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Examining the physicochemical properties and engine performance of biodiesel from whole seed and extracted kernels of egusi (*Citrullus lanatus*)

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ABSTRACT: Egusi seeds are one of the lesser known, but important sources of oil and protein in Africa. Egusi was grown in Malaysia to observe its adaptation to the local environment and to characterize the properties and biodiesel qualities of its seed oil. Oil from dehulled egusi seed (DESO) and whole egusi seed (WESO) were characterized. Extraction from both samples was done by Soxhlet extractor using n-hexane, and transesterified with KOH. Mean methyl ester (ME) yields from three replications averaged 87.3% and 86.7% for DESO-ME and WESO-ME, with cetane numbers of 52.54 and 53.06, respectively. Kinematic viscosities of 4.37 mm^2/s and 4.39 mm^2/s were found for WESO-ME and DESO-ME, respectively, making the former suitable as a bio-lubricant. Average flash points of DESO-ME and WESO-ME were 145.3 °C and 142.7 °C, with mean densities of 876.7 kg/m^3 and 871.0 kg/m^3, respectively. Six fatty acids were identified via gas chromatography. Total saturated and total unsaturated fatty acids were 20% and 80% for DESO-ME, and 21% and 79% for WESO-ME. Engine performance tests using pure diesel oil (PDO), B5 (5% biodiesel, 95% fossil diesel) and B10 (10% biodiesel, 90% fossil diesel) were carried out. Results showed that B5 and B10 of WESO-ME were better than DESO-MEs. The WESO-ME B5 was very similar in performance to PDO. The torques generated by PDO and WESO-ME B5 were the same. The latter had a lower exhaust temperature. However, power output from WESO-ME B5 was lower (by 0.02 kW) and fuel consumption higher by 7% than for PDO.

KEYWORDS: power, torque, fuel consumption, WESO-ME, DESO-ME

INTRODUCTION

The search for new sources of bio-energy has become more urgent in view of the diminishing levels of adverse environmental effects associated with the use of non-renewable fossil fuels. Biofuels generally offer two-fold advantages over fossil fuels. First, they are renewable. Their by-products are used as animal feed or bio-fertilizers, their production provides employment opportunities, and they are environmental friendly[1]. Biodiesels are predominantly made from the seeds of plants that may be edible, or not. In Europe, USA, and Malaysia, a number of crops, including coconut, rape seed, soy, corn, and oil palm, have been used to produce biodiesels. In India, the most prominents are mahua (*Madhuca indica*) and jatropha (*Jatropha caucas*)[2]. Other non-conventional biodiesels sources recently studied includes Argemone seed oil[3], rubber seed oil[4], and *Pongamia pinnata*[5]. Some of the highlighted shortcomings of biodiesels are the food- fuel competition caused by their effect on cost, availability, and sustainability[6]. Qualities of good biodiesel include low exhaust emission, biodegradability, and a high cetane number.

One of the lesser-known tropical crops that has recently received the attention of researchers is 'egusi' (*Citrullus lanatus*); a member of the Cucurbitaceae family. It is grown as a cash crop for its seed in many African countries. The seed serve as a food source after they are dehulled and processed. Originally, egusi was utilized in the manufacturing of soap. It is also used in the making of cosmetics and medicaments[7]. Egusi seed contains about 50% oil and 30% protein[8]. It has been suggested that the high content of unsaturated fatty acids in egusi seed may provide a hypocholesteronic effect.

