalog, for the ambient conditions above 305 m altitude, it has a loss of 3.5% in power and every 5.6 ° C above the standard temperature (15.6 ° C), it loses 1% of power.

The specific fuel consumption was determined according to Mialhe (1996), from the values of mass of fuel consumed, measured power and time (Equation 2).

$$SFC = \frac{3.6 \times 10^3 \times C \times \mu}{EP_{\text{observed}}} \qquad (2)$$

that,

SFC - Specific fuel consumption (g kW^{-1} h^{-1});

C - Hourly consumption (mL s^{-1}), and

μ - Specific mass (kg m^{-3}).

With the values of effective power observed and rotation, the torque (Equation 3) was obtained, according to Mialhe (1980).

$$T = \frac{EP_{\text{observed}} \times 974}{rpm} \qquad (3)$$

that,

T − Torque (kgf m), and

rpm − Engine speed (rotations per minute).

The data were submitted to analysis of variance and Tukey's test was applied at 5% probability. In addition, regression analysis was carried out to describe the behavior of torque, effective power observed and specific consumption as a function of the rotations.
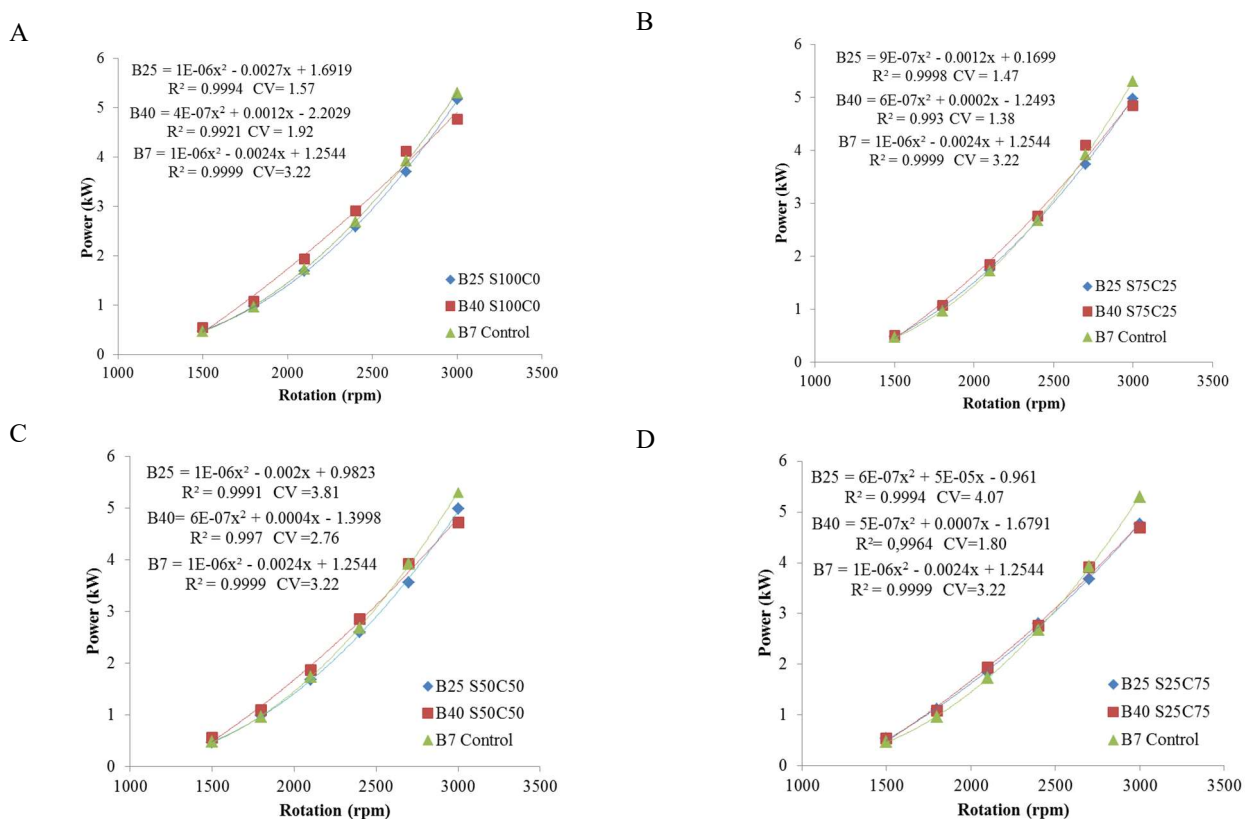
RESULTS AND DISCUSSION

Significant differences were observed in the results of effective power observed, specific consumption and torque from the BX/SyCx mixtures and the operating regimes (rotations), as well as for the interaction of these factors with each other.

