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Research Article

Comparative Study of Biodiesels Produced from Waste of Beef Tallow, Avocado Pear, Watermelon and Desert Date as Alternative Source of Energy

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Abstract

Biodiesel is fossil fuel substitute in which it quantity continually decreases due to increasing demand. This work entails the production of biodiesel from waste of beef tallow fat, Avocado pulp, watermelon (*Citrullus lanatus*) oil and desert date (*Balanite aegyptiaca)* kernel. Oils from plant materials were extracted with N-hexane using Soxhlet extractor. Biodiesel or fatty acid methyl esters (FAME) were produced from these four feedstocks via transestrification with NaOH as catalytst. Results show percentage biodiesel yield of 87.40%, 81.92%, 57.24% and 92.03% for beef tallow, avocado seed pulp, watermelon seeds and *balanite* kernel oils respectively and this indicate that they are viable feedstock for biodiesel production. Results of the physico-chemical evaluation of their individual biodiesels showed viscosities (4.92, 5.02, 3.70, 5.42 mm^2/s), densities(0.87, 0.93, 0.86, 1.33 g/cm^3), acid value (0.28, 0.84, 3.09, 0.56 mg KOH/g), free fatty acid (0.14, 0.42, 1.54, 0.24 mg/g), iodine value (45.04, 38.7, 0.89, 0 $gI_2/100g$), flash point (154, 172, 102, 172 ^0C) and cloud point (-8, -5, -2, -13 ^0C) for beef tallow, avocado seed pulp, watermelon seeds and *balanite* kernel biodiesels respectively. Not all fuel samples are consistent with ASTM D6751 standard limit. Thus, B20 blends were made and evaluated for major fuel parameters. Comparison of the four B20 blends results show that all four biodiesel blends were within regulatory standard limits. The B20 blends of *balanite* and watermelon have advantage of improved diesel characteristics thus can be used in place of fossil based diesel.

Keywords: Biodiesel; Feedstocks; Transesterification; Soxhlet; Beef tallow.

Introduction

The continues depletion of reserves of non-renewable petroleum, price volatility, feedstock availability concerns have caused an intensified search for alternative sources of energy. Biodiesel derived from biological sources like lipid materials such as fats and oils have received increasing attention [1]. Biodiesel can be defined as a natural and renewable fuel which comprises of mono-alkyl esters of long chain fatty acids derived from vegetable oil or animal fats made by typically reacting lipids with an alcohol through a chemical process called transesterification yielding fatty acid alkyl esters (biodiesel) and glycerol as by-product [1].

Tallow is beef fat gotten from slaughterhouses. Animal fats are also an interesting option for biodiesel production, especially in countries with plenty of livestock resources like Nigeria, although it is necessary to carry out preliminary treatment since they are solid; Also, highly acidic grease from cattle, pork, poultry, and fish can be used [2]. The use of animal fats eliminates the need to dispose them, besides contributing to the supply of biodiesel [3]. Avocado *(Persea americana)* is a tree between 5 and 15 m in height. The avocado fruit matures after picking and not on the tree. Avocado oil may be obtained from the fruit pulp and pit. The oil content of the fruit is in the range 12–30% [4]. *Balanite aegyptiaca* is a perennial tropical plant. It is called desert date (English), Adowa (Yoruba, Nigeria), adua or Aduwa (Hausa, Nigeria) and heglig (Arabic). *Balanite aegyptiaca* belongs to the family *Balanitecea* [5]. The plant attains a height of more than 6 meters. It has a multiplicity of uses and almost every part of the plant is useful including, leaves, thorns, back, root and fruit. *Balanite aegyptiaca* seeds contain non-edible plant oil that can be used for biodiesel and bio-ethanol production [6]. Watermelon plant *(Citrullus lanatus*)

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originally comes from Africa, but today you can grow it anywhere. It is a juicy and sweet fruit which grows to a height of approximately 24 inches, and sprawl approximately 3 to 20 feet wide. Most watermelon varieties, including "All Sweet" and "Royal Sweet," have fully developed seeds that contain oil which can be planted directly in the ground [7].

The aim of this research work is to produce, characterize and compare biodiesels from waste oils of Beef tallow fat, avocado *(Persea Americana)* seed pulp, watermelon seed (*Citrullus lanatus*) and desert date (*Balanite aegyptiaca)* kernel as substitute for petro-diesel. This study of biodiesel feedstocks is very timely because it will allow a balance to be sought between agriculture, economic development and environment waste management by contributing to the reduction of greenhouse gas emissions; help security of energy supply, promote a greater use of renewable energy, diversify agricultural economies into new markets and channelling plant and animal waste into useful fuels.

