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Article

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Energy Reports

Provided in Cooperation with:

Elsevier

Suggested Citation: Adekunle, Abolanle Saheed; Oyekunle, John Adekunle Oyedele; Obisesan, Olaoluwa Ruth; Ojo, Oluwaseyi Samson; Ojo, Olatunji Seyi (2016) : Effects of degumming on biodiesel properties of some non-conventional seedoils, Energy Reports, ISSN 2352-4847, Elsevier, Amsterdam, Vol. 2, pp. 188-193,
<https://doi.org/10.1016/j.egy.2016.07.001>

This Version is available at:

<https://hdl.handle.net/10419/187860>

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Effects of degumming on biodiesel properties of some non-conventional seedoils

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ARTICLE INFO

Article history:

Received 28 May 2016

Received in revised form

26 July 2016

Accepted 27 July 2016

Available online 6 August 2016

Keywords:

Degummed

Non-conventional oils

Raw oil

Cetane number

Biodiesel

Bio fuel application

ABSTRACT

This study examined the effect of degumming process on physicochemical and biodiesel properties of six non-conventional oils in Nigeria extracted from the seeds and flesh of *Terminalia catappa* (seed), *Irvingia gabonensis* (seed), *Glycine max* (seed), *Persea americana* (flesh), *Tithonia diversifolia* (seed), and *Dacryodes edulis* (flesh). The fruits and seeds were air-dried to constant weight and pulverized. Oil was extracted from the milled sample using Soxhlet extraction method. The oils were degummed using 300 µg/mL of NaCl solution to obtain the refined (degummed) oil. Physicochemical properties of both degummed and crude oils were carried out using the AOAC (1990) methods. The fuel properties of the biodiesel obtained were carried out using ASTM methods. Results showed that degumming process lead to high biodiesel yield and reduced the acid value and iodine value compared with the crude oils. The study therefore concluded that degummed oils were a better substitute for biodiesel fuels production.

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1. Introduction

Free fatty acids, phosphatides, metal ions, waxes, oxidation products and color bodies are some of the known impurities in raw vegetable oils that impact negatively on their suitability for consumption and other uses. Thus it becomes imperative to refine vegetable oils using different treatment processes such as water degumming, alkali refining and oil bleaching to produce high quality oil that will stand the test of time and resistant to oxidative degradation (Wiedermann, 1991; Haraldsson, 1983). Refining of vegetable oils solve the problem of oil rancidity, deterioration and incomplete combustion when used as fuel. It also improves the transesterification process of vegetable oil to biodiesel (Demirbas, 2008). Arisa and Lazarus reported there is improvement in the qualities of Native Pear oil after refining process (Arisa and Lazarus, 2008). Oyekunle et al. studied the efficiency of different easy-to-come by degumming agents as cheaper refining method for the developing nations and concluded that 300 µg/mL of NaCl solution as degumming agent is efficient and capable of tremendously

reducing the heavy metal levels of the oils and thus capable of increasing their shelf life (Oyekunle et al., 2013).

The imminent scarcity of conventional fossil fuels due to fast depletion in the capacity of oil and gas reserves, plus the growing emissions of combustion generated pollutants, and increasing costs has led to search for an alternative energy sources using biomass materials (Sensoz et al., 2000). To meet the rising energy demands and reduce the over dependence on petroleum reserves, experts have now suggested that the viable alternatives for compression-ignition internal combustion engines are biodiesel and bioethanol (Demirbas, 2008). Transesterification, dilution, microemulsification and co-solvent blending, and pyrolysis are methods use for obtaining diesel from vegetable oils but transesterification is the one most commonly employed (Bala, 2005). Transesterification is a process by which oil is converted into its corresponding fatty ester (biodiesel) by its reaction with methanol or ethanol in the presence of a catalyst (Demirbas, 2002). Due to the rising energy demand and the need for vegetable oils for biodiesel production, experts have calculated the economy land space that will be required to produce sufficiently reasonable amount of biodiesel for basic needs. It was reported that 2.67 hectares of soybean, 1 hectare of rape seed, and 0.14 hectare of palm seed respectively would produce 1 tonne of biodiesel (Gunstone, 2004). Apart from the economic land advantage required for biodiesel production, other advantages such as jobs creation for the teeming population, rural revitalization, low CO and hydrocarbon emissions, clean and save

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<http://dx.doi.org/10.1016/j.egyr.2016.07.001>

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environment as compared to the conventional petroleum-based diesel cannot be overemphasized (Kaewta, 2008). Biodiesel also have added advantages of ease of ignition and, higher lubricity, and less corrosive thus making engines to undergo less wear and tear (Vasudevan and Briggs, 2008).