The performance of the engine, from the effective power observed, in relation to the rotations used (Figure 1), indicates an increase in power using the proportions B25 and B40, according to soybean and castor bean biodiesel mixtures (SyCx), similar to that obtained with B7. In general, the effective power observed increases as the rotation increases, reaching maximum value at the maximum rotation imposed, corresponding to 3000 rpm, regardless of the proportion of biodiesel (BX) or mixture (SyCx) analyzed.

The increase in the castor bean biodiesel concentration in the mixtures promoted reduction of the maximum potency using the proportions B25 and B40 compared to B7 (Figure 1), so that these points are further from the commercial diesel (B7) when using the mixtures S25C75 (Figure 1D) and S0C100 (Figure 1E), with power of 4.48 and 4.36 kW respectively, while the diesel presented 5.30 kW of power (Table 2). The distance from the curves, from certain ranges of rotation, was justified by Castellanelli et al. (2008) as a phenomenon associated with inefficient fuel atomization due to the higher viscosity of biodiesel.

In this case, although all mixtures of biodiesel from soybeans and castor bean and proportions of diesel/biodiesel studied presented viscosity and oxidative stability (Table 1) within the limits established by the ANP, the increase of castor bean biodiesel concentration in the mixture increases considerably the viscosity.

A

B25 = 1E-06x² - 0.0027x + 1.6919
R² = 0.9994 CV = 1.57
B40 = 4E-07x² + 0.0012x - 2.2029
R² = 0.9921 CV = 1.92
B7 = 1E-06x² - 0.0024x + 1.2544
R² = 0.9999 CV = 3.22

B25 S100C0
B40 S100C0
B7 Control

B

B25 = 9E-07x² - 0.0012x + 0.1699
R² = 0.9998 CV = 1.47
B40 = 6E-07x² + 0.0002x - 1.2493
R² = 0.993 CV = 1.38
B7 = 1E-06x² - 0.0024x + 1.2544
R² = 0.9999 CV = 3.22

B25 S75C25
B40 S75C25
B7 Control

C

B25 = 1E-06x² - 0.002x + 0.9823
R² = 0.9991 CV = 3.81
B40 = 6E-07x² + 0.0004x - 1.3998
R² = 0.997 CV = 2.76
B7 = 1E-06x² - 0.0024x + 1.2544
R² = 0.9999 CV = 3.22

B25 S50C50
B40 S50C50
B7 Control

D

B25 = 6E-07x² + 5E-05x - 0.961
R² = 0.9994 CV = 4.07
B40 = 5E-07x² + 0.0007x - 1.6791
R² = 0.9964 CV = 1.80
B7 = 1E-06x² - 0.0024x + 1.2544
R² = 0.9999 CV = 3.22

B25 S25C75
B40 S25C75
B7 Control

E

$B25 = 3E-07x^2 + 0.0012x - 2.0546$
$R^2 = 0.9969 \ CV = 3.02$
$B40 = 4E-07x^2 + 0.0009 - 1.8047$
$R^2 = 0.9924 \ CV = 1.64$
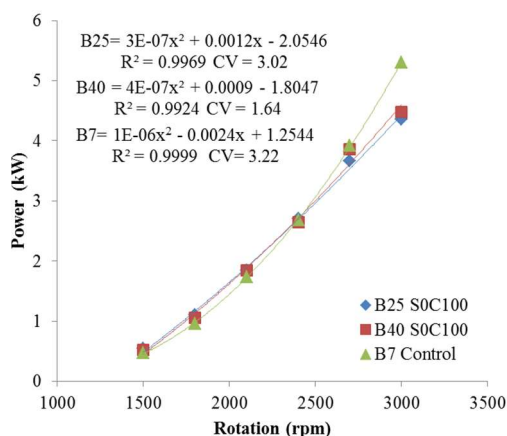$B7 = 1E-06x^2 - 0.0024x + 1.2544$
$R^2 = 0.9999 \ CV = 3.22$

FIGURE 1. Effective power curves observed as a function of engine rotation, using the proportions B25 and B40 with the mixtures: (A) S100C0; (B) S75C25; (C) S50C50; (D) S25C75 and (E) S0C100 compared to the diesel B7 control.

For the maximum rotation (3000 rpm), the engine had the highest effective power observed with the use of B7 (diesel), followed by the use of B25 with 100% of soybean biodiesel (S100C0), which presented a 2.5% reduction compared to diesel (Table 2). There were reductions in the maximum power values, with the use of higher proportions of biodiesel added to commercial diesel, which, according to Nietiedt et al. (2011), may be related to the lower calorific value of the biodiesel. The reduction of the energy power is related to the presence of oxygen in the fuel molecule, which is a characteristic of the biodiesel (Iscan & Aydin, 2012), which varies according to the raw material used in its production (Boldaji et al., 2011).

