A Comprehensive Appraisal of African *Parinari polyandra* Oil as Feedstock for Biodiesel Production

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ABSTRACT

This study is aimed at evaluating biodiesel production from *Parinari polyandra* seed and its use as engine fuel. Oil was extracted from ***Parinari polyandra*** seeds obtained from bushes in Ilorin, Nigeria via solvent extraction method. The preparation of biodiesel from ***Parinari polyandra*** was carried out by transesterification reaction. The reactants for the transesterification process were the raw ***Parinari polyandra*** oil, anhydrous ethanol and calcined egg shell which was used as catalyst. The experiments were conducted within 60 - 65 ^oC temperatures, 60 - 120 min reaction time, alcohol to oil ratio 3:1 - 6:1 mol and catalyst concentration of 1 % by weight of oil. The fuel properties of *Parinari polyandra* biodiesel were determined using American Standard for Testing Materials methods. Optimisation of biodiesel production was done using response surface method. Engine bench tests were done using blends of biodiesel and Automated Gas Oil (AGO) from 5 - 20% of biodiesel with AGO (B5 – B20, respectively) .

Oil yield of 53.13% and biodiesel yield of 90% were obtained. Specific gravity and kinematic viscosity @ 40 ^oC of biodiesel were 0.899, 3.905 Cst, respectively. Optimal biodiesel yield of 92.75% was predicted at 61.20 °C temperature, 60 min, and 1 wt% of catalyst amount. Exhaust gas temperature increase from B5 except for slight decrease from 75 - 100% load condition when B20 was used. Biodiesel was found to have break thermal efficiency close to that of AGO.

Keywords: engine, fuel, biodiesel, *Parinari polyandra*.

1. Introduction

The global community is currently facing an intense crisis of environmental deterioration from the combustion of fossil fuel, which is fleeting in reserves year on year [1]. In light of this, concerted efforts are being made globally to salvage our environment. This has led to practical appraisal of sustainable use of natural resources through the application of engineering science principles and technology to ensure fuel security and environmental sustainability [2], [3].

The relevance of renewable fuels to the conservation of our environment cannot be underestimated. Renewables, whether we like it or not, are part of our future. A high level of transition to clean energy has been witnessed over the years as nations like US, EU and China have emerged as high producers of biofuels, coupled with the colossal research studies and publications on renewable biofuel [8]. As much as this represents a huge feat for so many of these developed nations, relevant information and data are still needed on promising feedstocks that are energy rich and suitable for biofuel production in the developing world [1].

Biofuels synthesis from seed oils has brought about developments such as “first-generation”, “second-generation” and “third-generation” oils depending on the feedstocks used in production [10]. First generations of biofuels are generally produced from commonly available edible feedstocks while second generation of biofuel refers to biofuels produced from non-edible oil seeds. Third-generation oils refer to recent explorations of micro and macro organisms, such as algae [10], [11].

