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Performance analysis of biodiesel derived from pork fat of swill and concentrate-fed pigs#

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Abstract

With the escalating demand for sustainable energy solutions, unconventional sources are gaining attention, including the utilisation of pork fat for biodiesel production. This study investigates the influence of different pig feeding systems, namely swill and concentrate, on the characteristics and performance of biodiesel derived from pork oil. Twelve Large White Yorkshire piglets were divided into two treatments: one following standard feeding practices (T1), and the other exclusively fed with swill (T2). The pigs were slaughtered, and their fat was processed into biodiesel through transesterification. The fuel properties of the biodiesel were analysed, including kinematic viscosity, flash point, fire point, gross calorific value, and low-temperature fuel properties. Additionally, engine performance and exhaust emissions of a biodiesel blend (B20) derived from pork oil were evaluated and compared to commercial diesel fuel using a Kirloskar single-cylinder diesel engine connected to an eddy current dynamometer. Results indicate that both T1 and T2 B20 biodiesel exhibit favourable characteristics comparable to diesel, with promising fuel density, injection duration, mass flow rate, brake-specific fuel consumption, and brake thermal efficiency across various load conditions. Moreover, critical factors such as cetane number and gross calorific value suggest suitable ignition qualities and energy content, highlighting the potential of pork oil-derived biodiesel as a sustainable alternative fuel source.

Keywords*: Biodiesel, pork fat, swill, concentrate feeding systems*

The demand for sustainable energy is increasing, prompting the exploration of unconventional sources to bridge the gap. Pigs, ubiquitous in the agricultural sector, are considered the oldest food waste recyclers in history. Swill feeding, a traditional practice, involves feeding pigs cooked food waste, thereby converting discarded scraps into high-quality meat (Murugan *et al*., 2009). Pigs produce not only meat but also significant amounts of fat as a byproduct, which can be used as an energy source. Biodiesel, a clean-burning and renewable fuel source, can be produced from animal fats and vegetable oils, making it a perfect substitute for petroleum diesel.

Recently, consumers have started showing a preference for lean meat due to health consciousness (Font-i-

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Furnols and Guerrero, 2014). This situation has provided an abundance of animal fat supply to the industry. The biodiesel from animal fat is found to have a high cetane number which is a quality standard that is important in the case of diesel fuels. The high cetane number helps to start and run the engine more efficiently when the animal fat biodiesel is mixed with petro-diesel (Encinar *et al.,* 2011).

This study focuses on biodiesel production from pork fat sourced from two different pig feeding systems: swill and concentrate. The large fat yield of pigs makes them a valuable resource for biodiesel production (Dias *et al*., 2008). In an era where climate concerns intertwine with agricultural practices, understanding the impact of swill and concentrate feeding on biodiesel production is crucial. The objective of this study is to optimise the production of biodiesel from lard and investigate the influence of pig diets on the characteristics and performance of biodiesel.

Materials and method

The study was conducted from January 2021 to August 2022 at the Department of Livestock Production Management, School of Bioenergy Studies and Farm Waste Management, College of Veterinary and Animal Sciences, Pookode. Twelve weaned Large White Yorkshire (LWY) piglets reared at the Pig Farm of Instructional Livestock Farm Complex, Pookode, Wayanad were divided into two treatments. Treatment 1 (T1) followed ICAR feeding standards, receiving a grower ration and then a finisher ration. Treatment 2 (T2) was exclusively fed with swill. Animals were fed twice daily for up to a year and slaughtered for meat production and to separate fat from them. This fat was heated to produce pork oil and then turned into biodiesel using transesterification.

Fuel properties of pork oil biodiesel

The fuel properties of pork oil biodiesel (Kinematic viscosity, flash point, fire point, gross calorific value and low-temperature fuel properties like cold and pour point) were worked out (AOAC, 2010).

Performance of a biodiesel-fueled engine

Biodiesel blend B20 (20 per cent biodiesel and 80 per cent diesel) was prepared from pork oil, on engine performance and exhaust emissions. Comparisons were made between B20 of pork oil (T_1B20- the B20 of biodiesel produced from concentrate-fed pigs and T_2B20- the B20 of biodiesel produced from swill-fed pigs) and commercial diesel fuel. A Kirloskar single-cylinder diesel engine (Table 1) that was connected to an eddy current dynamometer was chosen for the experiment. The sensors for temperature, pressure, emissions etc. of the engine test rig were integrated into a computer specifically used for this purpose for performance testing. Performance characteristics were plotted against the percentage load. The performance parameters considered were specific fuel consumption (SFC), brake thermal efficiency, and percentage smoke opacity. For measuring smoke opacity AVL 437C smoke meter was used. The instrument worked on the principle of photocells with an accuracy of ± 0.5%.