TABLE 2. Average of the effective power observed for the BX/SyCx mixtures as a function of the rotation, the overall average of the effective power observed as a function of biodiesel types/proportions and variance analysis synthesis.

BX/SyCx Mixtures	Effective power observed (kW)						Overall average
	Rotation (rpm)						
	3000	2700	2400	2100	1800	1500	
B25 S100C0	5.17 b	3.70 de	2.58 f	1.68 c	0.97 bc	0.47 a	2.42 de
B40 S100C0	4.77 de	4.12 a	2.90 a	1.93 a	1.07 abc	0.54 a	2.55 a
B25 S75C25	4.98 c	3.74 cd	2.72 cd	1.74 bc	1.04 abc	0.48 a	2.45 cd
B40 S75C25	4.84 d	4.10 a	2.76 bcd	1.85 ab	1.07 abc	0.51 a	2.52 ab
B25 S50C50	4. 98 c	3.55 e	2.59 ef	1.68 c	0.98 bc	0.46 a	2.37 f
B40 S50C50	4.72 de	3.91 b	2.85 ab	1.86 a	1.09 ab	0.55 a	2.50 bc
B25 S25C75	4.76 de	3.68 d	2.80 abc	1.84 ab	1.11 a	0.53 a	2.45 cd
B40 S25C75	4.69 e	3.91 b	2.76 bcd	1.93 a	1.08 abc	0.54 a	2.49 bc
B25 S0C100	4.36 f	3.66 de	2.71 cde	1.84 ab	1.10 a	0.54 a	2.37 f
B40 S0C100	4.48 f	3.86 bc	2.65 def	1.84 ab	1.05 abc	0.52 a	2.40 ef
B7	5.30 a	3.92 b	2.68 def	1.73 bc	0.96 c	0.47 a	2.51 ab
CV%						2.59	

Averages followed by same letter in column do not differ by Tukey test ($p < 0,05$). CV: coefficient of variation (%).

In the rotations between 2700 and 1500 rpm (Table 2), with the proportions B40, the engine presented power higher than or equal to that obtained with B25 mixtures, considering the same mixture. In addition, all diesel/biodiesel ratios containing biodiesel mixtures of soybean and castor bean, regardless of the concentration studied, present sufficient power performance, in the range of 2400 to 1500 rpm, taking as reference the diesel, since the power values are higher or equivalent to the B7, as observed in the 1500 rpm rotation.

The binary mixtures with higher proportions of biodiesel can promote good performance of diesel engine, considering the increase in cetane number in mixtures containing higher levels of biodiesel, which improves the combustion of the fuel in the combustion chamber. In addition, studies show that the engine presents better thermal efficiency with the use of larger proportions of biodiesel, which contributes to increase the performance (Monteiro et al., 2013).

Among the mixtures tested, the ones that provided the best engine power performance, on average (Table 2), were the B40 proportions, containing 100% soybean biodiesel (S100C0), followed by the S75C25 mixture, with an equivalent power achieved with the B7 (commercial diesel). The satisfactory result of B40 S100C0 and B40 S75C25 is linked to the higher power developed by these fuels at below-peak rotations, with better performance under these conditions compared to the commercial diesel.