Several studies have reported the use of some conventional and non-conventional oils for biodiesel production (Adekunle et al., 2015; Bello et al., 2011; Betiku and Adepoju, 2013; Kumar and Kant, 2013; Sandip and Ahindra, 2008). For example, Adekunle et al. studied the potentials of some non-conventional oils (*Persea Americana*, (Avocado pear), *Irvingia gabonensis* (Dika nut) and *Darcryodes edulis* (Native pear)) biodiesel and suggested that they can serve as an alternative to biodiesel made from a conventional seed oil (palm kernel oil), and petroleum-based diesel (Adekunle et al., 2015). Similarly, Bello et al. reported that the performance characteristic of African bush mango Nut (Dika nut, or *Irvingia gabonensis*) oil biodiesel is similar to that of diesel fuel and the specific fuel consumption is 8% higher than diesel fuel, thus the oil will be a potential source of alternative fuel for diesel engine (Bello et al., 2011). It was also reported that the fuel properties of biodiesel produced from Sesame oil were found to be within the ASTM D6751 and DIN EN 14214 biodiesel specifications (Betiku and Adepoju, 2013). However none of these studies explored the effect of oil refining on the physico-chemical and fuel properties of the produced biodiesel hence the present study.

The motivation to this study is predicated on the rising demand for alternative sources of energy supply due to the increasing world population, and accelerated rate of industrial and domestic activities that require constant supply of energy. Thus, the present study investigated the effect of refining of raw oils on the biodiesel properties of some non-conventional oils using a relatively cheap and cost effective degumming process that could be used in the developing countries to effectively reduce the presence of impurities in the oils and improve their shelf life and guide against combustion engine corrosion during biodiesel application. Results showed that the degumming process gave improved biodiesel parameters that compare favorably with the presently used conventional petroleum diesel.

2. Materials and methods

2.1. Fruits and seeds preparation

The fruits and seeds were collected from various locations around in Ife Central local government, Ile-Ife, Osun State, Nigeria with an area of 111 km² (43 sq mi) and coordinates of 7°33'N 4°32'E. The collection was done during the month of January through March, 2013. The plants from which the fruits and seeds were obtained are *Persea americana* (Avocado pear) fruits, *Terminalia catappa* (Almond fruit) seeds, *Tithonia diversifolia* (Wild sunflower) seeds, *Dacryodes edulis* (Native pear) fruit, *Irvingia gabonensis* (Wild mango) seeds and *Glycine max* (Soya beans) seeds. The fruits were thoroughly washed and the seeds decorticated and selection were manually done. The seeds and flesh removed were air-dried to a constant weight. They were milled and stored in a refrigerator prior to further analysis.

2.2. Extraction of the oils

The extraction was carried out using the Soxhlet extractor method (AOAC, 2004) in which case 20 g of the milled samples was weighed at a time and packed into a cellulose thimble prewashed with acetone/*n*-hexane mixture and allowed to dry in an oven at a temperature of 70 °C for 2 h before used. The extraction of the oils with *n*-hexane lasted 7 h on the average. After extraction, the content in the flask was concentrated by distilling off the solvent content to obtain a solvent-free crude oil. The flask was later placed in the oven maintained at 70 °C to drive off traces of the solvent left.