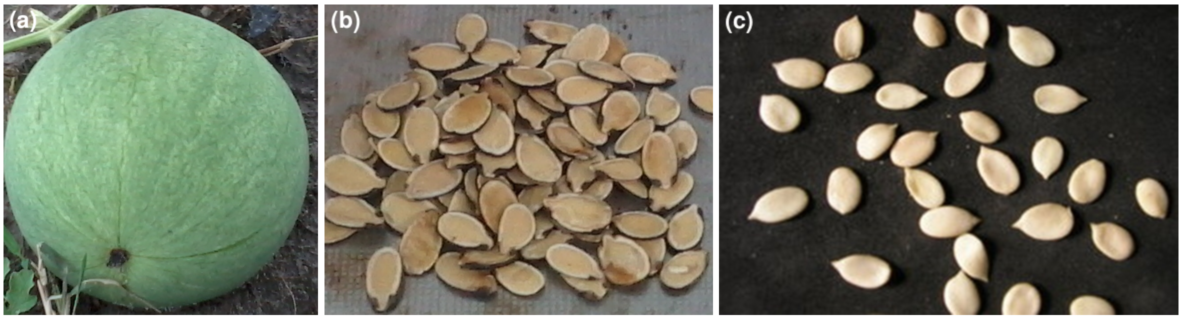

Fig. 1 (a) Egusi fruit, (b) whole seed, and (c) seed kernels.

Egusi melon was reported to have originated in the Western Kalahari region of Namibia and Botswana and the Kalahari Desert areas[9]. These areas include the Sahelian zones, savannahs, and arid areas. Although now recognized as *C. lanatus* (Thunb.) Matsum. & Nakai, egusi has also been referred to in the literature as *C. vulgaris* Schrader and *C. vulgaris* Eckl. and Zeyh., and is sometimes mistaken for other species. Egusi melon is cultivated across Africa, more specifically in West African countries like Nigeria, Togo, Ghana, Benin Republic, Sudan, and Cameroon[10, 11].

The physicochemical properties of egusi oil methyl esters from dehulled (but no whole seed) seed have been studied[11]. Egusi seed are difficult to dehull and this process is typically done manually. On average, 2 h are required to dehull 1 kg of whole egusi seed[12]. Egusi was recently introduced into Malaysia in order to characterize its potential as bioenergy source. The specific aim of the research was to extract oil from whole egusi seed and seed kernels, transesterify the crude oils into their methyl esters, and characterize the biodiesel oils using engine performance tests in accordance with ASAE 2001 (SAE J708 FEB 99).

MATERIALS AND METHODS

The egusi seeds were obtained from Nigeria and planted in Field 2 (Ladang 2) at Putra University, Malaysia. The plants were monitored and grown for 13 weeks. At that time, mature fruits were harvested and processed to obtain seeds. The seeds were cleaned and sun dried to a moisture content of 10%, a level considered safe for long-term storage[13]. Two samples, whole seeds (with hull) and dehulled seeds were used for the experiments. A total of 800 g of each sample was collected and prepared for experiment. Tests on physicochemical properties of both samples were conducted at the Engineering Faculty laboratories using KOH as catalyst, n-hexane (95%), and methanol.

Extraction of oil and evaporation of hexane excess

One hundred gram samples of whole seed and seed kernels were cleaned, and then coarsely minced at low speed in a blender for 10 s. The condenser-incorporated soxhlet extractor was preheated to 80 °C, with round bottom flasks properly placed to evaporate water particles, and then set to 70 °C (slightly higher than the boiling temperature of the solvent n-hexane[14]). The seed samples were placed in the thimbles with 250 ml of n-hexane in round bottom flasks, and extracted for 8 h. Excess hexane was evaporated using a rotary evaporator. The oil/hexane mixture was filtered using a double layer laboratory filter paper (Sigma-Aldrich)

Pre-transesterification and transesterification

Methods developed at the Palm Oil Research Institute Malaysia (PORIM, 1995), that conform with ASTM D6751 and EN 14214, were utilized for the determination of selected physicochemical properties including kinematic viscosity, acid value, saponification, iodine values, density, and fatty acid profiles[11]. Similar methods were also used for the determination of physicochemical properties of the methyl esters. All experiments were conducted in three replicates, and average values were reported.