Regarding the specific engine consumption, the highest value occurred in the rotation of 1500 rpm, independent of the BX/SyCx mixture (Figure 2).
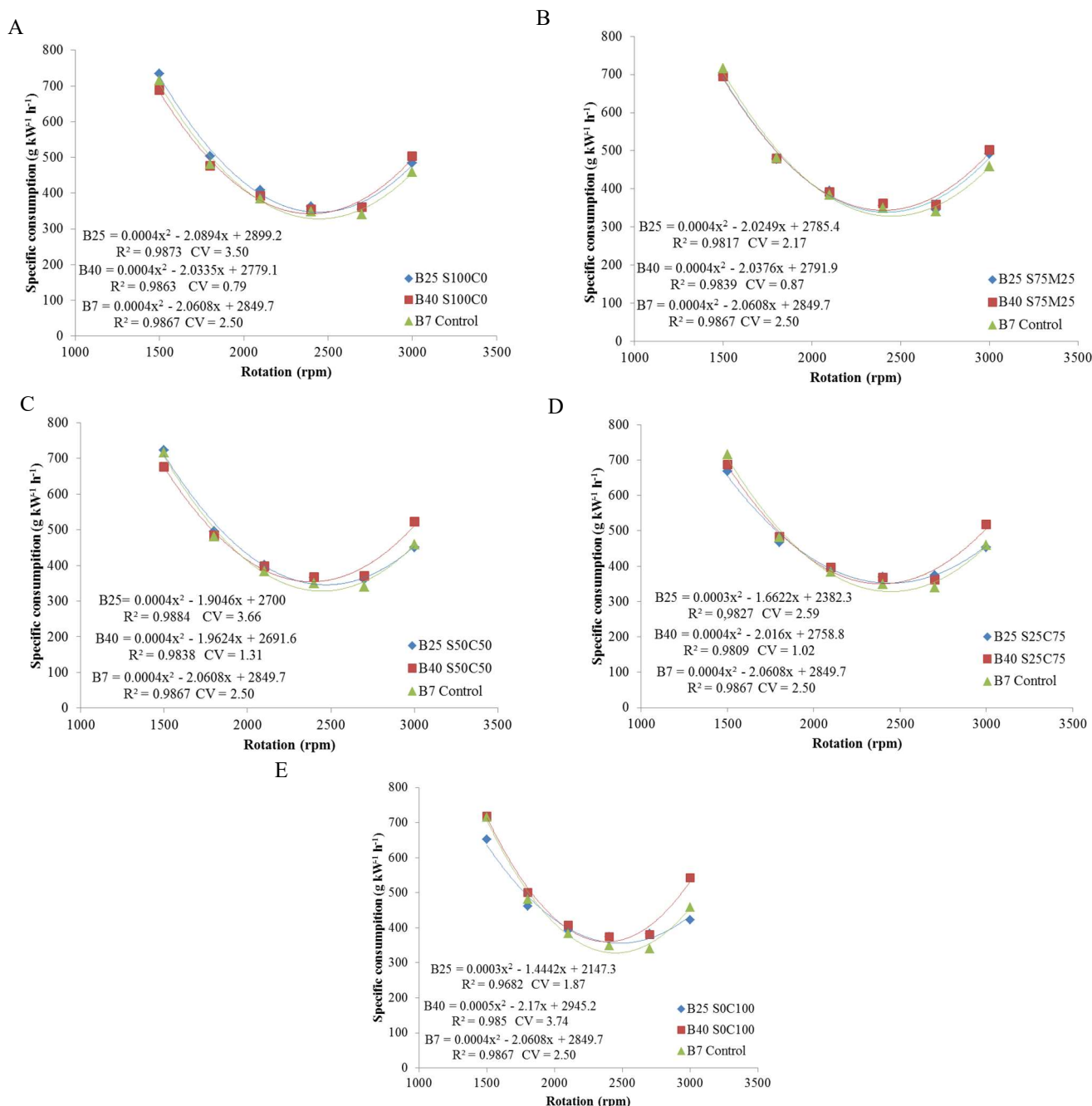
A

B

C

D

E

FIGURE 2. Curves of specific consumption according to the engine rotation, using the proportions B25 and B40 with the mixtures: (A) S100C0; (B) S75C25; (C) S50C50; (D) S25C75 and (E) S0C100 compared to the diesel B7 control.

The increase in engine speed reduces the specific consumption until it reaches its minimum value at speeds of 2400 and 2700 rpm (Figure 2). From this point, the increased rotation promotes increase in specific consumption.

In the maximum rotation, where the engine develops higher power, there is an increase in the specific consumption for proportions with 40% biodiesel (B40), mainly for mixtures with higher concentration of castor bean biodiesel (S0C100) (Figure 2). On the other hand, the increase of biodiesel of castor bean in proportions with 25% of biodiesel (B25) reduces the specific consumption

of the engine in the rotation of 3000 rpm, so that the lowest value found in this condition was with the use of B25 S0C100, in comparison also with commercial diesel.