Table 1. Specifications of the Kirloskar single-cylinder diesel engine

Rated hp	5
Speed	1500 RPM (constant)
Type of stroke	4
Stroke length	110 mm
Bore	80 mm
Diameter of brake drum	300 mm
Diameter of rope	15 mm
Orifice diameter	20 mm

The cetane number (ASTM D-613) of the biodiesel was analysed optically using ZX-101 XL portable cetane analyser (Zeltex Inc, Maryland, U.S.A).

The gross calorific value of raw biodiesel was determined by the IS:1448-2012 method. An adiabatic oxygen bomb calorimeter was used for this study. A weighed quantity of sample was burned in oxygen in a bomb calorimeter under controlled conditions. The temperature rise was recorded. The gross calorific value was then calculated from the weight of the sample and the temperature rise. Before using the formula, the water equivalent of the bomb was measured. It was achieved by burning 0.9 g of benzoic acid with a known mass of water (2 litres) and then measuring the temperature rise.

All data were analysed adopting a completely randomised design using the software package SPSS 10 except for the comparative data of mechanical and solvent extraction of oil, which were analysed by students-t test.

Results and discussion

This study was an investigation of the impact of biodiesel blend B20 (20 per cent biodiesel and 80 per cent diesel) prepared from pork oil, on engine performance and exhaust emissions. Several reports (Canakci and Van Gerpen, 2001; Wyatt *et al*., 2005; Shahid and Jamal, 2008; Lapuerta *et al*., 2009; Gürü *et al*., 2010) suggested that among the biodiesel blends, B20 would be safe in unmodified diesel engines, above which it would cause maintenance problems.

Engine Performance Parameters

Table 2 presents the engine performance parameters at various load conditions. At a no-load condition (0 kg), the engine ran at a constant speed of 1500 RPM with no torque or brake power generated, as expected. As the load increased incrementally to 4, 8, 12, and 16 kg, the engine continued to maintain a constant speed. The torque and brake power increased proportionally with the load.

Table 2. Engine performance parameters at different load conditions

Load (kg)	N (RPM)	R (effective radius)	Torque (Nm)	Break power (kW)	Vcc (cc)
0	1500	0.165	0	0	10
4	1500	0.165	6.0588	0.951714078	10
8	1500	0.165	12.1176	1.903428157	10
12	1500	0.165	18.1764	2.855142235	10
16	1500	0.165	24.2352	3.806856314	10

Engine speed (N) in revolutions per minute (RPM), effective radius (R), torque (in Newton-meters, Nm), brake power (in kilowatts, kW), and engine displacement (Vcc) in cubic centimetres (cc), Load (kg)

Table 3. Engine performance parameters at different load conditions

Variables	Type	Load (kg)				
		0	4	8	12	16
Pf (g/cc)	Diesel	0.81	0.81	0.81	0.81	0.81
	T1	0.84 ± 0.01	0.84 ± 0.01	0.84 ± 0.01	0.84 ± 0.01	0.84 ± 0.01
	T2	0.83 ± 0.001	0.83 ± 0.001	0.83 ± 0.001	0.83 ± 0.001	0.83 ± 0.001
T (s)	Diesel	75.05	54.5	43.65	35.2	29.2
	T1	75.15 ± 0	56.90 ± 0	44.50 ± 0	37.80 ± 0	30.00 ± 0
	T2	75.08 ± 0	55.80 ± 0	45.05 ± 0	37.40± 0	31.95 ± 0
Mass flow rate (kg/hr)	Diesel	0.389	0.535	0.668	0.829	0.999
	T1	0.403 ± 0.005	0.532 ± 0.006	0.681 ± 0.008	0.801 ± 0.01	1.010 ± 0.012
	T2	0.399 ± 0.0004	0.537 ± 0.001	0.665 ± 0.001	0.801 ± 0.001	0.937 ± 0.001
Brake Specific Fuel Consumption (kg/kW-hr)	Diesel	Not defined	0.562	0.351	0.290	0.262
	T1	Not defined	0.559 ± 0.007	0.358 ± 0.004	0.281 ± 0.003	0.265 ± 0.003
	T2	Not defined	0.564 ± 0.001	0.349 ± 0.0004	0.280 ± 0.0003	0.246 ± 0.0003
Calorific value (kJ/kg)	Diesel	43168	43168	43168	43168	43168
	T1	39020	39020	39020	39020	39020
	T2	40589	40589	40589	40589	40589
Break thermal efficiency (µ bth %)	Diesel	0	14.83	23.75	28.73	31.78
	T1	0	16.49 ± 0.20	25.8 ± 0.31	32.87 ± 0.39	34.78 ± 0.42
	T2	0	15.73 ± 0.02	25.40 ± 0.03	31.62 ± 0.03	36.02 ± 0.04

Table 3 provides a comparison of engine performance parameters at different load conditions for diesel and B20 biodiesel produced from pork oil of concentrate-fed pigs (T1) and swill-fed pigs (T2).