This work covers collection of animal fat (beef tallow) at Wurukun abattoir beside river Benue, Makurdi in Benue State. Nigeria. Watermelon seed (*Citrullus lanatus*) and Avocado *(Persea americana)* pulp was sourced from railway market Makurdi. Desert date (*Balanite aegyptiaca)* gotten from Bukuru market Jos, Plateau state. Nigeria. Laboratory extraction of oils, trans-esterification of oil, blending of biodiesels with fossil based diesel, physico-chemical analysis of samples, comparison of oils and biodiesels was carried out at Biochemistry laboratory, College of health science, Benue state university, Makurdi, Nigeria.

Materials and methods

Collection and identification of plants and animal feedstock

Beef tallow sample

Waste animal fat were collected from Wurukun slaughter house in Makurdi. Beef fat (400 g), were shredded into smaller pieces and then charged into a pot before melting as describe by [8].

Avocado sample

The seeds of Avocado were collected as waste from railway market, Makurdi. The seed pulp were collected, blended and microwave for 3 h to remove moisture content.

Watermelon sample

Watermelon fruits and waste were purchased from Daudu market, Makurdi. The watermelon seeds were collected and dried before carefully blending using an electric blender. The blended samples were sieved to remove unwanted particulate substances and the final product was an averagely coarse aggregate where oil was extracted as described by [9].

Balanite aegyptiaca sample

Balanite aegyptiaca seeds were purchased from Bukuru market in Jos, plateau state, Nigeria. The external seed pods were washed and crushed to recover the internal seed kernel which was grinded with an electric blender. *Balanite* oil was extracted as described by [10].

Plant oil extraction using Soxhlet apparatus

Oils from Avocado seed pulp, watermelon seeds and *Balanite aegyptiaca* kernel was extracted using basic procedure described by [10] with little modifications. The extraction was repeated until sufficient oil for transesterification as well as feedstock analysis were obtained

Determination of the percentage oil yield from plant and animal feedstocks

Percentage Oil yield was determined according to the method outlined by [4]. After extraction of oils, the solid avocado, watermelon, *Balanite aegyptiaca* were dried in the oven at 105°C and weighed until the constant weight is attained and the percentage of oil extracted was determined as:

$$\%\ \text{crude oil yield} = \frac{(W1-W2) \times 100}{W1} \quad \ldots(1)$$

Where, W1 =weight of sample before extraction

W2 = weight of sample after extraction

The percentage oil yield for beef tallow was calculated using the method described by [11]

$$\%\ \text{oil content} = \frac{\text{Weight of extracted oil (g)} \times 100}{\text{Weight of sample (g)}} \quad \ldots(2)$$

Characterization procedure for the extracted oils from seed and tallow

Physico-chemical characteristics of oils are important for determining their nutritional quality and commercial value [12] and some important physio-chemical properties were determined for the four oils by standard methods which were compared with properties of diesel, ASTM 6751 and EN 14214 standard specifications [13-14].

Specific gravity and density

Specific gravity and density of the oils were measured and calculated using the method according to [10].

Acid value and Free Fatty Acid (FFA)

Wet chemical method was used to determine the acid value of oils as described by [9].

Iodine value

Using the method described by [15]. Iodine value (I N) is the number in milligrams of iodine absorbed by one-gram fat.

Peroxide value

This is the measure of its content of oxygen. It is expressed in mol/kg. Peroxide value was determined according to the method of [9].

Saponification value

William and Devine's method was used [15]. This is the number of milligrams of potassium hydroxide required to neutralize the free fatty acids resulting from the complete hydrolysis of 1g of the sample. It is measured in (mg/g) [7]

Viscosity

The procedure for measurement is detailed in [16].

Cetane number:

The biodiesel sample's cetane numbers were determined in accordance with ASTM D4737 as calculated by [17].

Colour

According to [9], the colour of the various oils and biodiesel obtained was determined by oganoleptic method.

Biodiesel production

Pre-treatment of seed and tallow oil

Pre-treatment is usually carried out on oils that have high free fatty acid content in other to enhance optimum conversion of the sample oils into its corresponding esters. This method is according to the method described by [9].