The lowest specific consumption (Table 3) occurred with the use of B25 (S25C75, S0C100) and B40 (S100C0, S50C50 and S0C100) for the rotation of 2400 rpm and B7, B25 (S100C0, S75C25 and S50C50) and B40 (S75C25 and S25C75) for the rotation of 2700 rpm. In addition, the mixtures B25 S0C100 and B25 S25C75 presented lower consumption in the majority of the rotations, which contributed to a lower average consumption, equal to that obtained with commercial diesel (B7).
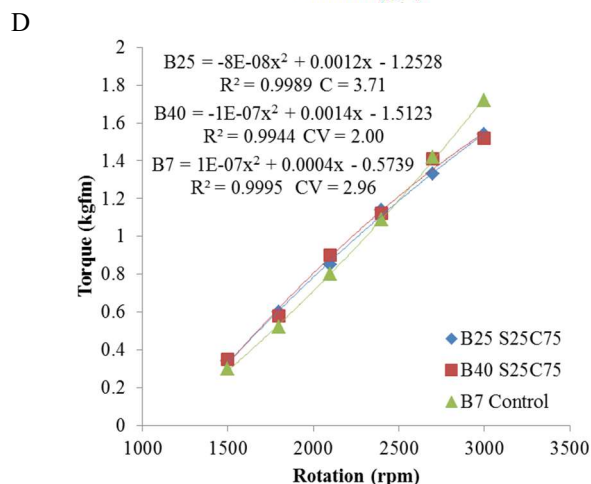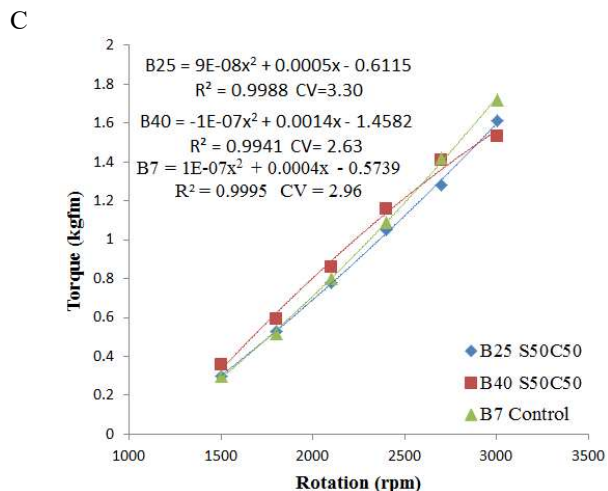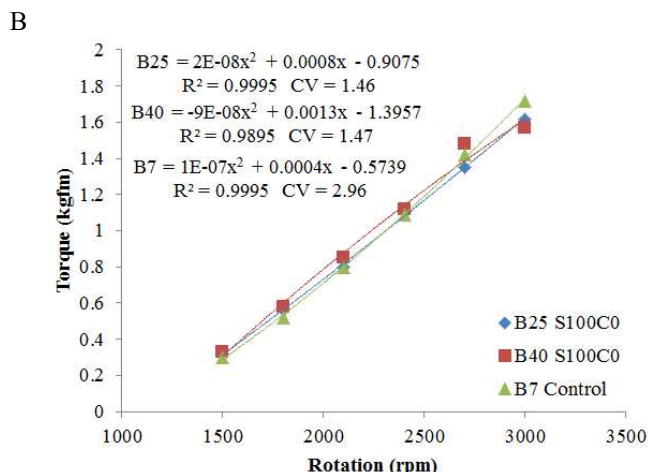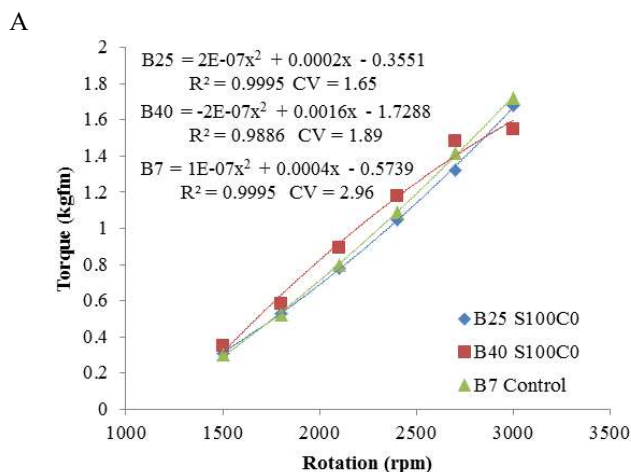
TABLE 3. Average of the specific consumption for the BX/SyCx mixtures as a function of the rotation, the overall average of the specific consumption as a function of biodiesel types/proportions and variance analysis synthesis.

BX/SyCx Mixtures	Consumption (g kW⁻¹ h⁻¹)						Overall average
	Rotation (rpm)						
	3000	2700	2400	2100	1800	1500	
B25 S100C0	485 c	354 cde	363 ab	408 a	504 a	734a	475 b
B40 S100C0	503 bc	361bcd	355 ab	392 ab	476 cde	689 de	467 cd
B25 S75C25	491 c	345 de	356 ab	395 ab	478 cde	698 bcd	461cde
B40 S75C25	502 bc	358 cde	362 ab	391 ab	480 bcde	695 cde	464 c
B25 S50C50	451 d	360 bcde	365 ab	401 ab	495 abc	722 a	466 c
B40 S50C50	522 ab	370 abcd	367 ab	398 ab	484 abcd	676 ef	470 bc
B25 S25C75	453 d	374 abc	369 ab	392 ab	468 de	668 fg	454 ef
B40 S25C75	518 b	362 abcd	367 ab	396 ab	484 abcd	687 def	469 bc
B25 S0C100	422 e	383 a	374 a	392 ab	462 e	653 g	448 f
B40 S0C100	543 a	380 ab	375 a	407 a	501 ab	718 ab	487 a
B7	459 d	340 e	349 b	384 b	481bcde	716abc	455 def
CV%				2.45			

Averages followed by same letter in column do not differ by Tukey test (p < 0.05). CV: coefficient of variation (%).