Various methods have been reported in the literature to optimize the yield of biodiesel from different seed oils[15, 16]. Egusi oil has a low acid value, and therefore a direct alkaline transesterification procedure was adopted, using methanol as a solute and KOH as a catalyst. Different alcohol/oil ratios, percentage of catalyst, and temperature were evaluated using 20 g of oil before adopting a method that generated an optimum yield using KOH as catalyst. The optimum conditions (for both samples) were 0.55% KOH, 7:1 alcohol/oil and 65 °C. Fifty grams of whole egusi seed oil (WESO) and dehulled egusi seed oil (DESO) were pre-heated to 70 °C and stirred at 300 rpm for 15 min. Then, for each mass of

Table 1 Physicochemical properties of crude oils of WESO and DESO.

Property	Unit	Standard	WESO	DESO
Acid value	mg KOH/g	ASTM D664 [18,19]	1.456	1.08, 0.98 [11]
Density at 15 °C	kg/m^3	ASTM D4052	897.96	906.82, 905.3 [11]
Iodine value	g I_2/100 g	–	116.1	114.3, 114.46 [11]
Saponification value	mg KOH/g	–	201.87	212.36, 204.44 [11]
Kinematic viscosity at 40 °C	mm^2/s	ASTM D445	13.14	7.0, 31.52 [11]
Calorific value	MJ/kg	ASTM D240	45.0	41.7, 39.37 [11]

sample (DESO and WESO), 0.55% catalyst (KOH) of the sample mass and methanol mixture was added to the pre-heated samples. Stirring was continued for 1 h to ensure complete reaction of the reaction. At that time, the transesterified samples were poured into separating funnels, and left for 8 h to settle. Two separate layers containing glycerol (bottom layer) and biodiesel (top layer) were observed. The glycerol was removed leaving only the biodiesel in the funnel [17]. The biodiesel was then washed with warm distilled water to remove soap and excess glycerol. The wash procedure was repeated until the distilled water at the lower part of the funnel was clear. One drop of tetraoxosulphate (IV) acid was added to convert the excess glycerol to soap, which was then washed off from the biodiesel, and then oven dried at 65 °C for 2 h before drying again over anhydrous Na_2SO_4 to remove excess water.

Fatty acids profiling

Fatty acid profiles were determined using GC, (Shimadzu, Japan), with helium as carrier gas. The fatty acid compositions were determined by converting the two oil samples to fatty acid methyl esters, done by adding 950 µl of n-hexane to 50 mg of oil followed by 50 µl of 1 ml of sodium methoxide. The mixtures were then vortexed for 5 s and allowed to settle for 5 min. The top layer (1 µl) was then injected into the gas chromatograph to obtain FA methyl ester peaks. The retention times of the peaks obtained were then compared with standard peaks for identification.

Properties of WESO and DESO biodiesels

Properties of whole egusi melon seed oil methyl ester (WESO-ME) and dehulled egusi melon seed oil methyl ester (DESO-ME) were determined according to ASTM D6751 and EN 14214 standards. These properties included; acid value (EN 14104), cloud and pour points (ASTM D2500), calorific values (ASTM D240), density (ASTM D4052), flash point (ASTM D93), kinematic viscosity (ASTM D445), saponification value, and iodine value.

Engine test bed

A single cylinder four-stroke diesel engine with the following specifications was used: Model: L48N, brand: Yanmar Engines, bore: 70 mm, stroke: 57 mm, displacement: 219 cc, maximum output: 3.1 kW/3000 rpm.

Engine test bed has the following specifications: Eddy current dynamometer brand: Xiang Yi, eddy current dynamometer model: GW 10, rated absorbing power: 10 kW, rated maximum speed: 13 000 rpm, measuring accuracy of torque: ± 0.2–0.3%, measuring accuracy of rotational speed: ± 1 rpm, air inlet pipe internal diameter: 54.8 mm, airflow meter range: 0–10 m/s, air temperature range: 0–100 °C, fuel consumption weighing balance: 6100 × 0.1 g, engine coolant: water.