2.3. Degumming operation

Accurately measured 5 mL of raw oil was mixed with 1 mL of the 300 µg/mL NaCl solution. The oil and NaCl solution mixture was agitated for 60 min at 60 °C on magnetic stirrer to render fat-soluble phosphatides insoluble. These insoluble phosphatides are then separated by centrifugation at 1000 rpm for 30 min. During the agitation process, a colloidal mixture beneath the oil layer was formed. This was believed to be a mixture of the fat-soluble impurities (phospholipid lecithin complexed with metals) contained earlier in the oil. The oil was separated from the colloidal mixture by decanting (Oyekunle et al., 2013).

2.4. Transesterification process: production of biodiesel

Transesterification of all the vegetable oils (raw oils and degummed oils) was carried out with methanol in the presence of KOH as a catalyst. The method recommended by Van Gerpen et al. (2004) was employed. The biodiesels generated for the oils are represented as biodiesel of *T. catappa* (BDTC), biodiesel of *P. Americana* (BDPA), biodiesel of *I. gabonensis* (BDIG), biodiesel of *G. max* (BDGM), biodiesel of *T. diversifolia* (BDTD), and biodiesel of *D. edulis* (BDDE). The percentage biodiesel yield was calculated using the relationship:

$$\text{Biodiesel yield} = \frac{\text{Mass of biodiesel produced}}{\text{Mass of oil used}} \times 100.$$

The physico-chemical properties of biodiesel produced for both the raw and the degummed oils were carried out according to American Society for Test and Material—ASTM and Leevijit method (Leevijit et al., 2016). The parameters determined are acid value, iodine value, cetane number, kinematic viscosity, density, higher heating value, heating efficiency, pour point, cloud point, smoke point and flash point.

3. Results and discussion

3.1. Percentage oil composition and biodiesel yield

The results of percentage oil yield of the oilseeds are presented in Table 1. *T. catappa*, *P. americana*, *I. gabonensis*, *T. diversifolia*, and *D. edulis* have a high oil yield (30.33%–81.94%). *T. diversifolia* has the lowest oil yield of 30.33% while *I. gabonensis* has the highest oil yield of 81.94%. Kyari (2008) considered an oil yield of 26%–42% to be reasonable oil yield. All the non-conventional seeds were considered economical for commercial production of oil in Nigeria. *G. max* has a yield of 20.33% which falls below the considered value for oil yield, but agreed closely to 18% reported by Ene-Bong and Carnovale (1992). The oil yield of *D. edulis* (69.60%) obtained in this study was higher than that reported for *D. edulis* (50.00%) by Arisa and Lazarus (2008). This might be due to the maturity of the seed before extraction and the mode of extractions. Other factors such as soil fertility, environmental conditions, and so on, can also affect the oil yield of the materials. *T. catappa*, *P. americana*, *I. gabonensis*, *T. diversifolia*, and *D. edulis* had a high oil yield compared with the conventional oilseed (*G. max*), thus, these fixed oils can compete favorably with conventional oils thereby reducing over dependence on them.

Base catalyzed transesterification is preferred over acid catalyzed transesterification reactions for the production of biodiesel at industrial level because it provides better conversion rates and efficiencies (Fukuda et al., 2001). The percentage conversion yield of raw oils to biodiesel ranged from 63.35% in *P. americana* to 91.07% in *I. gabonensis*. However, it was observed that the conversion of degummed oil to biodiesel gave higher percentage yield

Table 1
Percentage oil yield and biodiesel yield for the vegetable oils.

Sample	Oil composition (%) ^a	Raw biodiesel (%)	Degummed biodiesel (%)
<i>T. catappa</i> (seed)	62.88 ± 0.05	88.68 ± 1.09	94.09 ± 2.21
<i>P. americana</i> (flesh)	52.12 ± 0.12	63.35 ± 3.16	91.09 ± 2.09
<i>I. gabonensis</i> (seed)	81.94 ± 1.10	91.07 ± 1.66	98.94 ± 3.54
<i>G. max</i> (seed)	20.33 ± 0.68	88.78 ± 0.95	93.84 ± 1.64
<i>T. diversifolia</i> (seed)	30.33 ± 0.06	90.05 ± 2.86	96.04 ± 3.40
<i>D. edulis</i> (flesh)	69.60 ± 0.42	76.13 ± 1.34	91.59 ± 2.91

^a Value = mean of triplicate determinations ± RSD.