Trans-esterification process

Transesterification of the four different oils was done using method outlined by [8] with little modifications. It includes mixing of alcohol and catalyst, methyl ester mixture and separation of the biodiesel and glycerin.

$$\text{Biodiesel yield} = \frac{\text{Recovered Biodiesel} \times 100}{\text{Initial oil used}} \quad \ldots(3)$$

Biodiesel-Diesel Blends (B20)

According to [13], Fatty acid methyl esters (FAME) obtained from watermelon seed oil, avocado pulp oil , *balanite* kernel oil and beef tallow oil were mixed with petroleum diesel purchased from Conoil filling station Makurdi on a volume basis individually, i.e. a ratio of 1:4 (v/v) of biodiesel to diesel, yielding blends of B20 (20% biodiesel mixed with 80% diesel). The purpose of blending was to understand if all the quality parameters would fulfil the standard of ASTM D6751 and EN 14214 without the need of using further additives. Blends were characterized following the same procedures described above for biodiesel [8].

Results and discussion

Isolation and fusion of protoplasts

The results obtained from the study of physico-chemical properties of the four sample oils shows that the average percentage yield of the oil from Beef tallow is highest with 92.8% followed by *Balanite* 39.65%, Watermelon 20.02% and Avocado 10.96% as represented in table 1. The percentage biodiesel yield from *balanite* kernel oil sources is highest having 92.03%, beef tallow biodiesel yield is second with 87.40%, avocado 81.92% and watermelon with the least biodiesel yield of 57.24%. Table 2, 3 and 4 shows the physico-chemical properties of sample oils, pure biodiesel (B100) and biodiesel blends (B20) of beef tallow, avocado, watermelon and *Balanite* respectively. Result in table 1 reveals that Beef tallow and *Balanite* oil being non-edible oils would be suitable feedstocks for biodiesel producing industries as compared to Avocado and watermelon plant materials due to their high oil yields.

The percentage oil yield for *balanite* and beef tallow also shows that there could also be good feedstock for biodiesel production comparing them with Linseed and soybean oil with 33.33% and 18.53% percentage oil yield respectively [18]. In comparison with *jatropha curcas* with oil yield of 60.35%, palm oil with 35.08% as reported by [19], beef tallow with 98% oil yield is a better material for biodiesel production. High oil content of Beef tallow, *balanite* and watermelon indicates that they are also suitable for use in oleochemical industries for production of surfactants, detergents, soap and nitrogeneous derivatives [19].

Table 1. Average percentage oil and biodiesel yield

Sl. No.	Plant and tallow oil	Average % oil yield	Average % biodiesel yield
1	Avocado (Av)	10.96%	81.92%
2	Watermelon (Wm)	20.02%	57.24%
3	Balanite (Be)	39.65%	92.03%
4	Beef tallow (Bt)	92.8%	87.40%

Table. 2. Characterization of oils from Avocado pulp, watermelon seeds, *Balanite* kernel and Beef tallow

Parameters	Av Oil	Wm Oil	Be Oil	Bt Oil	ASTM D6751	ASTM D975 Limits (Diesel)	EN14214
Specific gravity	0.98	0.93	0.90	0.99	0.88	0.85	
Density (g/cm^3)	0.95	1.50	1.50	0.92	0.86-0.90	0.82-0.845	0.80-9.0
Acid value (mgKOH/g)	4.49	9.54	1.68	1.68	0.80max	0.50max	0.50 max
Free fatty acid (mg/g)	2.74	4.77	0.84	0.84	0.50max	0.27	
Iodine value (gI_2/100g)	41.20	191.89	77.41	46.30	130max	128.5	-
Peroxide value (mol/kg)	18.0	8.2	1.15	-			
Saponification value (mg/g)	221.60	145.86	171.1	-70.12	-	-	-
Viscosity (mm^2/s) at 40°C	36.70	1	14.72	45.29	1.9-6.0	1.9-4.1	3.5-5.0
Cetane number	61.66	40.54	60.78	-	47-65	40-55	
Colour	Light green	Light brown	Pale yellow	Light yellow		Golden brown	

All values are less dense than water and slightly different from values obtained by [10] for jatropha (0.88), coconut oil (0.91) and mango oil (0.92). The experimental results for their corresponding biodiesel (B100) and blends (B20) in table 3 and table 4 show lower specific gravity values for all diesels compared with their oils except for Av (B100) with 0.96. The ASTM D6751 specifications for specific gravity show that only Av (B100) has a specific gravity higher than it specifications, making it a less suitable biodiesel considering this parameter only [13].