The torque reached the highest values at 3000 rpm (Figure 3). In this rotation, the commercial diesel (B7) and the proportion B25, containing S100C0, presented higher torque, being verified reduction with the increase of castor bean biodiesel in the mixtures. According to Monteiro et al. (2013), the density and the high compressibility of the fuel from the castor bean can compromise the operation of the injection system and thus reduce the torque compared to that developed with diesel and other Bx/SyCx mixtures at 3000 rpm.

A

$B25 = 2E\text{-}07x^2 + 0.0002x - 0.3551$
$R^2 = 0.9995 \quad CV = 1.65$
$B40 = -2E\text{-}07x^2 + 0.0016x - 1.7288$
$R^2 = 0.9886 \quad CV = 1.89$
$B7 = 1E\text{-}07x^2 + 0.0004x - 0.5739$
$R^2 = 0.9995 \quad CV = 2.96$

B

$B25 = 2E\text{-}08x^2 + 0.0008x - 0.9075$
$R^2 = 0.9995 \quad CV = 1.46$
$B40 = -9E\text{-}08x^2 + 0.0013x - 1.3957$
$R^2 = 0.9895 \quad CV = 1.47$
$B7 = 1E\text{-}07x^2 + 0.0004x - 0.5739$
$R^2 = 0.9995 \quad CV = 2.96$

C

$B25 = 9E\text{-}08x^2 + 0.0005x - 0.6115$
$R^2 = 0.9988 \quad CV = 3.30$
$B40 = -1E\text{-}07x^2 + 0.0014x - 1.4582$
$R^2 = 0.9941 \quad CV = 2.63$
$B7 = 1E\text{-}07x^2 + 0.0004x - 0.5739$
$R^2 = 0.9995 \quad CV = 2.96$

D

$B25 = -8E\text{-}08x^2 + 0.0012x - 1.2528$
$R^2 = 0.9989 \quad C = 3.71$
$B40 = -1E\text{-}07x^2 + 0.0014x - 1.5123$
$R^2 = 0.9944 \quad CV = 2.00$
$B7 = 1E\text{-}07x^2 + 0.0004x - 0.5739$
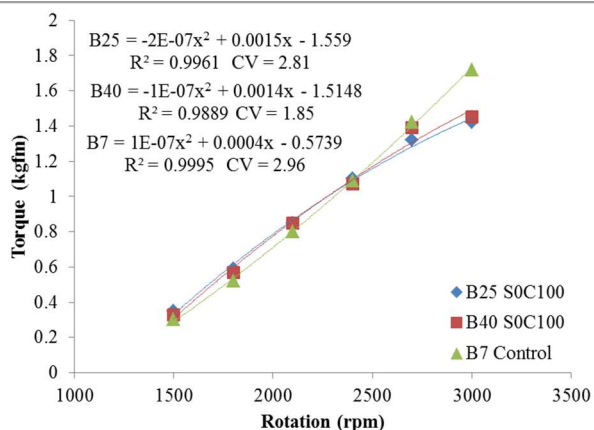$R^2 = 0.9995 \quad CV = 2.96$

E

FIGURE 3. Curves of torque as a function of engine speed, using proportions B25 and B40 with mixtures: (A) S100C0; (B) S75C25; (C) S50C50; (D) S25C75 and (E) S0C100 compared to the diesel B7 control.

Compared to the fossil diesel, the biodiesel presents higher values in the number of cetane (Lôbo et al., 2009), being higher for soybean than for castor bean. Thus, the thermal efficiency and cetane number compensated for the lower calorific value and higher viscosity of the B25 S100C0 in relation to the diesel, maintaining the torque similar to that of B7 at maximum rotation.

At the other rotations, for the SyCx mixtures under analysis, the B40 tends to have a torque result greater than or equal to that developed with B25 of the same mixture, generally resulting in better performance of B40 (Figure 3).

In general, the highest torque was obtained with the use of B40 S100C0 and B40 S75C25 (Table 4), whose result is 3% higher than that developed by the engine with the use of commercial diesel (B7). This is because the mixtures cited have better performances than the B7 at speeds below 3000 rpm, which influences the overall result.

TABLE 4. Average of the torque for the BX/SyCx mixtures as a function of the rotation, the overall average of the torque as a function of biodiesel types/proportions and variance analysis synthesis.