(91.59%–98.94%) than the raw oils (Table 1). High percentage increase in the biodiesel yield of *P. americana* (42.45%) indicate that degumming process led to the removal of high gummy materials in the oil thus enhancing its biodiesel conversion. Phospholipids, carotene, protein and gummy materials present in raw vegetable oil might affect the transesterification reaction which may be the reason for the low yield conversion observed. The result obtained agreed with the high biodiesel yield reported by Aldo et al. (2011), for neutralized *Jatropha* oil than the raw oil. Also, the results indicate that degumming of oils improves biodiesel production.

3.2. Acid Values (mg KOH/g)

The acid value measures the amount of unreacted acids remaining in the finished fuel, and is also an indicator of oxidized fuel (Boz et al., 2009). Usually, for a base catalyzed process, the acid value after biodiesel production will be low since the base catalyst will strip the available free fatty acids (Van Gerpen et al., 2004). Considering that the presence of free fatty acids influences fuel aging due to hydrolytic cleavage of ester bond, the European and American Standards specify a maximum value of 0.5 mg of KOH/g and 0.8 mg of KOH/g of sample respectively (Edward, 2000).

Acid values of biodiesel from raw oils ranged from 0.281 in *T. catappa* to 1.122 mg KOH/g in *P. americana* (Fig. 1). Only *P. americana* biodiesel have acid value (1.122 mg KOH/g) higher than the acceptable standard limit of both European biodiesel standard and ASTM standard. The remaining acid values were within the range of both standards. After degumming, the acid values of biodiesel from degummed oils were reduced (0.141–0.476 mg KOH/g) (Fig. 1). Percentage decrease in acid value of biodiesel from *I. gabonensis* (71.48%) after the degumming process suggests high resistance to corrosion due to decrease in the free fatty acid content of the biodiesel. This might be due to the reduction in free fatty acid present in the oil during degumming process and the results obtained were in agreement to the report of Demirbas (Demirbas, 2008) where degumming process increases the susceptibility of vegetable oil for transesterification during their conversion to biodiesel. All the methyl esters obtained from degummed oils have acid values lower than both ASTM and European biodiesel standard.

3.3. Iodine values (I_2 /100g)

The iodine value provides information about the unsaturation degree of the oil which directly affects its stability to oxidation. The reason for auto-oxidation occurrence is the presence of double bonds in the chains of the fatty compounds. Higher unsaturated fatty acid on heating results in polymerization of glycerides. This can lead to the formation of deposits or deterioration of the lubricating property (Salles et al., 2010). Hence, the limitation of unsaturated fatty acids in biodiesel is necessary. Iodine value is limited to 120 g I_2 /100 g in the European biodiesel standard (EN 14214, 2003).

The iodine value of biodiesel of raw oils ranged from 32.994 in *I. gabonensis* to 141.113 in *G. max* (Fig. 2). They all have

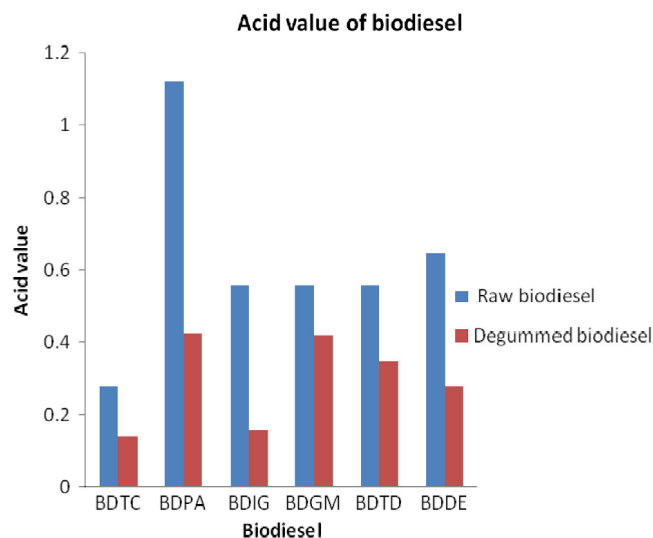


Fig. 1. Acid values (mg KOH/g).

