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1 **Spatio-Temporal Analyses of Extracted Citrullus Colocynthis Seeds (Handal Seed Oil) as**
2 **Biofuel in Internal Combustion Engine**

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14

15 **Abstract**

16 Herein Handal oil extraction from waste biomass is investigated for biodiesel production via esterification
17 and transesterification processes. Furthermore, the physicochemical characteristics of Handal biodiesel
18 (density, kinematic viscosity, specific gravity, pour point, flash point, and cloud point) was performed along
19 with testing the fuel quality used in internal combustion engines. The flash point of the obtained Handal
20 biodiesel (49.5 °C) was lower than that of petroleum diesel (68.3 °C). While at 40 °C, the kinematic
21 viscosity of used Handal oil (4.476 cSt), which was higher than that of diesel fuel (2.6 cSt) and fossil diesel
22 (2.27 cSt). Pourpoint of the used Handal oil was -9 and lower than that of Handal biodiesel, which is +3.
23 The sulfur content of Handal oils was 193 mg/kg, which was higher than the Handal biodiesel value of 62
24 mg/kg, but significantly lower than that of diesel fuels (≤ 100 ppm). Similar engine performance regarding
25 thermal efficiency between pure diesel and biodiesel at different engine speeds and loads was detected. The
26 utilisation of such waste stream (Handal wild plant) in the production of biodiesel fuel will aid upcycling
27 an otherwise waste and problematic thermochemical conversion feedstock by adding value for the
28 application in the energy sector.

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31 **Keywords:** Handal seed oil, biodiesel, biofuel, physicochemical properties, Internal Combustion Engine.

1. Introduction

Biofuels are a growing source of energy primarily due to the increase of global demands of fuels combined with environmental impact concerns [1, 2]. Most of the world production of biodiesel (>95%) uses edible vegetable-based oils, including coconut, sunflower seed, palm, soybean, peanut, canola, and corn [3]. Thus, a biofuel derived from non-edible resources is an auspicious alternative in several countries, especially developing ones, keeping in mind the fuel versus food debate [4]. Such developing countries are more vulnerable to energy crisis than developed countries, resulting in a high challenge to provide cost-effective energy supply [5, 6]. Vegetable oils have formed renewable feedstock for many industrial uses in various sectors that required “once-through” materials such as lubricants, engine oils, hydraulic fluids and others [7, 8]. Biodiesel is a carbon-neutral fuel as emissions associated with its combustion are approximately equal to CO₂ sequestration of the plants that are the main feedstocks for its production. Conversely, the utilisation of fossil fuels has led to augmented emissions, particularly CO₂, resulting in the greenhouse gas effect. The challenge is to decrease dependency on fossil fuel, keeping the environment from CO₂ release with carbon sequestration from biomass is one of the negative emission technologies (NETs) that is effective in climate change mitigation [6]. Furthermore, the utilisation of renewable fuel is one of the conventional approaches in climate change strategies.

Vegetable oils obtained from a variety of oils as well as seed crops, featuring high energy density in addition to good fuel characteristics, can be processed to biodiesel with further safe utilisation as a biofuel in engines of compression ignition [9]. The properties obtained from palm oil processing under basic catalyst transesterification method were investigated, and experiments exhibited that the optimum yield value of 88% was at a reaction temperature of 60 °C, reaction time of 40 minutes, and methoxide to oil ratio of 6:1 [10]. The produced biodiesel had similar properties to the American Standard for Testing and Material (ASTM) D 6751,

and European Norm (EN)14214. Other oils that have been investigated for biodiesel production from various feedstocks, including *Croton Megalocarpus* [11], Mahua (*Madhuca Indica*) [12], Thumba (*Citrullus colocynth*) [13-15].

The transesterification process to produce biodiesel was found to be the most appropriate and adequate route. Alkali-catalysed transesterification process, in particular, is commonly used in producing biodiesel production but requires optimisation for parameters that governed the production process [16]. The transesterification technique is more practical when performed for scaling-up, though it can still be a promising pathway for small scale areas, especially in developing countries. Vegetable oils (heated or blended), when utilised as an alternative to petroleum fuel, they afford highly attractive vegetable oil-diesel blends with encouraging features to be explored by the scientific community [17-19]. Transesterification process is an equilibrium-based reaction which is reversible and relies on various factors such as residence time, reaction temperature, catalyst loading and methanol: oil ratio [20].