BX/SyCx Mixtures	Torque (kgf.m)						
	Rotation (rpm)						Overall average
	3000	2700	2400	2100	1800	1500	
B25 S100C0	1.68 a	1.32 de	1.05 f	0.78 d	0.53 bc	0.31 bcd	0.94 efg
B40 S100C0	1.55 cd	1.48 a	1.18 a	0.89 ab	0.58 a	0.35 ab	1.00 a
B25 S75C25	1.62 b	1.35 cd	1.10 cde	0.80 cd	0.56 abc	0.32 abcd	0.96 de
B40 S75C25	1.57 c	1.48 a	1.12 bcd	0.85 ab	0.58 a	0.33 abcd	0.99 ab
B25 S50C50	1.61 b	1.28 e	1.05 f	0.78 d	0.53 bc	0.30 d	0.93 g
B40 S50C50	1.53 cd	1.41 b	1.16 ab	0.86 ab	0.59 a	0.36 a	0.98 b
B25 S25C75	1.54 cd	1.33 d	1.14 abc	0.85 bc	0.60 a	0.34 abc	0.97 cd
B40 S25C75	1.52 d	1.41 b	1.12 bcd	0.90 a	0. 58 a	0.35 ab	0.98 bc
B25 S0C100	1.42 e	1.32 de	1.10 cde	0.85 ab	0.59 a	0.35 ab	0.94 fg
B40 S0C100	1.45 e	1.39 bc	1.07 ef	0.85 bc	0.57 ab	0.33 abcd	0.95 ef
B7	1.72 a	1.42 b	1.09 def	0.80 d	0.52 c	0.30 cd	0.97 bcd
CV%				2.44			

Averages followed by same letter in column do not differ by Tukey test (p < 0.05). CV: coefficient of variation (%).

Factor that also justifies the effects of improvement in the efficiency of the engine operating with greater proportions of biodiesel, comes from the reduction of the friction of the moving and static parts of the engine, due to the lubrication action that the biodiesel holds, when compared with diesel oil (Fiorese et al., 2012).

Studies with biodiesel from castor bean using mixtures containing 10 and 20% of biodiesel in mixture with diesel, indicate viability, both for electric generation and for mobility (Monteiro et al., 2013), because with the use of these fuels the engines had similar or superior performance to that obtained with diesel. The concentrations of castor bean biodiesel in the mixture are higher than those studied by other authors, but the B25 and B40 mixtures of castor bean (S0C100) presented similar results of similar power and torque, however lower than that obtained with diesel (B7).

It was possible to identify that the performance of the engine in the rotation of 2700 rpm is improved with the use of mixtures B40 S100C0 and B40 S75C25, since it obtained greater effective power observed and torque, comparing with the other fuels tested, besides the specific consumption is feasible, making these mixtures more suitable for the operation of the engine in this operating regime. In addition, they stand out when considering the average result, providing average power, equivalent to the diesel, and higher average torque, compared to diesel, which makes them appropriate when considering the average total performance.

The agricultural operations in diesel-powered tractors are usually conducted at lower rotations in a working range between 1200 and 2100 rpm (Fiorese et al., 2012), being below the maximum rotation evaluated in this study (3000 rpm), which reinforces the results obtained in the minor rotations, favoring the use of the mixtures used. In this sense, Silveira et al. (2013) verified that when using a no-tillage tractor set in no-tillage system in the range of 1500 to 2100 rpm, which the rotation of 1500 rpm provides a reduction of hourly consumption in relation to the maximum rotation, since it is influenced by rotation and speed used in agricultural operations.

Thus, considering the rotation range of agricultural tractors, the condition of operation (rotation) highlighted by Silveira et al. (2013) and the results found in this study, it was possible to identify that the proportions with up to 40% of diesel containing mixtures of soybean and castor bean biodiesel present promising use.

CONCLUSIONS

The mixtures of biodiesel from soybean and castor bean added to diesel in the proportions of 25 and 40% are feasible for use in a stationary diesel cycle engine, which performance curves are similar to those developed with commercial diesel (B7).

Although the highest consumption in the rotation of 1500 rpm for all fuels (mixtures) under analysis, with similar and decreasing behavior until reaching a minimum value and then increasing behaviors from 3000 rpm, the analysis of the consumption correlation with the composition of the mixtures and operating conditions (rotations) allowed to identify different minimum consumptions for the mixtures in rotations in that interval. For the rotations of 2400 and 2700 rpm, for example, the lowest consumption for the B40 S100C0 and the B40 S75C25, respectively, is verified. In addition, the mixtures B25 S0C100 and B25 S25C75 presented lower consumption in the majority of the rotations, which contributed to a lower average consumption, equal to that obtained with commercial diesel (B7).

The operating regime influences the results, so mixtures of biodiesel of soybean and castor bean in the proportions of 25 and 40% in mixture with the diesel promote better or similar performance of the engine, in relation to the B7, in the rotations below 2700 rpm. In the rotation of 3000 rpm, the best performance of power, consumption and torque is ensured by diesel.

