Biodiesel Production from Fluted Pumpkin (*Telfairia Occidentalis*) Seed Oil Through Koh-Catalysed Transesterification Reaction

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Abstract
The global energy concerns and increased awareness of the environmental issues resulting from the extensive consumption of fossil fuels has made the search for the production of biodiesel as an alternative energy source worldwide. Biodiesel is one such renewable fuel for diesel engines which is made from biolipids that receives a considerable attention. In this research work, the Fluted pumpkin (Telfairia occidentalis) seed oil was investigated for its suitability as a feedstock for biodiesel production. The seed oil was extracted on a dry matter basis using petroleum ether and found to be within 51-53%. and the seed oil quality parameters of Telfairia occidental seed oil (TOSO) were determined and found to be; moisture content – 8.29%, specific gravity (SG) – 900kgm^{-3}, viscosity – 21.21mm^{2}s^{-1}, iodine value (IV), 98.4g iodine/100g oil, saponification value (PV) – 105.19meqkg^{-1}, acid value (AV), 11.78mg KOH/kg oil, free fatty acid (FFA) – 5.92%. Subsequently the methyl ester of TOSO was prepared and the fuel quality parameters determined and compared to that of diesel number 2 (D2). Similar tests were carried out on the diesel D2 that was used as a standard and the following results obtained for TOSO methyl ester were as follows; kinematic viscosity, 2.65mm^{2}s^{-1}, flash point, 140^{0}C, pour point, - 2^{0}C, density, 859kgm^{-3}, cloud point, 0^{0}C, and calorific value, 12188J.The TOSO fatty acid methyl ester (FAMES) properties were further compared to literature data for Cucurbita pepo methyl ester (CPME) and Thevetia nerifolia methyl ester (TNME), and with the American and European standards for biodiesel (ASTM D6751 and EN14214) in order to assess their biodiesel performance properties and were found to fall within acceptable limits. The fuel properties obtained for the methyl ester are density – 0.856gml^{-1}, flash point – 174^{0}C, pour point - -5^{0}C, cloud point – 3^{0}C, viscosity – 2.35mm^{2-}s^{-1}, calorific value – 12017J and cetane number – 62.30. The fuel properties indicates that FAMES of TOSO can be used as a biodiesel in warm climate regions like Nigeria.

Keywords: *Telfairia occidentalis*, biodiesel, fluted pumpkin seed oil, fuel quality parameters, transesterification.

Introduction

Today, the increasing rate of fossil fuel energy consumption has led to a fast depletion of the global non-renewable reserves, and has now become a major issue for which many countries are looking for alternate sources (Knothe, 2001). Vegetable oil fuel or biodiesel is a suitable substitute for diesel fuel as it is produced from renewable sources (Ali & Hanna, 1994). Additionally, it can equally be described as 'carbon neutral'. This implies that, the fuel forms zero carbon in the form of carbon (vi) oxide (CO_2). This effect happens because when the oil crop grows, it absorbs the same amount of CO_2 as it is released when the fuel is burnt (Knothe, 2001). The American Society for Testing Material (ASTM) defines biodiesel as a fuel composed of monoalkyl esters of long-chain fatty acids derived from renewable vegetable oils or fats meeting the requirements of ASTM D6751 (Canakci & Sanli, 2008).

Advantages of biodiesel

The main reasons why the development of biodiesel should be encouraged in Nigeria are; provision of market for excess vegetable oils and animal fats produced, reduction of nation's dependence on Petro diesel currently being imported, renewability and does not contribute to global warming, exhaust emissions from biodiesel are lower than the fossil diesel, and has excellent lubricating properties than Petro diesel and therefore minimises engine wear.

In addition to these, biodiesel has another advantages over Petro diesel including biodegradability, low toxicity, negligible sulphur content, superior flash point, etc (Arjun, 2008).