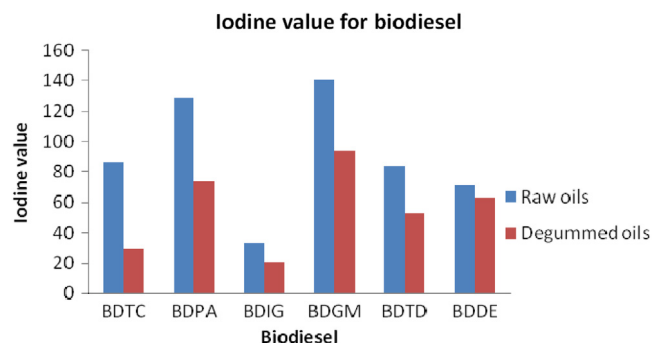


Fig. 2. Iodine value (g I_2 /100 g).

iodine values lower than or closer to 120 g I_2 /100 g which is the set standard except *G. max* (141.113 I_2 /100 g). Biodiesel of degummed oils have iodine values (20.304–93.906 I_2 /100 g) lower than that of biodiesel of raw oils. Biodiesels of raw and degummed oils investigated in this study, have iodine value less than European biodiesel specification, thus they have moderate degree of unsaturation and they are suitable for fuel application. Percentage decrease in iodine value of *T. catappa* biodiesel (65.88%) due to degumming process suggests decrease in the degree of unsaturation of its biodiesel compared to others.

3.4. Cetane number

The cetane number of biodiesel obtained from raw oils ranged from 49.8 in *G. max* to 69.1 in *D. edulis* (Fig. 3). The result show that all the methyl esters (biodiesels) have high cetane number higher than the minimum standard value of 51 established by European standard except *G. max*, and all the methyl esters have cetane number that exceed 47 set by ASTM D 6751. Cetane

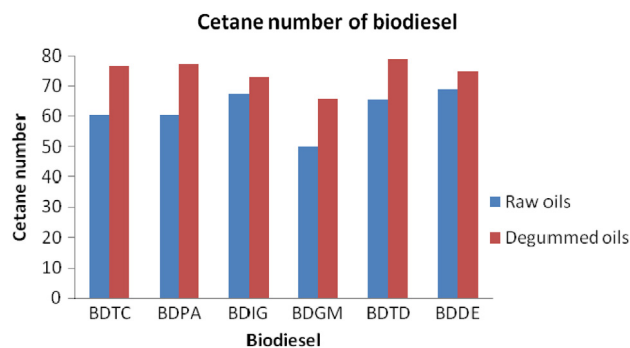


Fig. 3. Cetane number of biodiesel.

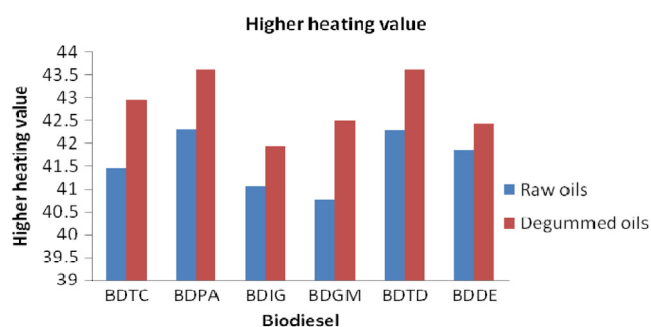


Fig. 4. Higher heating values of biodiesels (MJ/kg).

numbers of biodiesels obtained from degummed oils are higher than that of raw oils. It ranged from 65.7 in *G. max* to 79.0 in *T. diversifolia*. Since cetane number increases with increase in degree of saturation, the decrease in degree of unsaturation in degummed oil might be the reason for the increase in cetane number of the degummed biodiesels. Except for *G. max*, all degummed biodiesels have cetane number higher than the minimum value of 47 and 51 set by ASTM and European standard respectively. High cetane numbers signify only short delays between fuel injection and ignition, and thus ensure good cold start behavior and a smooth run of the engine (Boz et al., 2009). According to (Graboski and McCormick, 1998), esters of vegetable oils that are composed of C_{12} or higher carbon number have cetane number of above 60. Hence, it can be stipulated that the biodiesel obtained from both the raw and degummed oils may be composed of C_{12} and higher carbon number.