Hoekmana et al. [21] reported that several fuel properties such as cetane number, viscosity, iodine value, specific gravity, and low-temperature efficiency are associated with the degree of unsaturation within the fatty acid methyl ester (FAME) structure. Back to the structure of FAME, it is difficult to identify a particular composition that makes it ideal for all the necessary fuel characteristics. Biodiesel should have relatively low concentrations of saturated long-chain FAME as well as poly-unsaturated FAME for a sufficient operating efficiency. Fuel characteristics such as flash point, kinematic viscosity, and calorific value, density were determined for various biodiesel in comparison with diesel. Plant oils possess high viscosity with an inability to be employed as a fuel; thus, the viscosity should be reduced through the chemical process for transesterification. Such a process includes a catalytic reaction between triglyceride and three alcohol molecules, yielding a mix of fatty acids, alkyl ester and glycerol as a significant by-product [22-25]. Patil et al. [24] used triglycerides vegetable oils'

transesterification to synthesise biodiesel, including catalytic reaction with short-chain alcohols (mostly methanol). Other alcohols such as ethanol, propanol, and butanol are highly miscible in oil, making the next separation step highly challenging and costly. There have been many reports related to the biodiesel blends for engine testing to characterise the fuel performance, including biodiesel generated from biomass-based feedstocks such as sunflower seeds [26, 27], *Jatropha* [28], melon/watermelon seed oil [29], castor oil [30], rubber seed oil [31] and thumba oil [32, 33]. However, very few studies were performed on the *Citrullus Colocynths* (Handal) as a non-edible biomass feedstock [34]. In many cases of utilising biodiesel, the achieved findings possess torque outputs, characteristics, and precise fuel consumption similar to those of diesel fuel, which prove its feasibility as a substitute fuel in diesel engines. However, the low cetane number of biodiesels prevented the use of 100% replacement of diesel, where the results obtained from biodiesel were compared with the diesel fuel as a reference fuel.

Handal is a non-edible, creeping plant that is a poisonous, desert/wild strongly linked to watermelon, which is regarded as a member of the *Cucurbitaceous* family [35]. It can survive under hyper-arid desert settings of annual precipitation (< 50 mm) and annual temperature (14.8-27.8 °C) [36, 37]. The plant with a creeper-shaped can grow in sandy soil, especially in a rainy season with fruit production in winter. Handal oil contains a higher content of seed oil; seeds contain 50 wt.% of a golden yellow-brown oil (advanced biofuel centre), [38]. Herein we aim to extract the seed oil of the Handal plant and investigate the physical as well as chemical characteristics of Handal seed oil, followed by the production of biodiesel using conventional esterification and transesterification technology. To assess the performance of biodiesel, we also reported the engine testbed data for several blends of the produced biodiesel mixed with diesel.

2. Experimental work

A schematic demonstration of the process is displayed in Figure 1. The Handal plant was collected from different places in Jordan, as shown in the supplementary information (Figure S1). One sample of 20 kg of Handal was collected, and then the seeds were removed and cleaned. After that, seeds were dried for three days at room temperature and then were ground using an electric blender (Home Electric blender 400W (T-608 BL) (Figure S2).

Figure 1: Schematic diagram showing the steps of biodiesel production.

For determining the NaOH amount needed for the transesterification of the oil, *ca.* 1 mL oil was dissolved in isopropanol (10 mL), followed by titration with 0.1 M NaOH solution

(standardised against KHP). A suitable mass of the catalyst based on this titration is dissolved in methanol (NaOH: Methanol: Oil; 0.0016 g: 0.2 mL: 1 mL) with 20 min vigorous stirring until dissolution is complete to prepare methoxide (CH_3O^-). After that, such mixture was brought to the reactor (R-flask) charged with treated moisture-free oil. The obtained mixture was continuously stirred at temperatures range of 60-65 °C for an hour. The produced mixture was then isolated, with further pouring in a separating funnel for separating glycerol as well as methyl ester of Handal oil. 4% H_3PO_4 solution with steam floatation was used to wash the biodiesel to remove moisture and impurities.

2.1 Esterification process

The FFA present in an oil sample was determined as the acid value (AV) by titrating the oil, with the produced mixture is presented in Figure 2.

Figure 2: Esterification process of Handal oil plant into biodiesel fuel.

The acid value (AV) is expressed as (mg KOH/g oil) according to the equation below [39, 40]:

$$\text{Acid value (AV)} = (\text{Volume of KOH used (mL)} \times 56.1 \times N \text{ of KOH}) / \text{Weight of sample (g)} \quad \text{Eq.1}$$

$$\text{Free fatty acid (\%)} = (\text{AV}) \times 0.503 \quad \text{Eq.2}$$

Generally, fatty acid composition percentage is determined by species of plants as well as their growth requirements, so several experiments were done, and the average value of free fatty acid of the Handal oil was 7%, which was a high percentage and needed pretreatment. The esterification prior treatment process is optimised to lower the content of free fatty acid (FFA), and according to Biodiesel Education Program Issue TN #33, 2018, the esterification based on acid catalysis needs extra use acid as well as methanol, where sulfuric acid is the catalyst and methanol is the reactant. The new free fatty acid was measured to oil to ensure that it was less 0.5%. [41]. Esterification is considered as the prevalent utilised process for viscosity reduction of different vegetable oils [42, 43].