Relative Density value for Avocado oil is 0.95 (g/cm^3), 1.50 (g/cm^3) value was obtained for both watermelon and *balanite* oil with 0.92 (g/cm^3) for Beef tallow oil which is similar to 0.92 (g/cm^3) reported by [20] for Laloub seed oil. Density of 1.38 (g/cm^3) for watermelon oil was reported by [9]. Density of 0.93 (g/cm^3) was also reported for Beef tallow by [21]. The relative density from the experimental results (table 2 and 3) shows that the respective oils produced biodiesel of lower relative density with Av (B100) and it B20 blend having 0.93 (g/cm^3) and 0.84 (g/cm^3), Wm (B100) and (B20) having 0.86 (g/cm^3) and 0.81 (g/cm^3), Be (B100) and (B20) having 1.33 (g/cm^3) and 0.86 (g/cm^3) while Bt(B100) and (B20) having 0.87 (g/cm^3) and 0.85 (g/cm^3) relative density. specifications range for relative density 0.86-0.90, 0.82-0.845, 0.80-0.90 respectively shows that all four produced B20 blend (table 3) of biodiesel met regulatory specifications, making them good biodiesel considering this parameter only [13,14]. Acid values of 4.49, 9.54, 1.68 and 1.68 mgKOH/g was obtained from Avocado, watermelon, *balanite* and Beef tallow oil respectively as reported in table 2.

Table. 3. Characterization of Biodiesel (B100) from Avocado, Watermelon, *Balanite* and Beef tallow

Parameters	Av B100	Wm B100	Be B100	Bt B100	ASTM D6751 Limits	ASTM D975 Limits (Diesel)	EN14214
Specific gravity	0.96	0.88	0.83	0.85	0.88	0.85	
Density(g/cm^3)	0.93	0.86	1.33	0.87	0.86-0.90	0.82-0.845	0.80-9.0
Acid value (mgKOH/g)	0.84	3.09	0.56	0.28	0.80 max	0.50max	0.50 max
Free fatty acid (mg/g)	0.42	1.54	0.28	0.14	0.50 max	0.27	
Iodine value ($gI_2/100g$)	38.7	0.89	-	45.04	130 max	128.5	-
Peroxide value (mol/kg)	49.2	-	-	-			
Saponification value (mg/g)	-	134.64	-	-	-	-	-
Viscosity (mm^2/s) at 40°C	5.02	3.70	5.42	4.92	1.9-6.0	1.9-4.1	3.5-5.0
Flash point (°C)	172	102	172	154	130-170	60-80	120 min
Pour point (°C)	-6	-3	-12	-4	-15-10	-35-15	-
Cloud point (°C)	-5	-2	-13	-8	-12 to -3	-15 to -5	-
Fire point (°C)	132	125			100-170	68	
Cetane number		86.59		-	47-65	40-55	
Colour	Pale green	Brown	Pale yellow	Brown		Golden brown	

Table. 4. Quality parameter of B20 blends of Avocado, watermelon, *Balanite* and Beef tallow

Parameters	Av B20	Wm B20	Be B20	Bt B20	ASTM D6751 Limits	ASTM D975 Limits (Diesel)	EN14214
Specific gravity	0.87	0.87	0.81	0.82	0.88	0.85	
Density (g/cm^3)	0.84	0.81	0.86	0.85	0.86-0.90	0.82-0.845	0.80-9.0
Acid value (mgKOH/g)	0.92		0.26		0.80max	0.50 max	0.50 max
Free fatty acid (mg/g)			0.13		0.50max	0.27	
Iodine value ($gI_2/100g$)	37.20		-		130max	128.5	-
Peroxide value (mol/kg)	57.0		-				
Saponification value (mg/g)	-		-		-	-	-
Viscosity(mm^2/s) at 40°C	4.52	2.25	2.72	3.50	1.9-6.0	1.9-4.1	3.5-5.0
Flash point (°C)	86.9	70	82.4	94.5	130-170	60-80	120 min.
Pour point(°C)	-9	-8	-13	-7	-15-10	-35-15	-
Cloud point (°C)	-8	-2	-19	-11	-12 to -3	-15 to -5	-
Fire point (°C)	75	80			100-170	68	
Cetane number	-	-	-	-	47-65	40-55	
Colour	Brown	Brownish	Light brown	Brown		Golden brown	

All values are lower than that of olive oil with 17 mgKOH/g and 10.3 mgKOH/g for shea nut butter. 0.84, 3.09, 0.56 and 0.28 in (mgKOH/g) are their corresponding B100 Acid values showing reduction in their values after transeterification (table 3). Table 4 shows that only two blends namely AV (B20) and Be (B20) acid values of 0.92 and 0.26 in (mgKOH/g) where obtained with no value for Wm (B20) and Bt (B20). Only Bt (B100) with value of 0.28 mgKOH/g and Be (B20) with 0.26mgKOH/g were within the ASTM D975 and EN 14214 specifications of 0.50 max but within ASTM D6751 range of 0.80max. Free Fatty Acid values (FFA) were 4.77, 0.87, 2.74, and 0.84 mgKOH/g for watermelon, *balanite*, Avocado and Beef tallow oils which differ from 2.8 mgKOH/g and 1.84 mgKOH/g reported by both [11,22] for *balanite* and Laloub seed oil respectively. FFA values are showed in table 2, 3 and 4.