3.5. Higher Heating Values (HHV)

The heat of combustion or heating value is not specified in the biodiesel standards (EN 14214, 2003; ASTM). However, European standard for using biodiesel as heating oil (EN 14214, 2003) specifies a minimum heating value of 35 MJ/kg (Sokoto et al., 2011). From this study, the biodiesel obtained from raw oils all have HHV higher than the specification of 35 MJ/KG. The value ranged from 40.758 ± 0.47 in *G. max* to 42.313 ± 1.34 in *P. americana* (Fig. 4). The HHV of biodiesel obtained from degummed oils increase slightly than the ones obtained from the raw oils. Since HHV increases with decrease in unsaturation (Sokoto et al., 2011), the slight increase in degummed biodiesel may be as a result of decrease in degree of unsaturation after degumming process. Based on their HHV result, both degummed and raw biodiesel can be potential supplement or alternative to petroleum diesel. After degumming, percentage increase in HHV of *G. max* biodiesel implies that the biodiesel is a good fuel supplement compare with others.

3.6. Kinematic viscosity and density of biodiesel

The kinematics viscosities of biodiesel at 40 °C obtained from crude oils ranged from 2.97 ± 0.11 in BDGM to 18.31 ± 0.98 mm²/s in BDPA while that of biodiesel obtained from degummed oils ranged from 5.08 ± 0.91 in BDGM to 20.49 ± 1.59 mm²/s in BDPA (Table 2). According to ASTM and European standard for biodiesel, kinematics viscosity must be between 1.9 and 6.5 mm²/s and 3.50 and 5.0 mm²/s respectively. The viscosities of most of the biodiesel produced from crude oils are within the ranged specified by ASTM except that of BDPA and BDIG. Increment was observed in viscosities of biodiesel produced from degummed oils than that of crude oils. Since viscosity increases with increase in fatty acid chain (Knothe, 2002) and decreases with increase in unsaturation (Nourredini et al., 1992), then the increase in viscosities of biodiesel of degummed oils might be as a result of the decrease in degree of unsaturation of degummed oils. Thus, biodiesel from raw oils have more potential for fuel application than those from degummed oil.

The density of material is defined as the measurement of its mass per unit volume (e.g. in g/mL). Biodiesel fuels are, in general, characterized by higher density than conventional petroleum diesel, which means that volumetrically-operating fuel pumps will inject greater mass of biodiesel than conventional diesel fuel (Evangelos, 2013).

Fuel density directly affects fuel performance, and some of the engine properties, such as cetane number, heating value and viscosity are strongly connected to density. The density of the fuel also affects the quality of atomization and combustion (István and Ioan-Adra, 2011). From this study, the density of biodiesel produced from crude oil at 30 °C ranged from 828.90 ± 0.03 in BDDE to 872.10 ± 0.08 in BDTD, while biodiesel obtained from degummed oil at 30 °C ranged from 827.80 ± 0.01 in BDDE to 870.70 ± 0.09 in BDTD (Table 2). Densities of biodiesel obtained from crude and degummed oil are very close; this may be due to the density of methanol used in their production since density of biodiesel is affected by fatty acid composition and purity. This result is similar to the result of biodiesel obtained from *Jatropha* and castor oil reported by Aldo et al. (2011).

3.7. Pour, cloud, smoke and flash points

Cloud and pour points of biodiesels are presented in Table 3. Cloud point of biodiesel obtained from crude oils ranged from 5 °C in BDGM to 27 °C in BDIG. Their pour point ranged from −2 °C in BDGM to 21 °C in BDIG. While the cloud point of biodiesel obtained from degummed oils ranged from 1 °C in BDGM to 13 °C in BDIG. Pour points also ranged from −3 °C in BDDE to 8 °C in BDIG. According to ASTM, no limit is specified for pour and cloud point. The reason is that the climate conditions in the world vary considerably, thus affecting the needs of biodiesel users in a specific region (Anwar and Rashid, 2008). It can be deduced that high cloud point and pour point observed in BDIG might be due to the influence of the high saturated fatty acid chain present in the oil. Biodiesel obtained from degummed oils was observed to have lower cloud point and pour point than those biodiesels obtained from crude oils. This also might be due to the reduction in degree of unsaturation of oils after degumming process.