2.2 Transesterification process

If the FFA content is less than 0.5%, the oil is ready to be converted into biodiesel. The optimal setup for transesterification of Handal oil with adding methanol amount equivalent to $0.217 \times$ [grams of triglycerides unreacted] and sodium methoxide amount equivalent to $[0.25 + (\% \text{FFA}) 0.190] / 100 \times$ [grams of triglycerides unreacted]. The detailed procedures are shown in the supplementary information. This was followed by the washing process, where water was used for purification; thus, the separator funnel was charged with hot distilled water to wash the crude biodiesel. Then the separating funnel was shaken gently to mix water with crude biodiesel. The layers were permitted for settling for one day. The bottom aqueous layer was

runoff, while frequent washing process (3 to 4 more times) was performed until realising clear water. To remove undesired components such as the excess methanol or residual water, the washed biodiesel samples were dried at 110 °C for 2 hrs.

2.3 Physical and chemical analyses

Physical as well as chemical characteristics of oil in addition to biodiesel of the samples were carried out guided by the standard methods. Test methods have been utilized as follows: Density (ASTM D4052-1a), specific gravity (ASTM D4052-1a), kinematic viscosity (ASTM D445-19), flash point (ASTM), pour point (ASTM D97-17b), cloud point (ASTM D2500-17a), copper correction (ASTM D130-19), carbon residue (ASTM D189-06), Gross Heat of Combustion (ASTM D240-17), sulfur content (ASTM D4294-16), water concentration (ASTM D6304-16e1), Ash content (ASTM D482-13), cold filter plugging point (BS EN116:2015).

The samples were subjected to chemical analyses governed by standard test methods: ASTM using Gas Chromatography-Mass Spectrometry analysis (GC-MS) analysis. GC-MS was employed for determining the composition of the biodiesel from Handal seeds oil. Handal oil molecular weight was determined utilising fatty acid composition. The preparation of biodiesel samples intended to measurements of GC-MS was realised through different methods, as stated by [44], as shown in the supplementary. The FAME contents of Handal oil biodiesel were determined by GC-MS (Shimadzu qp2010 Plus, Japan) equipped with a fused-silica capillary column (DB-5MS (30 m x 0.25 mm I.D x 0.25 µm of film thickness) (J & W Scientific, Folsom, California)).

2.4 IC engine experiments setup

The performance testing internal combustion engine was carried out for the produced biodiesel. For performance testing internal combustion engine purposes, four blends consisting of Handal

biodiesel with diesel were prepared by volume as **B20** (20% Handal oil biodiesel and 80% diesel fuel), **B50** (50% Handal oil biodiesel and 50% diesel fuel), **B100** (100% Handal oil biodiesel and 00% diesel fuel), and **B00** (00% biodiesel and 100% diesel) to analyse the engine performance characteristics.

3. Results and Discussion

3.1 Physical and chemical results

Blending biomass-based fuel along with diesel has been widely studied in the literature. Balajee et al. [45] utilised *Jatropha* and *Pongamia Pinnata Methyl Ester* (PPME) blend with diesel in the variable compression ratio (VCR) CI engine. The performance as well as combustion properties of B10, B20 and B30 blends of *Jatropha* and *Pongamia* with diesel for various compression ratios (13, 14, 15, 16, 17.5) have been studied, and such blends could replace pure diesel as a substitute fuel source. Sivakumar et al. [46] assessed both efficiency and combustion properties in a given diesel engine using Thumba biodiesel and blends with diesel. On a volume basis, the preparation of blends was realised as of 20, 40, 60 and 80% biodiesel with diesel. The biodiesel characteristics like viscosity, volatility and boiling point are higher than that of diesel fuel. However, again the low cetane number of biodiesels prevented the use of 100% replacement of diesel. An upsurge was accomplished for brake thermal efficiency in all blends when load rises. Thumba oil methyl ester (40%) and diesel blend (60%) demonstrated an upsurge in brake thermal efficiency (2%) in comparison with diesel fuel. The physical characteristics of Handal oil, as well as its biodiesel, are shown in the Tables (1-3). The results discussed below are for different characteristics of the biodiesel derived from used vegetable oils in comparison to those of pure diesel fuel.