Mathew Brown, an energy consultant (Holbrook, 2001), says that "Replacing only five percent of the nation's diesel consumption with biodiesel will require diverting approximately sixty percent of today's soya crops to diesel production,"

Fluted Pumpkin (*Telfairia occidentalis*)

Telfairia occidentalis is a member of Cucurbitaceae family, cotyledonous and a perennial plant with more than 80 genera and about 750 species distributed across the global warm parts (Odiaka, Akoroda & Odiaka, 2008). The crop originated probably in the south east of Nigeria and spread all over the country by Igbos who have been cultivating this crop for decades (Olaniyi & Oyerele 2012). The variety *Telfairia occidentalis* is the one mostly found, widely consumed and cultivated in Nigeria for its eatable leaves, succulent shoots and seeds as a terrace plant mainly by the Igbos. With the spread of Igbos in Nigeria, *Telfairia* is now grown in almost all the parts of Nigeria (Odiaka et al. 2008). It is a leafy green vegetable plant that climbs by its coiled tendrils and bifid. Its compound leaves, usually 3-6 foliate, have petioles and blades covered with multicellular hairs. The fruits are variable in size, colour, shape and weight, and possess 10 clearly visible longitudinal ridges and are among the largest known (15-55 cm length, 10 cm diameter). The seeds are large, non-endospermic and normally dark red in colour embedded within a bright-yellow fibrous endocarp (Olurunfemi, Munavvar, & Hassaan, 2014).

Kayode & Kayode (2011) reported that *Telfairia occidentalis* amino acid profile revealed that it is very rich in the nine essential amino acids (histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine) and some of the non-essential ones which includes, alanine, cystine, glutamine, glycine, serine, and tyrosine. *Telfairia* leaf has abundant minerals (such as iron, magnesium, phosphorus, potassium and sodium) antioxidants, vitamins (such as ascorbic acid, nicotinamide, riboflavin and thiamine) and phytochemicals like phenols. The leaves have high nutritive value when compared with other warm climate vegetables. It has higher protein content (22 %) than those of commonly consumed leafy vegetables. The leaves have abundant vitamins and minerals such as Calcium, iron, phosphorus etc and are also consumed as food (Olurunfemi et al. 2014; Odiaka et al. 2008). The seed oil obtained is useful for cooking.

Olurunfemi et al. (2014) reported that *Telfairia* plants possess important Antioxidant, Antidiabetic, Hematological, Anticanceral, Hepatoprotective, Antimicrobial, Biochemical, Anti-inflammatory and Analgesic properties. Kayode & Kayode (2011) reported that *Telfairia* seeds have high oil content, particularly unsaturated fatty acids that contain 62% of the oil. *Telfairia* seeds have high protein content of (>26%) and extractable oil (50-60%). Its oil serves as a breast massage to enhance milk flow and promotes hair lustre and growth. The oil equally softens and supple skin. (Ajayi, Dulloo, Vodouhe, Berjak, & Kioko, 2007). Odiaka et al. (2008) says that *Telfairia* seeds nutritional value (about 52% fat and 28% crude protein) justifies the wide consumption by possession of excellent quantity of amino acids (almost 94%) containing greater percentage of the essential amino acids (except lysine), and higher content of K and Na available (almost 59%). The higher oil yield of *Telfairia* seeds have made them good raw materials for the vegetable oil and margarine companies in Nigeria.

Despite its abundance in south eastern part of the country, its richness in seed oil and crude protein and the fact that the plant has the potentiality to become a good source of essential vitamins and minerals. There are limited studies on this plant, particularly in Nigeria. As such, this work is therefore focused at carrying out the extraction and the characterization of the seed oil of this plant.

Materials and Methods

The *Telfairia* pulps were collected from an Igbo woman at Muda-Lawan Market, behind Bayan Gari Area of Bauchi town. The seeds were then perfectly identified at the Biological Sciences programme of Abubakar Tafawa Balewa University Bauchi by Dr. Ahmad Abdulhamid.

The pulps were broken and the seeds removed, cleaned, air-dried at room temperature, cracked and peeled manually to remove the endocarp. The endocarps were then grounded and prepared for oil extraction.

The oil was Soxhlet extracted using petroleum ether (40-60°C) and the oil content calculated on dry matter basis. The following oil quality parameters were determined following the methods of Association of Official Analytical Chemists, (AOAC, 1975); acid value, iodine value, saponification value, free fatty acid, peroxide value, kinematic viscosity and specific gravity. The results are presented on **Table 1**.