From Table 3, flash point of raw biodiesel ranged from 154 °C in BDTC to 176 °C in BDIG while the flash points of biodiesel obtained from degummed oils ranged from 108 °C in degummed BDTD to 162 °C in degummed BDIG. Biodiesel of both raw and degummed oils have high flash point than the minimum value specified by ASTM (130 °C) and European standard (120 °C) except the biodiesel of degummed BDTD (108 °C) which is lower than both minimum specifications. The high flash points of both raw and degummed

Table 2Kinematic viscosity (mm^2/s) and density (kg/m^3) values of raw and degummed biodiesels.

Sample	Kinematic viscosity (mm^2/s)			
	Raw biodiesel		Degummed biodiesel	
	30 °C	40 °C	30 °C	40 °C
BDTC	6.09 ± 1.73	5.31 ± 0.71	7.37 ± 1.08	6.20 ± 0.17
BDPA	21.53 ± 1.58	18.31 ± 0.98	24.37 ± 2.29	20.49 ± 1.59
BDIG	10.06 ± 03.06	5.96 ± 1.02	10.82 ± 4.16	7.62 ± 0.88
BDGM	3.56 ± 1.00	2.97 ± 0.11	5.85 ± 1.15	5.08 ± 0.91
BDTD	6.78 ± 0.40	5.29 ± 0.81	8.57 ± 0.58	6.02 ± 0.23
BDDE	4.58 ± 0.00	3.87 ± 0.15	7.76 ± 0.57	6.06 ± 0.49
	Density (kg/m^3)			
	30 °C		50 °C	
	30 °C	50 °C	30 °C	50 °C
BDTC	854.70 ± 0.01	840.00 ± 0.05	851.50 ± 0.14	833.30 ± 0.01
BDPA	859.30 ± 0.09	856.00 ± 0.01	852.10 ± 0.09	848.70 ± 0.01
BDIG	845.70 ± 0.01	830.50 ± 0.01	840.10 ± 0.19	827.10 ± 0.07
BDGM	867.40 ± 0.08	851.20 ± 0.12	865.70 ± 0.01	820.10 ± 0.05
BDTD	872.10 ± 0.08	862.20 ± 0.02	870.70 ± 0.09	851.90 ± 0.02
BDDE	828.90 ± 0.03	817.00 ± 0.01	827.80 ± 0.01	810.00 ± 0.02

BDTC = biodiesel of *T. catappa*, BDPA = biodiesel of *P. americana*, BDIG = biodiesel of *I. gabonensis*, BDGM = biodiesel of *G. max*, BDTD = biodiesel of *T. diversifolia*, BDDE = biodiesel of *D. edulis*.

Table 3

Pour point, cloud point and smoke point of biodiesel.

Sample	Cloud point (°C)		Pour point (°C)	
	Raw biodiesel	Degummed biodiesel	Raw biodiesel	Degummed biodiesel
BDTC	7 ± 1	5 ± 0	2 ± 1	1 ± 0
BDGM	5 ± 0.1	1 ± 0	-2 ± 1	-4 ± 1
BDDE	12 ± 3	2 ± 1	8 ± 1	-3 ± 0
BDIG	27 ± 2	13 ± 2	21 ± 2	8 ± 1
BDPA	20 ± 1	10 ± 2	10 ± 1	4 ± 0
BDTD	12 ± 3	7 ± 1	6 ± 3	4 ± 1
	Smoke point (°C)		Flash points (°C)	
	Raw biodiesel	Degummed biodiesel	Raw biodiesel	Degummed biodiesel
BDTC	41 ± 1	36 ± 2	154 ± 4	133 ± 1
BDGM	53 ± 3	45 ± 1	160 ± 4	143 ± 7
BDDE	63 ± 2	58 ± 1	157 ± 4	150 ± 3
BDIG	42 ± 3	39 ± 1	176 ± 4	162 ± 4
BDPA	54 ± 1	49 ± 2	164 ± 3	159 ± 1
BDTD	63 ± 4	57 ± 2	166 ± 4	108 ± 2