In terms of fuel density (Pf), both T1 and T2 B20 biodiesel showed slight variations compared to diesel across different load conditions, with consistent values. Injection duration (T) also remained fairly consistent for all fuels and load conditions. The mass flow rate increased as the load increased and both T1 and T2 B20 biodiesel showed similar trends to diesel, indicating good fuel supply capabilities. Brake-specific fuel consumption (BSFC) measured the fuel efficiency of the engine and both T1 and T2 B20 biodiesel consistently demonstrated competitive BSFC values comparable to diesel, with some variations depending on the load. The calorific value, which measured the energy content of the fuel, was slightly lower for T1 and T2 B20 biodiesel compared to diesel.

Both T1 and T2 B20 biodiesel exhibited break thermal efficiency values (µ bth %) that closely followed diesel's trend across different load conditions. Overall, the data in this table suggested that both T1 and T2 B20 biodiesel have performance characteristics such as total fuel consumption and brake-specific fuel consumption comparable to diesel, making them potentially sustainable alternatives for diesel fuel in various load conditions. In a similar study, Abraham *et al.* (2015) conducted engine experiments to evaluate the performance of biodiesel derived from rendered chicken oil. Their findings indicated that this biodiesel consistently outperformed commercial diesel across all load conditions. Specifically, it exhibited lower total fuel consumption and brake-specific fuel consumption. Mikulski *et al.* (2016) in their study examined the combustion characteristics of a biodiesel blend derived from swine lard methyl esters in a CRDI engine. Their observations revealed a decrease in fuel efficiency as well as an increase in brake-specific fuel consumption, and these changes were directly linked to the percentage of the biocomponent in the blend. These alterations in performance were primarily attributed to the lower heating values of the biodiesel mixtures when compared to conventional mineral diesel (MD) fuel. The reduction in ignition delay of pure biodiesel played a role in the increased fuel consumption.

Cetane number

The cetane number, reflecting fuel ignition quality, was higher in T1 (55.60 ± 0.38) compared to T2 (54.37 ± 0.26), but the difference wasn't statistically significant. Cetane number is a measure of the ignition quality of a diesel fuel. Fuels with higher cetane numbers have shorter ignition delays, providing more time for fuel combustion. High-speed diesel engines operate more effectively with higher cetane number fuels. Maithomklang *et al.* (2022) found a cetane number of 48.03 for pork oil biodiesel. Janchiv and Choi (2012) reported a cetane number of 57.8 for lard-derived biodiesel, exceeding the ASTM standard. Ejikeme *et al.* (2013) measured a cetane index of 54.8 for refined lard biodiesel, while petroleum diesel had a cetane index of 46. These results indicated favourable cetane values for lard-derived biodiesel, comparable to or better than petroleum diesel, which is crucial for engine performance.

Gross calorific value

The calorific value, was lower in T1 (36689 ± 0) compared to T2 (37644 ± 0), although this difference was statistically insignificant. In the study conducted by Maithomklang *et al.* (2022) to assess the gross calorific values (MJ/kg) of biodiesel from various fats, calorific values of 43.48 for diesel and 39.53 for biodiesel from pork oil was reported. In another study investigating the calorific value (MJ/kg) of biodiesel from lard, a value of 38.8 MJ/kg was reported for the biodiesel, which was lower than that of petroleum diesel (42.7 MJ/kg) (Janchiv and Choi, 2012).

Conclusion

The results of the study indicate that both concentrate and swill feeding systems can yield high-quality biodiesel from pork oil. The data conclusively prove that both T1 and T2 B20 biodiesel exhibit favourable characteristics across different load conditions, with fuel density (Pf), injection duration (T), mass flow rate, brake-specific fuel consumption (BSFC) and break thermal efficiency (µ bth %) comparable to diesel. The study also considers critical factors such as cetane number and gross calorific value, indicating that the biodiesel variants maintain suitable ignition qualities and energy content. Overall, this research contributes valuable insights into the viability of biodiesel derived from pork oil, shedding light on its compatibility with diesel standards and its potential as a promising alternative in the quest for environmentally friendly and efficient fuel sources.

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Conflict of interest

The authors declare that they have no conflict of interest.

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