Handal oil density is 899 kg/m^3 , whereas that of biodiesel was 888 kg/m^3 (Tables 1 and 2). It is higher than that of standard diesel ranged between $820\text{-}870 \text{ kg/m}^3$ located in Jordan and

marginally higher (nearly 6%) over diesel (835 kg/m³) Tables (1 and 3). At 15 °C, the density of used Handal oil (899 kg/m³) was higher density than those of diesel fuel (850 kg/m³) and fossil diesel (880 kg/m³). At 15 °C, Handal biodiesel density (888 kg/m³) was relatively higher than those of Jatropha biodiesel (879 kg/m³) and Babassu biodiesel (879 kg/m³) in another related research [47]. At the same time, it showed a lower value than that of Karanja biodiesel (929 kg/m³) (Table 3) [47]. The limit value proposed in pre-standard fuels for vegetable oil compatible combustion engines - fuel derived from rapeseed oil is in the range of 900-960 kg/m³, so as not to eliminate vegetable oils including jatropha, castor, mahua, babassu and neem oil [48], indicating that density of Handal agrees with pre-standard fuels for vegetable oil compatible combustion engines-fuel. In addition, it is important to regulate the density because a fuel pump is a volumetric unit. Thus, for almost the same higher heating value (HHV), low-density fuel means that the energy density for each unit of volume reduces, resulting in a lower ratio of fuel-air equivalence in the inside combustion chamber as well as a reduction in energy produced per cycle. This should impact the brake-specific fuel consumption (BSFC).

Table 1: Physical properties of used Handal oil with those of Thumba oil.

Properties	Unit	Handal		Thumba (India)1		Thumba (India)2	
		Oil	Biodiesel	Oil	Biodiesel	Oil	Biodiesel
Density at 15 °C	Kg/m ³	899.3	888.2				
Specific gravity at 20 °C	----	0.898	0.886	0.905	0.835	0.880	0.833
Kinematic viscosity at 40 °C	cSt	16.49	4.476	31.52	2.72	5.3	2.6
Flash Point	°C	142-152	49.5	201	66	187.5	65.5
Pour point	°C	-9	+3	-5	-20	-8	-12
Cloud point	°C	+5	+9			-1	-5
Copper corrosion 3hrs at 50 °C	----	1a	1a				
Total sulfur content	mg/Kg	193	62				
Gross heat of combustion	MJ/Kg	39.603	39.599				
Water concentration	mg/Kg	592	1070				
Conradson carbon residue	wt	-	0.5			0.01	
Cold filter plugging point, CFPP	°C	-	0				

Calorific Value	MK/Kg	39.603	39.599			39.80	46.05
Acid number	mgKO H/g	0.52					
Free Fatty acid	%	>1	0	>1	0		
Cetane Number	-	-	-	45	47		

1. Usta et al. [49] 2. Karnwal et al.[50]

Table 2: Properties of different vegetable oils [47])

Oils	Kinematic Viscosity	Density	Heating Value	Cloud Point	Pour Point	Flash Point	Cetane Number	Carbon Residue
	(cSt 40°C)	(kg/m ³)	(MJ/kg)	(° C)	(° C)	(° C)		(w/w)
Handal	16.49	899.1	39.60	+5.0	-9.0	221	-	-
Thumba	31.52	905.0	39.80	-1.0	-	201	45	-
Jatropha	49.90	921.2	39.71	16.0	8.0	240	40-45	0.64
Karanja	46.50	929.0	38.80	13.2	6.0	248	40	0.64
Rapeseed	37.0	911.0	39.70	-3.9	-31.7	246	37.5	0.30
Neem	57.00	938.1	39.40	8.0	2.0	295	47	0.96
Sunflower	33.90	916.2	39.61	7.2	-15.0	274	37.1	0.23
Soybean	32.60	914.3	39.60	-3.9	-12.0	254	38	0.27
Coconut	27.70	915.0	37.1	-	-	281	52	0.13
Cotton Seed	33.51	914.1	39.4	1.7	-15.0	234	42	-
Rice Bran	28.70	937.1	38.9	13.0	1.0	200	30	0.24
Peanut	39.60	902.0	39.7	12.8	-6.7	271	42	-
Linseed	27.20	923.0	39.3	1.7	-15.0	241	34.6	-
Palm	39.61	918.1	36.5	27.0	-15.0	271	42	0.043
Corn	34.90	909.0	39.5	-1.1	-40.0	277	37.6	0.24
Babassu	30.32	946.0	-	20.0	-	150	38	-
Tallow	-	-	40.0	-	-	201	-	6.10

The specific gravity of Handal oil is 0.898 at 20 °C, while in biodiesel was observed for 0.886.

The specific gravity of Thumba oil is slightly variable between 0.880 and 0.905. However, the specific gravity was reported that 0.835 in Thumba biodiesel (Table 1).

The significant physical characteristics of Handal oils shown in Table (1) indicate that the kinematic viscosity of Handal oils is 16.49 cSt at 40 °C, which is higher than that of the diesel value by four times. Table (3) shows that Handal oil was lower than that of vegetable oils, ranged between 27-57 cSt at 40 °C and slightly lies within the range of vegetable biodiesel (3-15 cSt at 40 °C). At 40 °C, the kinematic viscosity of used Handal oil (4.476 cSt), which was

higher than that of diesel fuel (2.6) and fossil diesel (2.27 cSt), while it was lower than Jatropha biodiesel (5.65 cSt), Karanja biodiesel (6.87 cSt) in addition to Rapeseed seed oil (7.2 cSt). The vegetable oil used has been noticed to build corrosion based on copper strip.