On average, the B40 S100C0 and the B40 S75C25 provide satisfactory engine performance over diesel.

ACKNOWLEDGEMENTS

REFERENCES

ANP – Agência Nacional de Petróleo, Gás Natural e Biocombustíveis (2014) RANP 45. Available in: http://legislacao.anp.gov.br/?path=legislacao-anp-resol-anp/2014/agosto&item=ranp-45--2014. Accessed: Aug 13, 2018.

Ballesteros R, Guillén-Flores J, Martínez JD (2014) Carbonyl emission and toxicity profile of diesel blends with an animal-fat biodiesel and a tire pyrolysis liquid fuel. Chemosphere 96:155-166.

Boldaji MT, Ebrahimzadeh R, Kheiralipour K, Borghei AM (2011) Effect of some BED blends on the equivalence ratio, exhaust oxygen fraction and water and oil temperature of a diesel engine. Biomass and Bioenergy 35:4099-4106.

Carvalho AL, Santana SMF, Silva SC, Pepe IM, Bezerra MA, Aragão LM, Quintella CM, Teixeira LSG (2013) Evaluation of the Oxidative Stability of Biodiesel Blends from Soybean, Tallow and Castor Bean using Experimental Mixture Design. Journal of the Brazilian Chemical Society 24(8):1373-1379.

Castellanelli M, Souza SNM, Silva SL, Kaier EK (2008) Desempenho de motor ciclo diesel em bancada dinamométrica utilizando misturas diesel/ biodiesel. Revista Engenharia Agrícola 28(1):145-153.

Chauhan BS, Kumar N, Cho HM, Lim HC (2013) A study on the performance and emission of a diesel engine fueled with Karanja biodiesel and its blends. Energy 56:1-7.

Fiorese DA, Dallmeyer AU, Romano LN, Schlosser JF, Machado PRM (2012) Desempenho de um motor de trator agrícola em bancada dinamométrica com biodiesel de óleo de frango e misturas binárias com óleo diesel. Ciência Rural 42(4):660-666.

Iscan B, Aydin H (2012) Improving the usability of vegetable oil as fuel in a low heat rejection diesel engine. Fuel Processing Technology 98:59-64.

Kosow IL (1982) Máquinas elétricas e transformadores. Rio de Janeiro, Globo.

Lôbo IP, Ferreira SLC, Cruz RS (2009) Biodiesel: parâmetros de qualidade e métodos analíticos. Química Nova 32(6):1596-1608.

Nietiedt GH, Schlosser JF, Ribas RL, Frantz UG, Russini A (2011) Desempenho de motor de injeção direta sob misturas de biodiesel metílico de soja. Ciência Rural 41(7):1177-1182.

Mialhe LG (1980) Máquinas motoras na agricultura. São Paulo, EDUSP, v.1. 367p.

Mialhe LG (1996) Máquinas agrícolas: ensaios & certificação. Piracicaba, FEALQ. 722p.

Monteiro LA, Pianovski Júnior G, Velásquez JA, Rocha DS, Bueno AV (2013) Performance impact of the application of castor oil biodiesel in diesel engines. Engenharia Agrícola 33(6):1165-1171.

Perin GF, Schlosser JF, Farias MS, Estrada JS, Treichel H, Galon L (2015) Emissões de motor agrícola com o uso de diferentes tipos de diesel e concentrações de biodiesel na mistura combustível. Pesquisa Agropecuária Brasileira 50(12):1168-1176.

Rashid N, Rehman MSU, Sadiq M, Mahmood T, Han JI (2014) Current status, issues and developments in microalgae derived biodiesel production. Renewable and Sustainable Energy Reviews 40:760-778.

Reis EF, Cunha JPB, Mateus DLS, Delmond JG, Couto RF (2013) Desempenho e emissões de um motor-gerador ciclo diesel sob diferentes concentrações de biodiesel de soja. Revista Brasileira de Engenharia Agrícola e Ambiental 17(5):565-571.

Selvam DJP, Vadivel K (2013) An experimental investigation on performance, emission, and combustion characteristics of a diesel engine fueled with methyl esters of waste pork lard and diesel blends. International Journal of Green Energy 10:908-923.

Silveira JCM, Fernandes HC, Modolo AJ, Silva SL, Trogello E (2013) Demanda energética de uma semeadora-adubadora em diferentes velocidades de deslocamento e rotações do motor. Revista Ciência Agronômica 44(1):44-52.

Zhou W, Chen P, Min M, Ma X, Wang J, Griffith R, Hussain F, Peng P, Xie Q, Li Y, Shi J, Meng J, Ruan R (2014) Renvironment-enhancing algal biofuel production using wastewater. Renewable and Sustainable Energy Reviews 36:256-269.