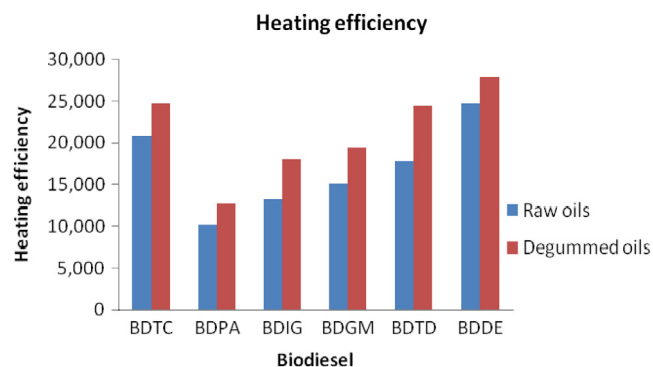
BDTC = biodiesel of *T. catappa*, BDGM = biodiesel of *G. max*, BDDE = biodiesel of *D. edulis*, BDIG = biodiesel of *I. gabonensis*, BDPA = biodiesel of *P. americana*, BDTD = biodiesel of *T. diversifolia*.

biodiesel means they will be safe to handle and for storage. The smoke and flash point of biodiesel obtained from degummed oil are lower than the biodiesel obtained from raw oils. This might be due to the removal of phospholipids in the oil which may contribute to high smoke and flash point observed in raw oil.

3.8. Heating efficiency ($\text{J}/^\circ\text{C}$) of biodiesel

Heating efficiency measures the amount of heat transferred to a specific volume of substance at a specific time. This parameter is important because it gives the knowledge of how efficient biodiesel will be for fuel substitution probably for domestic use in case of kerosene or petroleum diesel scarcity.

The value for heating efficiency for biodiesel from raw oils ranged from $10,255.70 \pm 148.97$ in *P. americana* to $24,697.40 \pm 147.47$ $\text{J}/^\circ\text{C}$ in *D. edulis* (Fig. 5). Biodiesel from raw *D. edulis* oil have the highest heating efficiency of $24,697.40 \pm 147.47$ $\text{J}/^\circ\text{C}$ and was the only biodiesel that have its efficiency higher than that of kerosene ($23,302.00$ $\text{J}/^\circ\text{C}$) and petroleum diesel ($21,617.07$ $\text{J}/^\circ\text{C}$). After degumming process, increase in heating efficiency was observed. It ranged from $12,767.30 \pm 187.98$ in *P. americana* to $27,836.90 \pm 173.72$ $\text{J}/^\circ\text{C}$ in *D. edulis*. Increase in heating efficiency of biodiesel from degummed oil might be due to the decrease in degree of unsaturation since the higher the degree of

**Fig. 5.** Heating efficiency of biodiesel.

saturation, the higher the heating energy exhibited by oil (Sokoto et al., 2011). Biodiesel from both raw and degummed oils were potential alternative to petroleum diesel for domestic and other technological uses.

4. Conclusion

This study showed that degumming process improves the physico-chemical and biodiesel properties of non-conventional

vegetable oils compared with that of the raw oils. Degumming process improves the biodiesel yield, ignition properties and reduces susceptibility of biodiesel obtained after degumming to peroxidation as compared to that of the biodiesel obtained from raw oils, making them more stable and suitable for fuel application. Degumming process also reduces the fire hazard associated with transportation, storage and utilization of these biodiesels as compared to hazard associated with petroleum-based diesel with much lower flash point. The study therefore concluded that degummed oils were a better substitute than undegummed oils as raw materials for biodiesel fuels production.

Acknowledgment

The authors acknowledge Obafemi Awolowo University (OAU) Ile-Ife, Nigeria, for providing the research platform for this study.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at <http://dx.doi.org/10.1016/j.egy.2016.07.001>.

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