The Iodine values of Avocado, watermelon, *Balanite*, and Beef tallow oils in gI_2/100g are 41.20, 191.89, 77.41 and 46.30 respectively as represented in table 2. 45.37 gI_2/100g value for beef tallow oil as reported by [8], 122.42 gI_2/100g for *balanite* oil reported by [23] and 157.1 5gI_2/100g for watermelon oil also investigated by [9]. Watermelon oil with 191.89gI_2/100g values is greater than 100 and within a range of semi-drying oils consisting predominately polyunsaturated fatty acids mainly oleic and linolenic fatty acids. There was a sharp reduction in iodine value after conversion of oils via transesterification to biodiesels giving values of 38.7, 0.89, 0, and 45.04 $gI_{2/}$100g for Avocado, watermelon, *balanite,* and Beef tallow respectively as shown in table 3. Values correspond with 0.87, 37.4, and 45 for watermelon, Avocado and beef tallow as reported by [8,9,24] respectively. No Iodine values for B20 blends of the biodiesel except for AV B20 with 37.20 gI_2/100g. In table 2 and 3, it could be seen that iodine values of both oils and their biodiesel derivatives fall below 130, 128.5 and 120 which are the maximum specification for ASTM D6751, ASTM D975 and EN14214 with exception of WM oil with 191.89 gI_2 /100g. This shows that under the iodine value parameter, all oils and their corresponding biodiesel are suitable to be used as fuels except for Wm oil.

Peroxide value was calculated as shown in table 2 and 3. Av oil has high peroxide value of 18.0 mgEq/kg. 8.2 mgEq/kg was recorded for Wm oil which is close to 8.0 mgEq/kg reported by [20] for Laloub seed oil. 1.15 mgEq/kg peroxide value for *Be* oil almost the same with 1.18 mgEq/kg reported by [23] for *balanite* oil. Beef tallow oil has no peroxide value. These values differ from 24.0 mgEq/kg value reported by [24] for Dilla Avocado oil and 6.0mgEq/kg for *Balanite* oil reported by [22]. No peroxide value for their individual Biodiesel and blends.

Saponification values of extracted sample oils were reported to be 221.595mgKOH/g for Avocado oil, 145.86 mgKOH/g for watermelon oil, 171.1 mgKOH/g for *balanite* oil and -70 mgKOH/g for Beef tallow as presented in table 2. Only watermelon B100 value of 134.54 mgKOH/g was recorded for biodiesel with no value for others (table 3). All values except for -70 mgKOH/g for beef tallow were within range and a little similar to 224,63 mgKOH/g, 168.80 mgKOH/g, 174.5 mgKOH/g, 168.3 mgKOH/g and 182.80 (mgKOH/g) reported by [5,11,20,22,23] respectively for different *balanite* oils.191.89 mgKOH/g saponification value for watermelon was reported by [9]. 219 mgKOH/g, and 223 mgKOH/g saponification values were reported for Avocado oil characterized by [24]. High saponification values obtained for Avocado, watermelon and *balanite* oils show the presence of normal triglycerides and can be very useful in the production of liquid soap and shampoo [25].

The viscosity of the produced biodiesel for Avocado, watermelon, *balanite* and Beef tallow are 5.02, 3.70, 5.52, and 4.92 mm^2/s respectively as represented in fig. 1. High Speed Diesel (HSD) of ASTM D975 has viscosity of 1.9 - 4.1 at 40°C. Results indicate that the viscosity of watermelon seed and beef tallow biodiesel were within the specifications for ASTM D6751, ASTM D975and EN14214 while *balanite,* Avocado and Beef tallow biodiesels meet both ASTM D6751, EN 14214 but slightly above ASTM D975 Standard of 1.9-4.1 mm^2/s. Viscosity analysis of biodiesel B20 Blends at 40°C gave values of 4.52, 2.25, 2.72 and 3.50 in mm^2/s respectively for Avocado, Watermelon, *balanite* and Beef tallow biodiesel. This is likely to have a marginally better lubricity than their B100 and their respective oils as it also met both US and EN standards. This is likely to have a better combustion profile when used as fuel in a diesel engine [11].