Table 3: Certain fuel-related characteristics of biodiesel derived from various vegetable oils [47].

Biodiesel	Kinematic Viscosity	Density	Heating Value	Cloud Point	Pour Point	Flash Point	Cetane Number	Carbon Residue
	(cSt 40° C)	(kg/m ³)	(MJ/kg)	(° C)	(° C)	(° C)		(w/w)
Diesel	2.75	835	42.25	-15	-20	66	47	0.001
Handal	4.48	888	-	+9	+3	50	-	0.5
Thumba	3.83-5.86	889	39.37	-5	-	66	53	-
Jatropha	5.65	879	38.5	13	-	175	50	-
Karanja	6.87	897	37.9	-	-1	187	49	0.05
Rapeseed	7.2	883	37.37	-	-12	-	51	-
Neem	15	882	38.5	-	-	180	47	-
Sunflower	4.6	868	40.58	1	-	183	45-52	-
Soybean	4.5	872	39.76	1	-7	178	37-45	1.7
Coconut	3.36	866	36.1	-	-4	122	56	0.03
Peanut	4.9	883	-	5	-	176	54	-
Palm	5.7	880	-	13	-	164	62	-
Babassu	3.6	879	-	4	-	127	63	-
Tallow	-	-	-	12	9	96	--	-

Viscosity is a good fuel quality indicator prior to application, particularly when the fuel origin is uncertain, or when oil can be polymerised throughout storing [51]. The kinematic viscosity of Handal seed oil is higher than that of conventional diesel fuel and should be preheated to decrease viscosity. It is very important to make sure that pump elements are strong and sufficiently robust for circulating such liquid [48, 52]. Of course, when the fuel has a high viscosity, this affects the efficiency of the pump and make it difficult to rotate and reduce the efficiency of the injection pump.

Handal oil has a high flashing point almost ($>180\text{ }^{\circ}\text{C}$) and heating value is 39.603 MJ/kg , while that for biodiesel and diesel fuel are 39.5 and 66 MJ/kg , respectively. The flash point of the obtained Handal biodiesel ($49.5\text{ }^{\circ}\text{C}$) was lower than that of petroleum diesel ($68.3\text{ }^{\circ}\text{C}$), diesel fuel ($68\text{ }^{\circ}\text{C}$), and fossil diesel ($66\text{ }^{\circ}\text{C}$). The flash point of biodiesel ($49.5\text{ }^{\circ}\text{C}$) is lower than the values, Thumba biodiesel (66), Jatropha Biodiesel ($175\text{ }^{\circ}\text{C}$), Karanja biodiesel ($187\text{ }^{\circ}\text{C}$), and Neem seed oil ($180\text{ }^{\circ}\text{C}$). The existence of chemically bound oxygen in vegetable oils leads to decreased heating values by around 10% . The fuel flash point is significant safety storage as well as handling specification without an effect on the engine performance [52].

The pour point of the Handal oil value is $-9\text{ }^{\circ}\text{C}$, whereas the biodiesel value is $+3$. The results showed that the vegetable oil offered the least values of pour point ranging from $-9\text{ }^{\circ}\text{C}$ to $40\text{ }^{\circ}\text{C}$, while Thumba oil holds a pour point of -8 and Thumba biodiesel possess a pour point of -12 . The corn oil had the pour point of $-40\text{ }^{\circ}\text{C}$, while the Jatropha oil and Karanja oil have two-pour point values of 8 and $6\text{ }^{\circ}\text{C}$, respectively (Table 3). Vegetable oils can be blended in all proportions with petroleum diesel, and such blends can be successfully utilised in engines [53, 54]. It can be concluded that all the chemically modified oil products have the pour points below $0\text{ }^{\circ}\text{C}$, which is a desirable property for lubricating oil.

The cloud points of Handal oil recorded is at $+5\text{ }^{\circ}\text{C}$, while biodiesel had the highest cloud point of $+9\text{ }^{\circ}\text{C}$, indicating an increase in cloud point with increasing carbon content [55]. The used Handal biodiesel held a cloud point $+9\text{ }^{\circ}\text{C}$, which was over that of diesel fuels $-20\text{ }^{\circ}\text{C}$. The used Handal oil held a cloud point of $+5\text{ }^{\circ}\text{C}$, which was over that of Thumba ($-1\text{ }^{\circ}\text{C}$), corn ($-1.1\text{ }^{\circ}\text{C}$), cottonseed ($1.7\text{ }^{\circ}\text{C}$), and rapeseed ($-3.9\text{ }^{\circ}\text{C}$), and lower than that of Sunflower ($7.2\text{ }^{\circ}\text{C}$), Karanja ($13\text{ }^{\circ}\text{C}$), Jatropha ($16\text{ }^{\circ}\text{C}$), and babassu ($-3.9\text{ }^{\circ}\text{C}$). Table (2) shows the least values of cloud point ranging from $1-4\text{ }^{\circ}\text{C}$. The cloud point of the Soybean oil used was $-4\text{ }^{\circ}\text{C}$ and lower than that of

262 soybean biodiesel (1°C). The Thumba oil products oil has the pour points is -1 °C, while the
263 rice bran oil and peanut oil both have pour point values of 12 °C.