Transesterification of the seed oil (biodiesel production)

The method used for the determination was that of British standards institute No. 684 method was used for the determination of FFA (Association of Official Analytical Chemists, (AOAC, 1975). Methanol (10ml) was added to 0.8g of KOH in a conical flask with little warming and gentle stirring until complete dissolution was achieved. The resulting mixture was then added to the oil (30ml) with slow stirring and this continued for about 14hrs after which the mixture was gently poured into a separation funnel and left to stand for an hour. Two different layers were seen and the lower layer (the glycerol layer) was drained off. Warm water was slowly added to the resulting fatty acid methyl ester (FAMES), and swirled slowly so as not to form an emulsion and the water was drained off. The washing process was repeated (10ml x 5) until the FAMES was clear. The FAMES were then dried and filtered through a plug of cotton wool containing anhydrous $MgSO_4$ to obtain a pure biodiesel and the yield calculated.

The following fuel quality parameter tests were then conducted on the FAMES under laboratory conditions: flash point, density, cloud point, calorific value, pour point, kinematic viscosity, cetane number and flame test. The same tests were conducted on diesel

D2 and on TOSO and the results compared [**Table 2**]. The results obtained for *Telfairia occidentalis* seed oil fatty acid methyl ester (TOSO FAMES) was then compared with other investigated seed oils from literature and with the European and American standards for biodiesel and was found to conform to those standards. The results are presented on **Table 3**.

Results and Discussion

Before subjecting biodiesel to be used as a commercial fuel, it has to be analysed in the laboratory and must conform to the various standards for biodiesel. The results are discussed below;

Table 1: The results of the oil properties of TOSO

Parameters	*Telfairia occidentalis* seed oil (TOSO)
Moisture %	8.29
Oil yield %	52.50
Specific gravity kgm^{-3}	900
Viscosity mm2/s	21.21 @ 30°C,
Acid value mgKOH/g oil	11.78
Iodive value g/100g	98.40
Peroxide value meq/kg	40
Saponification value meq/kg	105.19
Free fatty acid %	5.92

Oil yield

The results obtained for the seed oil quality parameters show that TOSO can be used as a good feedstock for the production of biodiesel, and the oil yield shows that the seed is highly economical.

Table 2: The results of the fuel quality parameters of TOSO, TOSO FAMES and D2

Fuel properties	TOSO	TOSO FAMES	D2
Kinematic viscosity (30°C), mm^2/s	21.21	2.35	2.65
Density, kgm^{-3}	900	859	835
Flash point, °C	0	3	0
pour point, °C	256	174	140
Cloud point, °C	-9	-5	-2
Cetane number*	-	62.30	-
Calorific value, J	12364	12017	12188

*CN = 46.3 + 5458/SV -0.225 IV (Demirbas, 1998).

Iodine value

Iodine value measures the degree of unsaturation in vegetable oils. In biodiesel production, it is used as an indication of the number of double bonds in biodiesel and hence a sign of the biodiesel oxidation stability. The obtained value for TOSO (**Table 1**) show a modest average molecular weight of the fatty acids that is acceptable for feedstock meant for the production of biodiesel.

Specific gravity

The specific gravity of oil is an indication of density of an oil, which in turn measures the energy content of the oil. Denser oils burn slowly and gives less energy as compared to less denser ones (Canakci & Sanli, 2008). Therefore, the value obtained for TOSO in this research work (**Table 1**) shows that the oil can be of use as a suitable feedstock for the production of biodiesel.

Moisture content

Moisture content is an essential parameter for measuring the success of a vegetable oil in transesterification reaction (Peterson, Haines & Chase, 1993). Hanna et al., (2005) reported that seed moisture content is a factor which was found to have a great impact on the oil quality. High moisture content leads to minimised extraction quantity, seed storage deterioration and high moisture content of oil. Low moisture content may minimise through put and result to high phosphorus content of the oil. "Moisture contents of 6.5 to 7.5% gave the best compromise between the various considerations" (Hanna et al., 2005). The moisture content obtained for TOSO in this research shows that the seed could be deteriorated when stored for a long period of time.

Biodiesel yield

Biodiesel yield is estimated after reaction phases, the weight yield of the biodiesel relative to the initial volume of the vegetable oil was worked out. The calculated concentration of the methyl ester was found to be 81.95wt % and based on this result, the alkaline transesterification process almost went to full completion. However, if there are no side reactions, the weight yield of the biodiesel relative to the initial volume of TOSO should be almost 99-100wt % (Hanna et al., 2005).