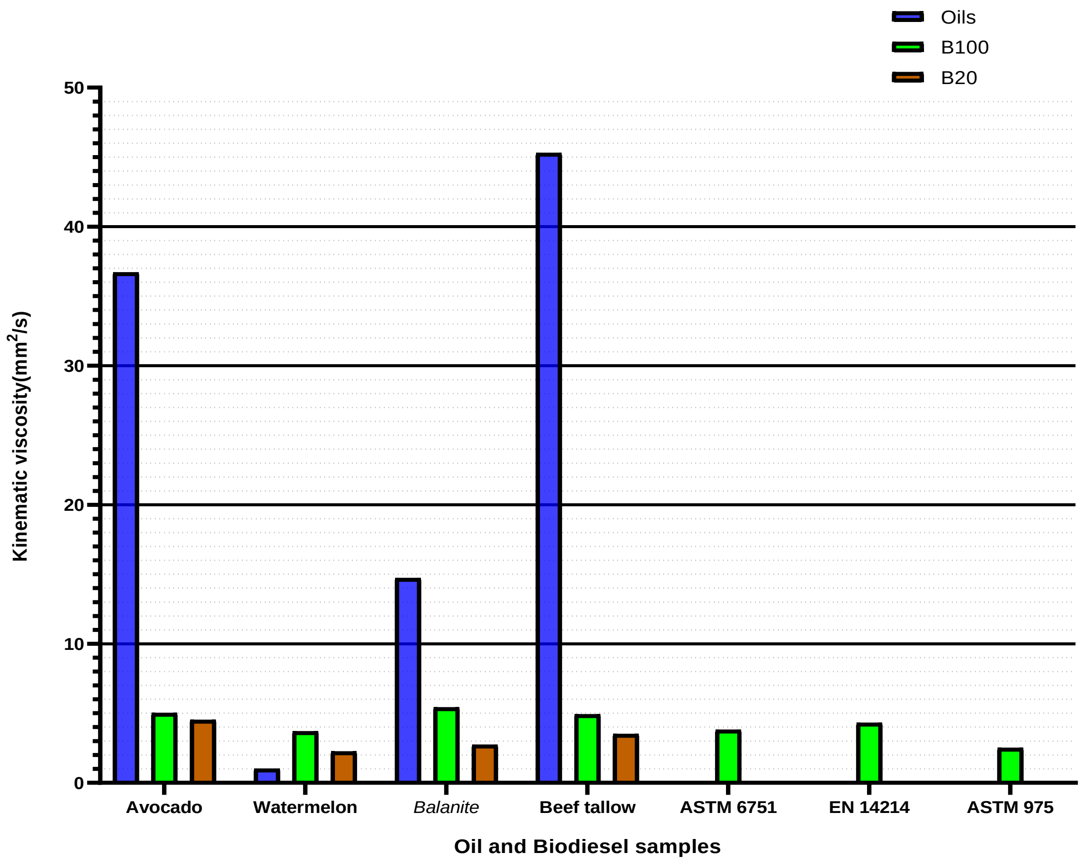

Fig. 1. Kinematic viscosities of Wm, Be, Av, Bt, petroleum diesel, and ASTM D6751 & EN 14214 specifications

Flash point is the temperature that indicates the overall flammability hazards in the presence of air; higher flash points make for safe handling and storage of biodiesel [9]. The Flash Points as represented in fig. 2 shows that watermelon B100 has 102°C, Avocado and *Balanite* with same value of 172°C while Beef tallow has flash point of 154°C which is consistent with Palm oil Biodiesel with 154°C but differ from Neem oil biodiesel (120°C) as reported by [26]. All values are higher than that of High Speed Diesel (60-80°C).The flash point temperature of diesel fuel is the minimum temperature at which the fuel will ignite (flash) on application of an ignition source. Flash point varies inversely with the fuel's volatility. The high flash point temperatures of the watermelon, *Balanite*, Avocado and Beef tallow biodiesel and their blends B20 derivatives shows that they all have very low flammability, which make them safer and better handled fuels. Fig. 2 further illustrates this comparison with ASTM D-6751 and EN 14214 biodiesel standards which stipulate values of 130˚C-170^{0}C and 120˚C min respectively for flash point. The results shows that tallow biodiesel with 154^{o}C, Avocado and *balanite* biodiesel with same 172^{0}C meets specifications of both American and European standards and are much safer fuel to handle than even petroleum diesels[13,14].