RESULTS AND DISCUSSION

Properties of crude WESO and DESO

The physicochemical properties of the crude oils are shown in Table 1. Acid values of the samples were 1.45 and 1.08 mg KOH/g for WESO and DESO, respectively. This corresponds to 0.728% and 0.54% free fatty acid. Low free fatty acid oils do not require double-stage acid-alkaline transesterification [13,20,21]. The density and saponification values of the WESO were lower than those of the DESO by 8.86 kg/m^3 and 10.76 mg KOH/g, respectively, with iodine value higher in WESO by 1.8 g I_2/100 g. Similarly, kinematic viscosities were 13.14 mm^2/s and 7.0 mm^2/s, with calorific values of 45.0 MJ/kg and 41.7 MJ/kg for WESO and DESO, respectively. All readings were in agreement with the literature on melon seed oil [2,11,22–25].

Fatty acids profiles of DESO-ME and WESO-ME

Six fatty acids were identified in both the DESO-ME and the WESO-ME samples. These were C16:0, C16:1, C18:0, C18:1, C18:2, and C18:3 (palmitic, palmitoleic, stearic, oleic, linoleic, and linolenic, respectively). Total saturated and unsaturated acids

Table 2 Fatty acids components of some vegetable oils, DESO-ME and WESO-ME.

Fatty acid (group)	Jatropha [17]	Safflower [19]	Sunflower [19]	Soybean [19]	EMOME [11]	EMOME [14]	DESO-ME	WESO-ME
Palmitic (C16:0)	18.22	6.6	6.0	10.3	10.48	13.5	10.22	11.62
Palmitoleic (C16:1)	0.0	0.0	0.0	0.0	0.06	13.7	0.07	0.08
Stearic (C18:0)	5.14	3.3	5.9	4.7	9.72	–	9.78	9.53
Oleic (C18:1)	28.46	14.4	16.0	22.5	17.95	14.6	16.50	16.56
Linoleic (C18:2)	48.18	75.5	71.4	54.1	61.41	56.9	63.39	62.12
Linolenic (C18:3)	0.0	0.1	0.6	8.3	0.38	0.5	0.04	0.09
Total saturated	23.36	10.00	12.00	15.10	20.20	28.10	20.00	21.15
Total unsaturated	76.64	90.00	88.00	84.90	79.80	71.90	80.00	78.85

Table 3 Fuel properties of DESO-ME and WESO-ME and other biodiesels.

Property	Standards Limits		DESO-ME	WESO-ME	EMOME	PME[a]	SnME[a]	SfME[a]
	ASTM D6751	EN 14214						
Acid value (mg KOH/g)	0.5 max	0.5 max	0.168	0.14	0.19 [11]	–	0.4 [34]	0.28 [35]
Linolenic Acid (%(mol/mol))	–	12 max	0.04	0.09	0.38 [11]	–	0.2 [34]	–
K/viscosity at 40 °C (mm^2/s)	1.9–6.0	3.5–5.0	4.39	4.37	3.83 [11]	7.532 [1]	4.85 [36]	4.29 [35]
Density at 15 °C (kg/m^3)	–	860–900	876.7	871.0	883 [11]	905.4 [1]	884 [36]	874 [35]
Flash point (°C)	130 min	120 min	145.3	142.7	142.0 [11]	90 [1]	168 [36]	176 [35]
Cloud point (°C)	−3 to 12	Report	10	8	0.5 [11]	−6.5 [1]	1 [36]	2 [35]
Calorific value (MJ/kg)	–	–	45.52	45.72	39.97 [11]	–	45.5 [35]	45.21 [35]
Pour point (°C)	−15 to 10	–	−7	−1	−6 [1]	−13 [1]	–	–
Ester content (%(mol/mol))	–	96.5 min	97.27	97.19	96.78 [11]	–	97.2 [34]	97.67 [35]
Cetane number	47–65	–	52.54[b]	53.06[b]	53.66 [11]	53 [1]	55 [36]	52.32 [35]

[a] PME = pongamia methyle ester, SnME = sunflower methyl ester, SfME = safflower methyl ester.
[b] Cetane numbers of DESO-ME and WESO-ME, determined empirically as sourced from Refs. 30, 31, 34.