Kinematic viscosity

Viscosity stands for flow properties and the possibility of liquids to distort with strain (Hanna et al., 2005). One of the main reasons for treating vegetable oils to be used in internal combustion engines is to minimise the viscosity, and hence enhancing fuel flow properties. Kinematic viscosity is a crucial parameter regarding fuel atomization as well as fuel distribution even more than the density (Demirbas, 1998). For biodiesel to be utilised in diesel engines, the kinematic viscosity (at 40°C) must range between 1.9 and 6.0 mm^2s^{-1} (Peterson, et al., 1993). However, due to lack of a thermostatic water bath that could not be achieved. What was reported (2.35mm^2s^{-1}) is at 30°C and not 40°C as recommended, but still okay compared to that of D2 (2.65mm^2s^{-1}). The results also show that there is a good transition from a vegetable oil to the biodiesel.

Density

The standard for biodiesel states that the fuel density should range between 860 and 900 kg/m^3 (Rantaren, 2001). Density is a key parameter for diesel fuel injection systems and must be met for the fuel to be adopted. This is because highly dense fuels do not atomize easily and this in turn affects the energy content of the fuel. The value reported in this work (859 Kg/m^3) is almost same as the lowest limit of biodiesel standard. The result shows that TOSOFAMES will atomize easily in the engine.

Flame test

Peterson, et al., (1993) reported that the use of biodiesel in a conventional diesel engine result in substantial reduction of unburned hydrocarbons, carbon monoxide and particulate matter. These emissions are generally divided into three components. The first and the one most closely related to the visible smoke often associated with diesel exhaust, is the carbonaceous material, which is composed of sub-micron sized carbon fractions which are produced during the diesel combustion process. The second component is the hydrocarbon material which is absorbed in the carbon particles, commonly referred to as the soluble fraction. The third particulate component is comprised of sulphates and bound water. All of these results in the particulate emissions associated with diesel engines (Peterson, et al., 1993).

The use of biodiesel however, reduces the solid carbon fraction of particulate matter (since the oxygen in biodiesels enables more complete combustion to CO_2), and removes the fraction of sulphate (as the fuel contains no sulphur) (Peterson, et al., 1993). As a result of these the use of biodiesel is more advantageous to petrodiesel since it burns more smoothly and reduces the emissions of greenhouse gases.

Comparing the results obtained from the flame test for TOSO, TOSO FAMES and D2 diesel (**Table 2**), it can be seen that the rate of burning of the biodiesel as well as the nature of the flame is quite different from those of TOSO and D2 indicating a good reduction in particulate emissions as mentioned earlier.

Flash point

A key property determining the flammability of fuel is the flash point. This is the lowest temperature at which an applied ignition source will make the vapours of a sample to ignite. Therefore, it is a measure of the tendency of a fuel sample to form a flammable mixture with air (Ma, & Hanna, 1999). It is used to access the overall flammability hazard of a fuel. The flash point values are used for the classification of flammable and combustible materials required for safety and shipping regulations.

The actual flash point of pure methyl esters is > 200°C classifying them as "non-flammable". "During the production and purification of biodiesel, not all the methanol may be removed making the fuel flammable and more dangerous to handle and store if the flash point falls below 130°C" (Ma, & Hanna, 1999).

The flash point obtained for TOSO FAMES in this research, compared to those of TOSO and D2 falls within the acceptable range making the biodiesel safe to store and transport. It also conforms to standard values **Table 3**.

Cloud point

The fuel characteristic that is specifically useful for the low temperature operation of diesel fuel is the cloud point. This is the temperature at which a cloud of wax crystals first forms in a fluid on cooling (Hanna et al., 2005). Therefore, it is an index of the lowest temperature of the fuel's utility under certain conditions. Operating at temperatures lower than the cloud point for a diesel fuel can lead to the clogging of fuel filter due to the wax crystals (Hanna et al., 2005).

Although the result of the cloud point obtained for TOSOFAMES in this research is higher than that of D2 (**Table 2**), this result is still acceptable for fuels intended for use in a region like Nigeria.

Pour point

Pour point is the second measure of the low temperature performance of diesel/biodiesel fuels. This is the lowest temperature at which a fuel sample will flow (Hanna et al., 2005). Therefore, the pour point gives an indication of the lowest temperature of the fuels utility for certain applications. The pour point also has implications for the handling of fuels during cold temperatures.