264 The carbon residue of Handal biodiesel (0.5%) was more than that of Thumba biodiesel (0.01%)
265 and pure diesel possesses (0%) as well. The heating value of the utilised vegetable oil biodiesel
266 (40 MJ/Kg) is slightly lower than that of diesel fuels (42 MJ/Kg) and petroleum diesel (47
267 MJ/Kg). The carbon residue of Handal biodiesel (0.5%) was also higher than that of coconut
268 biodiesel (0.03%) but lower than that of soybean biodiesel (1.7%). The heating value of
269 vegetable oil (39 MJ/Kg) was slightly higher than that of coconut biodiesel (36.6 MJ/Kg) from
270 a different study [56, 57].

271 The HHV of Handal biodiesel is relatively high (39.60 MJ/kg) but lower than that of diesel
272 (49.65 MJ/kg) [58]. The HHV values of vegetable biodiesel (36-40 MJ/kg) show slight
273 variation from one type to another but higher than the limit value of diesel (42.2 MJ/kg) (Table
274 1). The biodiesel oxygen content enhances the combustion system and reduces the risk of
275 oxidation. The fuel oxygen content helps to improve the efficiency of combustion with
276 homogenous oxygen distribution in fuel throughout combustion [58]. This leads to the higher
277 efficiency of biodiesel combustion over petro-diesel, while the efficiency of methanol and
278 ethanol combustion is higher than that of diesel as well.

279 The sulfur content of Handal oils (193 mg/kg) is higher than that of Handal biodiesel (62
280 mg/kg). It has been noticed that sulfur was dramatically decreased upon processing oils and fats
281 to biodiesel (Table 2). Accordingly, sulfur content assessment in vegetable oils to be used in
282 engines is not compulsory. In this regard, sulfur content could reach zero, which is lower than
283 that of diesel fuels (≤ 100 mg/kg) [59, 60]. Although light diesel requirements are set at about

284 10-15 mg/kg in Europe [61], this limit is higher in some countries, which rises to 500 mg/kg in
285 India [59], 5,000 mg/kg in the USA and 10,000 mg/kg in Burkina Faso.

286 The water content of Handal oil is 0.52%. In comparison, biodiesel had a water content of
287 0.107%; this shows that most of the water existence comes from biomass, which could be from
288 poor drying or derived from poor oil storage settings by condensation [48]. The moisture which
289 is presented in the used vegetable oil was less than 0.01%, and this ensures hydrolysis of
290 triglycerides by water molecules, forming free fatty acids. The presence of water in vegetable
291 oil deteriorates fuel filter cartridges. Besides, during combustion, in the combustion chambers,
292 water existence in this area will help to cause cavitation problems, especially at the piston head,
293 leading to severe damage in engine head in the future.

294 The acid content of Handal oil was 0.52% mg KOH/g oil; however, vegetable oils showed
295 values in the range of 0.01-10% wt. (corresponding to 0.02-20 mg KOH/g oil). The oils acidity
296 is primarily because of free fatty acids (FFA), which comes from the water hydrolysis of
297 triglycerides. It has smaller molecular weights than the triglycerides, which makes acidic
298 vegetable oil easier to flame. Increasing acidity from 0.01% to 1% wt, and 10% wt, led to
299 decreased flash points of 20 °C and 85 °C, respectively.

300 Nevertheless, the problem of the fatty acids tends to form corrosion and deposits of carbon and
301 residuals of ash in the engine. Such FFA brought a good quality of vegetable oil when they
302 produced high temperatures through the process and while ageing. These hydrolytic reactions
303 may happen in biomass when they were badly stored (moisture), through pressing under high
304 temperature. The acidity of a given oil is accountable for the destruction of engine consumables
305 (hose, gasket, and so on), corrosion of engine, as well as instability of straight vegetable oil
306 (SVO) through storage.