Cloud point is the temperature at which a cloud of wax crystals first appear in the biodiesel when it is cooled [9]. The pour point is the lowest temperature at which the biodiesel can still be moved. These properties are related to the use of biodiesel in colder region. The cloud point obtained from biodiesel B100 was -2°C for watermelon, -13°C for *balanite*, -5°C for Avocado and -8 °C for Beef tallow compared to -6°C for castor biodiesel [27]. Pour point values are -3°C for watermelon, -12 °C for *balanite*, -6 °C for Avocado and -4 °C for Beef tallow which is close but differ from castor (-9°C) as reported by [27]. The cloud point of the biodiesels and their B20 derivatives helps to indicate the temperature limit at which they could be used as fuel. Biodiesels would not be suitable for usage as fuel in region where the temperature is lower than their cloud points because they start waxing or solidifying below these temperatures [19]. In this light, fig. 3 shows watermelon, *Balanite*, Avocado and Beef tallow biodiesels cloud point of -2, -13, -5 and -8 °C respectively and their corresponding B20 blends with -2, -19, -8 and -11°C. It indicates that all four diesels have better advantage to be used in cold regions. This Biodiesel have advantage over to *Jatropha curcas* biodiesel derivative with 13°C cloud point and palm oil biodiesel derivative having cloud point of 20°C as reported by [19].

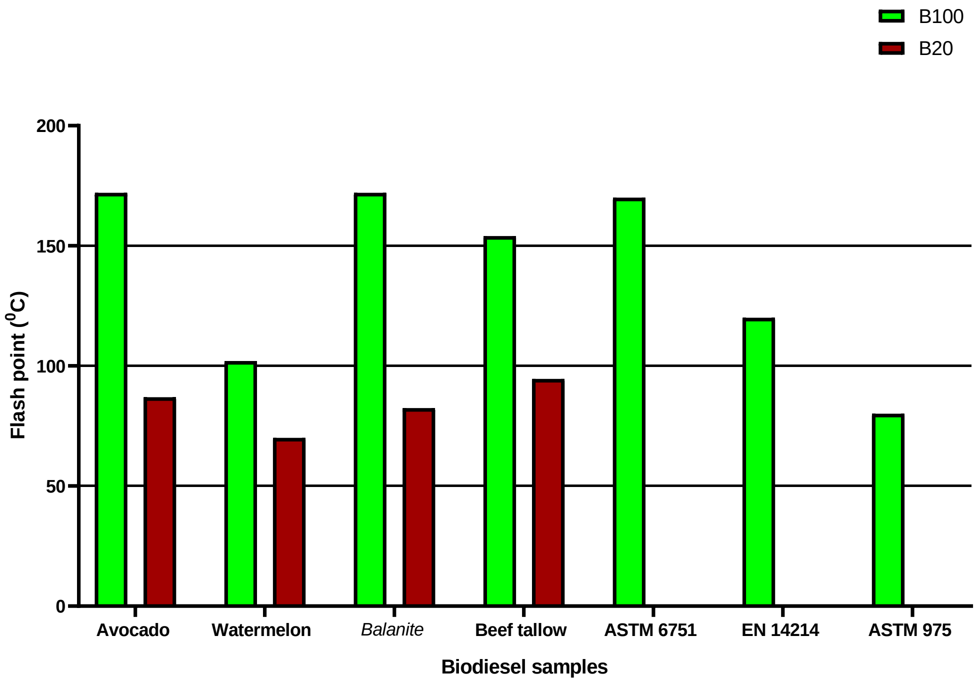

Fig. 2. Flash point of Wm, Be, Av, Bt, petroleum diesel, and ASTM D6751 & EN 14214 specifications