The result of pour point obtained in this research is lower than that of D2 (**Table 2**) implying that it can be used in hot climates like Nigeria, where temperatures do not fall to negative values. However, it can only be used in temperate regions as blends with petrodiesel.

Calorific value

This simply means a measure of the energy content of oil. It indicates how much energy is required to raise a known quantity of water to a given temperature and is an indicator of how well a fuel burns to produce the required energy (Hanna et al., 2005).

The value obtained for TOSO FAMES in this research is lower than that of D2 (**Table 2**). This shows that high quantity of diesel D2 and energy to heat a given quantity of water than TOSO FAMES.

Cetane number

Cetane number is a measure of the readiness of a fuel to auto ignites when injected into a diesel engine (Hanna et al., 2005). It relates to the delay between when fuel is injected into the cylinder and when ignition occurs. Fuels with a high cetane number will have short ignition delays and a small amount of premixed combustion since little time is available to prepare the fuel for combustion (Hanna et al., 2005).

The value obtained for the cetane number in this research work is based on calculation using the formula given by Demirbas, (1998). The obtained value meets the requirement for diesel fuels based on the EN 14214 (51min) and the ASTM D6751 (47min) standards (**Table 3**).

The results obtained for TOSO FAMES were compared with those of *Thevitia nerifolia* and *Cucurbita pepo* FAMES from literature (Abayeh, Onuoha & Ugah 2007) and with the American and European standards (ASTM D6751 and EN 14214) (**Table 3**) and were found to conform to the standards.

Table 3: Comparison of the TOSO FAMES fuel quality parameters results with TNSO FAMES and CPSO FAMES investigated and with standards

Parameter	TOSO FAMES	TNSO FAMES	CPSO FAMES	D2	ASTM D6751 Limits	EN 14214 limits
Density, kgm^{-3}	859	881	881	835	820 min	860-900
Kinematic viscosity, mm^2/s	2.35	3.00	2.20	2.65	1.9-6.0	3.5-5.0
Flash point, °C	174	120	190	140	130 min	>101
Cloud point, °C	3	7.7	5	0	NA	NA
Pour point, °C	-5	-3.8	-2	-2	NA	NA
Calorific value, J	12017	16204	12127	12188	NA	NA
Cetane number*	62.3	N.A	68.2	-	47 min	51min

Demirbas, (1998). min= minimum, **TOSO FAMES**= *Telfairia occidentalis* seed oil fatty acid methyl ester, **TNSO FAMES**=*Thevitia nerifolia* seed oil fatty acid methyl ester **CPSO FAMES**=*Cucurbita pepo* seed oil fatty acid methyl ester **D2**=Diesel fuel **NA**= Not Available

Conclusion

The initial investigation shows that the seed oil of *Telfairia occidentalis* is an economically workable source of oil due to its high oil content (52.5%). The oil quality parameters indicate that the oil is made up of reasonably long chain fatty acids with a moderate degree of unsaturation, thus low vulnerability to oxidative rancidity making it a suitable feedstock for production of biodiesel.

After transesterification process, which yielded 87.20wt% biodiesel, the fuel quality parameters of the TOSO FAMES equally show that the fuel can be used in warm climates areas like Nigeria. It has a high flash point making it free from fire hazards associated with fuel during transportation and storage. All the tested fuel quality parameters in line with the standards for biodiesel fuels. The result of the flame test equally indicated the advantage biodiesel has over petrodiesel as it shows a comparable reduction in the emission of greenhouse gases as it burnt with a flame.

In conclusion, from all the results obtained in this research, *Telfairia occidentalis* seed can serve as a -suitable feedstock for the production of biodiesel. The resultant fatty acid methyl ester can also be used unblended in diesel engines or as blends with petrodiesel as it fulfilled all the fuel quality parameters tested.

Recommendation

The results acquired in this research work give some crucial information that could be utilised for potential use of the *Telfairia occidentalis* seed oil in the production of biodiesel. It is therefore recommended that further research work should be under taken to ascertain if ethyl ester could be utilised in diesel engines alone or as blends with petrodiesel.

It is equally recommended that more researches should be diversified in the area of biodiesel production. Today, Nigeria is blessed with a diverse plants both eatable and non-eatable that has not been utilised or tested. Therefore, more researches should be intensified to explore the use of this plant in order to alleviate high dependence on petrodiesel in the country and create employment opportunities in the job search.

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