were 20% and 80% for DESO-ME and 21% and 79% for WESO-ME, respectively. Unsaturated fatty acids included palmitic and stearic acids. These accounted for 10.2% and 9.8% for DESO-ME and 11.6% and 9.5% for WESO-ME. Linoleic acid was the predominant fatty acid in both DESO-ME and WESO-ME at concentrations of 63.4% and 62.1%, respectively. Various other oils like safflower, sunflower, rape seed, and jatropha contain unsaturated acids at similar levels[26–28]. For purposes of comparison, Table 2 highlights the properties of DESO-ME and WESO-ME with methyl esters of some other seed oils. The literature has shown that a high percentage of linoleic and oleic acid in beneficial for a higher quality biodiesel[29,30]. The oleic and linoleic acid values for both DESO-ME and WESO-ME were 16.6% and 63.5% and 16.6% and 62.1%, respectively.

Biodiesel yields and fuel properties of DESO-ME and WESO-ME

Biodiesel yield is expressed in percentage of the ratio of weight of methyl ester obtained after purification to the weight of the oil used in the reaction[15,31]. DESO-ME and WESO-ME yields were determined to be 87.3% and 86.7%, respectively. Yields from other oil seeds were similar: *Pongamia pinnata* L., 90%[5]; palm oil, 83%[28]; tobacco seed oil, 84%[29]; sesame seed oil, 30%[32]; and karanya, 86%[33]. Fuel properties of DESO-ME and WESO-ME are described in Table 3, in comparison with other selected seed oils, with the standard limits per ASTM D6751 and EN 14214.

Acid values of biodiesels from DESO-ME and WESO-ME are also presented in Table 3. Acid values were within the ranges specified in ASTM D6751 and EN 14214 (0.5 max). Acid value is the measure of the milligrams of KOH required to neutralize 1 g of free fatty acid. Previous studies on egusi oil[11] from dehulled seed were also within this range, but lower than that of sunflower[34] and safflower[35]. Acid values of 0.168 mg KOH/g for DESO-ME and 0.14 mg KOH/g for WESO-ME suggest that egusi can provide good biodiesel. Higher acid values lead to polymerization and catalyse the hydrolysis of biodiesel.

Vegetable oils and animal fats are sources of oils that are typically used in the production of biodiesel. Their favourable flow characteristics and their ease of atomization and combustion make these sources of oil especially suitable as biodiesels. Kinematic viscosity (KV) is one of the principal characteristics used to evaluate biodiesels. The standard limits have been defined as 1.9–6.0 (ASTM D6751) and 3.5–5.0 (EN 14214) at 40 °C. The KV values for DESO-ME and WESO-ME were 4.39 mm^2/s and 4.37 mm^2/s at 40 °C, respectively. The value for DESO-ME falls within both standards, while WESO-ME falls within the ASTM D6751 standards only. Both KVs were lower than values in safflower[35] and sunflower[36], lower KV is better in biodiesel.

Another important property of biodiesel fuels is their flash point. This is, the temperature at which the fuel will ignite when exposed to flame. The flash point of a good biodiesel should be higher than that of fossil diesel oil, making it safer for handling and transportation. The minimum standards have been established as 130 °C and 120 °C in ASTM D6751 and EN 14214, respectively. In this study, we found the flash points for DESO-ME and WESO-ME to be 145.3 °C and 142.7 °C, respectively. Flash points of sunflower, jatropha, soybean, *Pongamia pinnata* and palm were determined to be 180 °C, 163 °C, 160 °C, 141 °C, and 135 °C, respectively[37].

Cloud point (CP) measures the temperature at which biodiesel will begin to solidify, and its pour point (PP) is that temperature at which the fuel ceases to flow. Usually, the PP is lower than the CP. ASTM D6751 established limits of −3 °C to 12 °C and −15 °C to 10 °C for CP and PP, respectively, with no limits established in EN 14214 (the manufacturer of biodiesel report to potential buyers). Biodiesels from the current work showed the cloud point and pour point for DESO-ME were 10 °C and −7 °C and WESO-ME were 8 °C and −1 °C on average of three replicates. Density of fuel is another important parameter in selecting a biodiesel since measures the mass of fuel per unit volume. The limit for EN 14214 was 860–900 kg/m^3. Densities of DESO-ME and WESO-ME in the current work were 876.70 and 870.96 kg/m^3, respectively, both values falling within the standard range. For comparison, densities of safflower and sunflower were reported[35,36] as 884 kg/m^3 and 874 kg/m^3.