GC–MS was utilised to determine the biodiesel composition from Hanadal seeds oil. The molecular weight of Handal seed oil was calculated using fatty acid composition and was found to be 885.07 kg/mol. Four major fatty acids (one saturated and three unsaturated) were detected in Handal oil biodiesel by GC-MS. The composition of FAME in Handal biodiesel was 90.30±1.7 wt. % of methyl oleate (C18:1) and followed by 4.83±0.5 wt. % of methyl linoleate (C18:2), 2.67±0.7 wt. % of methyl linolenate (C18:3), 1.73±0.4 wt. % of methyl stearate (C18:0), and 0.6±0.1 wt. % of the rest FAMS, as shown in Table 4. This result was different from that obtained for biodiesel produced from Indian Thumba seeds oil, where linoleic acid was highest (56.89 and 61.05 %), followed by oleic acid (18.19 and 17.04 %), palmitic acid (10.70 and 9.38 %) and stearic acid (7.89 and 7.34 %) [38, 50], respectively. The results also demonstrated that the Oleic acid (18:1) is the major fatty acid (90.30%) in the Handal seed oil, which appears to be an excellent source of oleic acid. The high Oleic acid value is higher than those found in other oils, such as Linseed, Soybean, Corn, Cottonseed, and Palm. The total saturated (Palmitic and Stearic) and unsaturated fatty acid (Oleic and Linoleic) contents of the seed oil were 1.73% and 95.13%, respectively. According to [62], the presence of major contents from linoleic acid and oleic acid could cause a self-ignition or self-heating of the oils. These two acids (> 95 wt. % of the oil) with multiple bonds make a Handal oil more likely to have a chemical tendency to self-ignite.

Figure 3. GC–MS characterisation of the components of Handal oil and its biodiesel.

Table 4: Properties and fatty acid distribution in different common vegetable oil (wt%).

Vegetable oils	Palmitic	Stearic	Oleic	linoleic	linolenic	Refs
	-	(C18:0)	(C18:1)	(C18:2)	(C18:3)	
Handal	-	1.73	90.30	4.83	2.67	This work
Thumba	10.7	7.89	18.19	56.89	61.05	[63]
Linseed	5.50	3.50	19.10	15.30	56.60	
Soybean	11.0	4.00	34.40	53.30	7.80	
Corn	10.9	2.00	25.40	59.60	1.20	
Cottonseed	21.6	2.60	18.60	54.40	0.70	
Rapeseed	4.00	2.00	56.00	26.00	10.0	
Palm	42.8	4.20	40.50	10.10	-	

329

330 **3.2 *Performance and discussion of internal combustion engine biodiesel***

331 The oxygen content of biodiesel improves the combustion process and decreases its oxidation
332 potential. The oxygen content in the fuel structure helps to improve the combustion efficiency
333 and more of homogeneity of oxygen with the fuel during combustion. This leads to higher
334 combustion efficiency of biodiesel than that of petrol-diesel fuel.

335 Torque is the measure of forces that act on an object, leading to object rotation. Torque variation
336 with various Handal blends of biodiesel and pure diesel concerning load is illustrated in Figure
337 (4a). The results detected that the variation of torque for different blends biodiesel and pure
338 diesel (B20, B50, B80, and B00) at an IC engine speed are slightly similar. The values torque
339 created by the engine under various loads for blends of biodiesel and pure diesel showed that
340 the torque was maximum with B20 at 60 kg. In comparison, the maximum torque was 44.44 N
341 m at 60 kg load, which is an indication of better performance. Overall, all different blends
342 biodiesel were exhibited similar results compared with pure diesel, with emphasised on the
343 blended biodiesel (B100).

344 Figure (4b) shows that the blending effect on torque variation is nearly analogous to the pure
345 diesel curve for a wide engine rpm range. Between speed 1000 and 1500 rpm, torque remains
346 almost constant with speed; after that, the torque decreases sharply, indicating that further
347 upsurge in speed leads to a reduction in torque. The maximum torque achieved in blend B20 is
348 44.44 N.M at 1100 rpm that is slightly higher than pure diesel. Overall, all different blends
349 biodiesel and pure diesel showed relatively similar performance results, exception blend B20
350 showed higher performance than pure diesel, taking into consideration blend B100 shows an
351 acceptable performance compared with pure diesel. This is in agreement with the characteristics
352 in Table 1 and 3 for Handal biodiesel and pure diesel.

Figure 4: a) torque vs. load for biodiesel blends and b) torque vs. engine speed for biodiesel blends.

The brake power (BP) is the produced force by using a motor without considering any of the various auxiliary components that may decrease the real motor speed. The influence of load on BP of a variety of blends of biodiesel and pure diesel is presented in Figure 5a. The result indicated that the blends B20 and B00 were similar values, whereas the different blends B100 and B50 were relatively decreased. Also, the result showed that 7.2 kW is the maximum power

363 for B20 fuel at 20kg load, and it then started a sharp decrease. The brake power at different
364 loads was higher for dual fuel combinations of B20 and B50 than pure diesel.

365 In conclusion, different blends can be suggested to be used in diesel engines with no required
366 changes in the engine. Furthermore, as explained in physical and chemical results in Table 1
367 that showed the sulfur content of Handal oils was 193 mg/kg, which was higher than the Handal
368 biodiesel value of 62 mg/kg, but significantly lower than that of diesel fuels (≤ 100 ppm).
369 Consequently, this should have a positive impact on the emissions when using Handal biodiesel
370 as a substitute for pure diesel fuel.