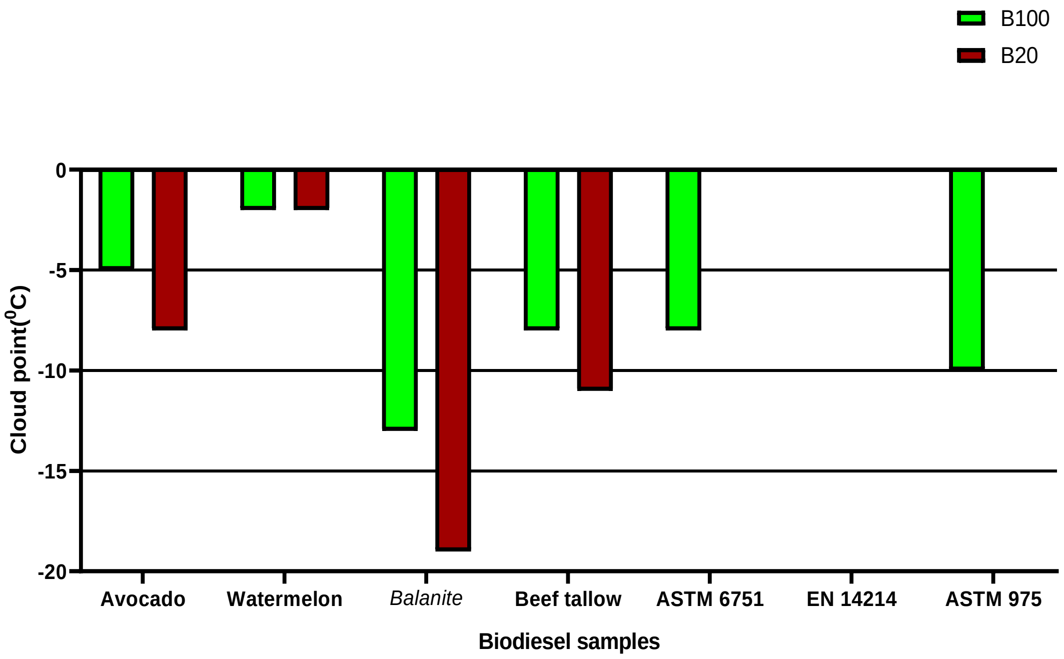

Fig. 3. Cloud point of Wm, Be, Av, Bt, petroleum diesel, and ASTM D6751 & EN 14214 specifications

The pour point of watermelon biodiesel and it B20 blend are -3 and -8°C. *Balanite* biodiesel and B20 has pour point of -12^{0}C and -13^{0}C. Avocado has pour point of -6 and -9°C for it biodiesel and B20 blend. Beef tallow Biodiesel and B20 has pour point of -4 and -7°C. The pour point of all biodiesel and B20 samples derivative are presented in table 3 and 4 shows that values fall in the range of ASTM D6751 and ASTM D975 specified limit [13].

The cetane number obtained (table 2, 3, 4) shows that Watermelon oil and biodiesel has 40.54 and 86.59 respectively. *Balanite* oil has value of 77.41 with no value for *balanite* B100 and B20, Avocado oil has 61.66 with no value for Avocado B100 and B20 blend. Beef tallow has no cetane number for sample oil, B100 and B20 blend. Values obtained were found to be within same range of 45 and 50 values for jatropha oil and B100 as reported by [10]. Watermelon biodiesel with high CN implies a good quality diesel that will decrease delay time between injection and ignition in diesel engines. This shows that watermelon seed biodiesel has a lower combustion quality than rape seed and jatropha biodiesel even though it was a little above ASTM D6751 and ASTM D975 standards.

The extracted Avocado oil gave light green colour probably from chlorophyll pigment [1]. Watermelon oil has a light brown color because of the presence of xanthophyll pigment which is consistent with biodiesel from castor oil as reported by [27]. Visual inspection also put the colour of *balanite* oil to be pale yellow as a result of presence of plant pigments while Beef tallow gave light yellow as a result of beta-carotene, a natural form of vitamin A and also a plant pigment present in the grasses fed to the animals [16]. B20 blends for the four colored diesels were all brownish as a result of bleaching from the fossil petroleum diesel used for the blends [11].

Conclusions

A number of useful findings and deductions were made from the biodiesel production from beef tallow, avocado, watermelon and *balanite eagypiatiaca*. These includes: High percentage biodiesel yield obtained from beef tallow, avocado seed pulp, watermelon seed and *balanite* kernel oils after transesterification shows that they are viable biodiesel fuel sources. Fuel quality parameters for these four biodiesels shows that the conform to regulatory standard limits except for few parameters like FFA value of watermelon biodiesel. B20 blends of all the four biodiesels indicate that they are good blending components for petro-diesel with improved cold–flow properties and all biodiesel B20 blends presented good performance quality when compared with standard limits. Watermelon and *Balanite* biodiesel and their B20 blends have proved to be good biodiesel prospect, having the best Kinetic viscosity and Cetane number with good flash point, cloud point and relative densities. The high flash point (154˚C) of beef tallow biodiesel and it high oil yield of 92% with a unique short separation period of approximately 10 minutes is typical of a biodiesel fuel and makes it safe to transport and handling. This applied research work has provided some insight and guidance that can lead to large scale development of biodiesel as energy sources in future. This work will be of benefit to commercial biodiesel producers around the globe, who are looking for quality oils that are cheap and readily available.

Conflicts of interest

Authors declare no conflicts of interest.

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