Calorific value represents the energy released when a gram unit of sample is burnt in the presence of oxygen, releasing CO_2 and H_2O. The heating value for DESO-ME and WESO-ME were 45.52 MJ/kg and 45.72 MJ/kg, respectively, when measured in accordance with ASTM D240 standards. The heating value of egusi melon methyl ester generated 39.0 MJ/kg[11] for Nigerian grown egusi, while safflower generated 45.21 MJ/kg[35] and sunflower generated 45.5 MJ/kg[36].

A good fuel (fossil or bio-derived) should have a high cetane number. The ASTM D6751 suggests a range of 47–65 in order to qualify a biodiesel. Cetane numbers of both DESO-ME and WESO-ME were determined empirically[31,34]. Cetane numbers for DESO-ME and WESO-ME were 52.54 and 53.06, respectively, both falling within the standards (Table 3). A previous reports for egusi melon methyl ester was indicated to have cetane number of 53.66 for Nigerian egusi[11]. In contrast, values of 53[5,35], 52.32[36] and 55[36] were reported for *Pongania pinnata*, safflower, and sunflower[36], respectively. Unsaturated compounds typically have higher cetane numbers[37].

Engine performance of biodiesel blends

A single cylinder diesel engine was tested according to ASAE 2001 (SAE J708 FEB 99) standards. The procedures described in the standards were as follows:

Maximum power-fuel consumption: The purpose of this run is to determine the maximum power as delivered through a mechanical power outlet to a dynamometer at the manufacturer's specified engine or mechanical power outlet speed; and to record the corresponding fuel consumption.

Varying power-fuel consumption: The purpose of this run is to determine the fuel consumption and speed when power is varied. The run shall consist of six power settings, each to be run for a fixed number of minutes in the following order:

1. 85% of dynamometer torque at maximum power.
2. Zero dynamometer torque.
3. One-half of 85% of dynamometer torque obtained at maximum power.
4. Dynamometer torque obtained at maximum power.
5. One-quarter of 85% of dynamometer torque obtained at maximum power.
6. Three-quarter of 85% dynamometer torque obtained at maximum power.

Maximum power-fuel consumption test: Table 4 provides data on the fuel consumption of the engine at maximum power using pure diesel oil (PDO), DESO-ME (B5 and B10) and WESO-ME (B5 and B10). The specific fuel consumption (SFC) on PDO at maximum power was 0.2452 kg/kWh. For DESO-ME B5 and B10, the mean SFC were 0.2906 kg/kWh and 0.2958 kg/kWh, while WESO-ME B5 and B10 had 0.2561 and 0.2638 kg/kWh, respectively, on three replicate runs. The SFC of WESO-ME blends were close to PDO. The highest mean exhaust temperature was recorded for PDO at 183.7 °C with minimum on

Table 4 Analysis of maximum power-fuel consumption for 300 s: Summary of results from three replicates.

Sample	MT[a] (Nm)	SD	MP[a] (W)	SD	ML[a] (N)	SD	MET[a] (°C)	SD	MFU[a] (g)	SD	Fuel flow (g/s)	SFC[a] (kg/kWh)
PDO	10.20	–	3001.1	1.0	10.67	0.06	183.7	1.5	61.33	0.06	0.204	0.2452
DESO-ME B5	9.73	0.06	2861.7	3.0	10.17	0.06	174.5	1.1	69.30	0.10	0.231	0.2906
DESO-ME B10	9.87	0.06	2888.9	0.9	10.3	0.0	168.5	0.7	71.20	0.10	0.237	0.2958
WESO-ME B5	10.20	–	2981.3	1.0	10.57	0.15	152.5	1.1	65.53	0.15	0.218	0.2561
WESO-ME B10	9.33	0.06	2976	11	9.87	0.06	146.3	1.0	63.50	0.10	0.212	0.2638

[a] MT = mean torque, MP = mean power, ML = mean load, MET = mean exhaust temp., MFU = mean fuel used, SFC = specific fuel consumption.