Figure 5: a) brake power (BP) vs. load for biodiesel blends and b) brake power (BP) vs. engine speed for biodiesel blends.

The brake power variation versus speed for Handal biodiesel blends when compared to pure diesel is illustrated in (Figure 5b). The results observed that the different blends biodiesel and pure diesel were relatively variable; however, B20 is marginally higher brake power in comparison with pure diesel, which is an indication of better performance. The maximum brake power achieved for B20 is 7.29 KW at 1650 rpm. Moreover, all blends result were increased to the maximum, with ranged between 1500 rpm to 1650 rpm and then sharply decreased.

383 The thermal efficiency results for different blends of biodiesel and pure diesel is illustrated in
384 Figure 6a. The results revealed that the thermal efficiency is relatively the same load for all
385 blends biodiesel and pure diesel. However, with increasing the load, brake thermal efficiency
386 augmented to the maximum 40 kg of load and 47.2% thermal efficiency, and then started
387 sharply decreasing for all blends biodiesel and pure diesel. Besides, it was observed that brake
388 thermal efficiency for blend biodiesel B100 was approximately equivalent to that of pure diesel.

389 The brake thermal efficiency variation and engine speed for a variety of blends of biodiesel and
390 pure diesel are demonstrated in Figure 6b. The result observed that the different blends
391 biodiesel and pure diesel was relatively the same values. It was also observed that when engine
392 speed increased, brake thermal efficiency increases to almost 1500 rpm, then started sharply
393 decreasing. The blend B50 shows flocculated values compared with other blends values. In
394 conclusion, the brake thermal efficiency for different blends of biodiesel and pure diesel was
395 relatively the same, focusing on the result of B100 value. Hence, in conclusion, the blend B100
396 can be recommended for use in diesel engines with no need for engine alterations with B20 was
397 better than B00.

Figure 6: shows a) the thermal efficiency versus load for biodiesel blends and b) the thermal efficiency versus engine speed for biodiesel blends.

407 The impact of changing engine load has a great influence on the brake-specific fuel consumption
408 (BSFC), as seen in Figure 7a. Starting from zero load up to 20 N, a substantial upsurge in fuel
409 consumption was observed due to the fact that at starting load, a very rich fuel mixture needed
410 to overcome the load occurred at the start; after that, the fuel consumption was almost stable.
411 Since the biofuel possessed a lower latent heating value of 39.59 MJ/kg (Table 1) than that of
412 diesel fuel of 42.25 MJ/kg (Table 3), pure diesel fuel (B00) is consuming less fuel than other
413 biofuels no matter what the biofuel percentages are, at all engine loads; thus, B100 is the worst
414 case. B00 is the best case of fuel consumption and increasing the Handal oil percentage as
415 biofuel will increase fuel consumption. The blended fuel amount utilised in the engine test
416 should be over that of diesel fuel for realising an identical equivalence ratio. Such a situation
417 results in BSFC augmentation with increasing biofuel percentage in fuel blend, as displayed in
418 Fig. 7 (a, b). BSFC for B20, B50 and B00 was found to decrease with increasing engine load.
419 BSFC was decreased with increased biodiesel amount and increased Handal rate in comparison
420 to those found in varying engine loads.

Figure 7: shows a) the effect of load on the brake-specific fuel consumption (BSFC) for biodiesel blends and b) the effect of load on the consumption rate (g/kWh) for biodiesel blends.

4. Conclusion

Herein, we extracted the Handal seed oil with its conversion into biodiesel along with testing fuel characteristics in the IC engine. The density of Handal seed oil agrees with pre-standard fuels for vegetable oil with compatibility to combustion engines- fuel. The Handal oil kinematic viscosity is larger than that of conventional diesel fuel but shows less value compared to heavy fuel oil. Handal vegetable oil possesses nearly 99% of the combustion heat of biodiesel. The HHV of biodiesel (39.60 MJ/kg) is slightly lower than the limit value of 42.2 MJ/kg for diesel fuels. The blend B20 (20% Handal oil biodiesel and 80% diesel fuel), engine performance was significantly higher performance results compared with pure diesel regarding torque, brake power, and efficiency of the engine. Variation of performance parameters for torque engine speed, brake power, and thermal concerning speed engine was relatively similar for blends biodiesel Handal with pure diesel. Thus, Handal can be blended successfully with biodiesel for the IC engine. Brake thermal efficiency improved significantly with an increase in the percentage of biodiesel blending. Hence, in conclusion, the different blends can be recommended for use in diesel engines with no need to modify the engine. The results of engine performance highlighted that the blend B100 (100% of biodiesel) could be efficiently used in IC engines without affecting the performance of engines. This will help in keeping the environment safe and in the conservation of natural resources for longer use. One significant area surrounds that of engine emissions when using Handal biodiesel, and diesel blends will need further evaluation in future work.

Disclaimer:

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