Table 5 Pure diesel oil (PDO) results of varying power engine performance for 300 s.

Torque	MP[a] (W)	SD	MS[a] (rpm)	SD	ML[a] (N)	SD	MET[a] (°C)	SD	MFU[a] (g)	SD	Fuel flow (g/s)	SFC[a] (kg/kWh)
8.67	2335	5	2938	28	8.807	0.015	195	4	48.5	0.3	0.162	0.2493
0.00	0	0	2999	1	0	0	124	1	23	0	0.077	0
4.34	1245	5	2961	4	4.513	0.015	148.3	1.5	36.33	0.12	0.121	0.3501
10.20	2889	3	2895	5	10.750	0.012	202.3	5.9	52	2	0.173	0.2160
2.17	622.1	1.9	2977	3	2.353	0.015	126.7	1.5	28.0	0.2	0.093	0.5401
6.50	1777	4	2932	3	6.83	0.02	171.3	1.5	44.47	0.12	0.148	0.3002

[a] MP = mean power, MS = mean speed, ML = mean load, MET = mean exhaust temp., MFU = mean fuel used, SFC = specific fuel consumption.

WESO-ME B5. Maximum SFC of all blends was with DESO-ME B10 at 0.2958 kg/kWh with mean load of 10.3 N.

The mean torques produced by PDO, DESO-ME B5, DESO-ME B10, WESO-ME B10 and WESO-ME B5 samples was 10.20, 9.73, 9.87, 9.33, and 10.20 Nm, respectively. The mean torque generated by the WESO-ME B5 especially, was similar as that of PDO. Similarly, the mean power generated by PDO was 3.0 kW, while DESO-ME and WESO-ME generated about 2.98 kW, but DESO-ME had less mean torque. The properties of WESO-ME B5 were close to that of PDO in terms of mean torque, mean power generated, mean load and mean fuel used and so was the mean exhaust temperature generated. Results on Table 4 indicate the WESO-ME B5 and B10 blends were slightly better in performance that the DESO-ME B5 and B10 blend. This led to conducting the second level of tests on WESO-ME B5 and B10, in comparison with PDO.

Varying power-fuel consumption tests: Table 5 summarizes the results of the varying power fuel consumption test using PDO, following standardized procedures. At maximum power, 10.20 Nm of torque was generated, while at 85% power, 8.67 Nm of torque was generated (mean SFC of 0.2493 kg/kWh). Mean power generated at 8.67 Nm torque was 2335 W (Table 5). With no torque, the generated power was 0 W and the SFC was also 0 kg/kWh. The lowest mean engine speed provided at maximum engine torque of 10.2 Nm, and as the torque declined to 0, the engine speed approached 3000 rpm.

Table 6 summarizes the performance of WESO-ME B10 on the same engine. The torque generated at maximum engine speed in this case was 9.4 Nm at 2985 W. At maximum engine speed, the mean exhaust temperature was 198.7 °C, which indicate heating contribution to the environment. The SFC was 0.2246 kg/kWh at 2985 W mean power. At 85% power, 8.0 Nm of torque was generated and the power declined to 2452 W. The mean exhaust temperature declined to 195.3 °C while the SFC increased to 0.2431 kg/kWh. The highest SFC was recorded as 0.5387 kg/kWh when the torque was 2 Nm at 629.7 W and engine speed of 2982 rpm mean exhaust temperature at this level was 127 °C. These values agree with the report by Karanja[38].

The results of varying power fuel consumption using WESO-ME B5 are presented in Table 7. Values obtained using this sample were similar to those obtained for PDO, thus WESO-ME B5 is a better blend for biodiesel than WESO-ME B10. WESO-ME B5 generated 10.2 Nm at maximum engine speed with an

Table 6 WESO-ME B10 results of varying power fuel consumption test for 300 s.

Torque	MP[a] (W)	SD	MS[a] (rpm)	SD	ML[a] (N)	SD	MET[a] (°C)	SD	MFU[a] (g)	SD	Fuel flow (g/s)	SFC[a] (kg/kWh)
8.0	2452.3	2.5	2957.7	2.1	8.367	0.058	195.3	4.5	49.67	0.31	0.1667	0.2431
0.0	0	0	2998.7	1.5	0.033	0.058	126.3	1.2	25.07	0.12	0.0836	0
4.0	1245	5	2970.3	2.5	4.197	0.081	148.7	1.5	36.47	0.46	0.1216	0.3515
9.4	2985	5	2849	4	9.85	0.05	198.7	2.1	55.87	0.31	0.1862	0.2246
2.0	629.7	1.0	2982	3	2.117	0.006	127	1	28.27	0.31	0.0942	0.5387
6.0	1640.3	2.5	2937.3	2.5	6.30	0.01	174	1	45.13	0.31	0.1504	0.3302

[a] MP = mean power, MS = mean speed, ML = mean load, MET = mean exhaust temp., MFU = mean fuel used, SFC = specific fuel consumption.

Table 7 WESO-ME B5 results of varying power fuel consumption test for 300 s.

Torque	MP[a] (W)	SD	MS[a] (rpm)	SD	ML[a] (N)	SD	MET[a] (°C)	SD	MFU[a] (g)	SD	Fuel flow (g/s)	SFC[a] (kg/kWh)
8.67	2763	35	2855	5	8.55	0.10	220	1	51.33	0.23	0.1711	0.2229
0.00	0	0	2999	1	0.137	0.025	120.7	1.5	26.0	0.2	0.0867	0
4.34	1241	10	2925	5	4.537	0.064	128.7	3.1	36.9	1.7	0.1231	0.3572
10.20	2869	7	2828.3	2.9	10.677	0.031	194	2	55.9	0.8	0.1862	0.2337
2.17	622.1	4.2	2981.7	4.0	2.347	0.051	122	2	30.13	0.31	0.1004	0.5813
6.50	1694.3	2.1	2912.7	2.5	6.620	0.046	171	1	44.93	0.42	0.1498	0.3182

[a] MP = mean power, MS = mean speed, ML = mean load, MET = mean exhaust temp., MFU = mean fuel used, SFC = specific fuel consumption.

SFC of 0.2337 kg/kWh and a mean exhaust temperature of 194 °C. At 85% torque, output power was reduced to 2763 W (mean engine speed of 2855 rpm). The lowest torque noted occurred when the engine was set to 3/4 of 85% dynamometer torque ($3/4 \times 85\% = 0.6375$). At this setting, the mean power generated was 622 W at a mean speed of 2981.6 rpm. The average exhaust temperature at this speed was 122 °C and an SFC of 0.5813 kg/kWh.

CONCLUSIONS

Methyl esters of egusi melon dehulled seed oil (DESO-ME) and egusi whole seed oil (WESO-ME) was characterized and their biodiesel properties determined. Both samples were suitable for use as biodiesel. The methyl ester yields of DESO-ME and WESO-ME were 87.3% and 86.7%, respectively. The cetane number of the WESO-ME was slightly higher than that of the DESO-ME, although both fell within the limits as defined in ASTM D6751. WESO-ME had a better kinematic viscosity (4.37 mm^2/s at 40 °C) than did DESO-ME (4.39 mm^2/s). The engine test bed performance of WESO-ME B5 was similar to PDO, and performances of both blends of WESO-ME were better than DESO-ME. Hence it is not necessary to dehull the egusi seed if it is to be utilized for the production of biodiesel, since whole seed oil methyl ester has superior biodiesel properties and performance than that from dehulled seed.

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