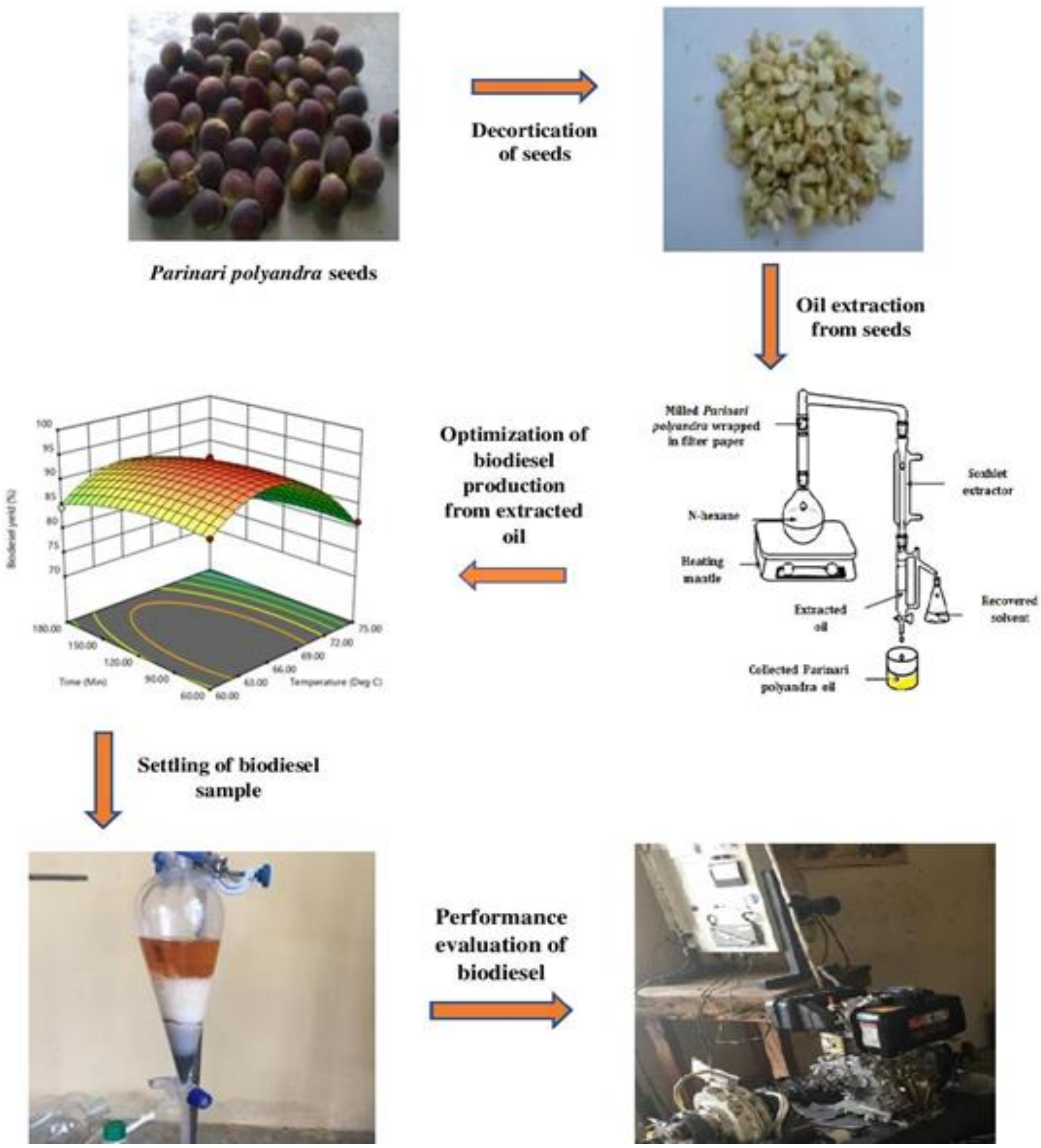

Figure 2: Graphical overview of research works on *Parinari polyandra* seed plant

3. *Parinari polyandra* oil seed plant

Parinari polyandra is an inedible evergreen plant found in the grassland of Tropical Africa extending from Mali to Sudan. It belongs to the family of *rosaceae* that grow mostly in West Africa region that includes Nigeria, Ghana, Senegal, Ivory Coast, Mali, Cameroon and Sudan [68]. It has been traditionally observed that the fruit has been grossly underutilized owing to its inedible nature and unavailability of sufficient scientific data as a result of inadequate extensive investigations on its fruit and seed properties [69].

Figure 3: The leaves, fresh fruits and dried nuts of *Parinari polyandra*

(Adapted by the author)

It has been observed that an average of 871200 seeds/hectare can be obtained in natural grassland that is filled with the *Parinari polyandra* trees. (Adeyemi 2019)

4. Oil extraction from *Parinari polyandra*

Parinari polyandra seeds were collected from bushes around Ilorin town, Nigeria. Oil was extracted from the seeds via solvent extraction method using petroleum ether as extraction solvent. The dried kernels were pounded using porcelain mortar and pestle and sieve to a fine particle size of 2 mm (Odetoye, Ogunniyi and Olatunji, 2012). A digital electrical weighing balance was used to measure 20 g of the grounded seed. A glass measuring cylinder was used to measure 30 ml of petroleum ether (solvent). The extraction of the oil was carried out using soxhlet apparatus of 500 cm^3 capacity. The filter paper was charged with 20 g grounded seed (sample) and inserted into the soxhlet extractor. Thirty milliliters (30 ml) of solvent was poured into a round bottom flask and placed inside round hole of the heating mantle that was preset to 40 °C.

As the solvent boils, the vapours from the solvent rose up through the vertical tube into the condenser at the top. The liquid condensed was dripped into the filter paper that contains the sample. When the liquid rises to the level of capillary tube, both the extracted oil and solvent was discharged back into the round bottom flask through the siphon tube. This was allowed to continue for 4h after which the oil in the solid sample in the filter paper was completely removed. Later the heating mantle was switched off and the round bottom flask was removed from the heating mantle to recover or decant the solvent that is lighter than oil in the flask and the oil poured into a plastic container. The volume of oil obtained was measured and recorded. The experiment was repeated.

The reaction variables taken into consideration for the extraction are temperature, residence time and solid/solvent ratio. The extraction was conducted at 60 ^{o}C residence time of 4 hours and solid/solvent ratio of 0.05 g/ml. (Odetoye *et al.*, 2013). It is important to note that the reaction parameters for the soxhlet extraction was chosen from related researches from literature and subjected to preliminary experiments in the laboratory to determine the extraction parameters that favour high yield of oil from ***Parinari polyandra***.

$$\%\ Oil\ yield = \frac{weight\ of\ extracted\ oil}{weight\ of\ grinded\ seed} \times 100 \qquad 3.1$$

6. Biodiesel production from *Parinari polyandra* oil

The preparation of biodiesel from ***Parinari polyandra*** was carried out by transesterification reaction. The reactants for the transesterification process were the raw ***Parinari polyandra*** oil, anhydrous ethanol and calcined egg shell which was used as catalyst. The reaction variables taken into consideration for the transesterification reactions are reaction temperature and reaction time. Catalyst derived from calcined egg shell was mixed vigorously with ethanol to form ethoxide. The ethoxide was swiftly introduced into heated oil and stirred to produce biodiesel and glycerol as by product.

The experiments were conducted at temperatures 65 ^{o}C which are below the boiling point of ethanol. The maximum temperature of 65 ℃ was adopted for the reaction temperature as recommended by Alamu *et al.* (2007). The reaction was carried out between 60 mins and 120 mins. The reaction time was enough to allow perfect contact between the reagents and the oil during transesterification as the reaction mixture was continuously stirred at a constant rate.

For this transesterification reaction, 12 moles of alcohol to 1 mole of oil was used which is more than the standard 3:1 alcohol to oil stoichiometric requirement. The reason for this was that the reaction is desired to proceed in the forward direction by shifting the equilibrium to the right. This was emphasized by Gerpen and Pruszko (2004). Catalyst concentration used was 6 % by weight of oil. All these reaction conditions are based on the conditions of transesterification of seed oils using heterogeneous catalysts derived from egg shells as noted by Wei *et al.*, (2009).

A constant volume of 70 ml of ***Parinari polyandra*** oil was pre-heated and measured into the reactor and placed on electric magnetic stirrer to the desired experimental temperature. Roger *et al.*, (2005). The required amount of catalyst was mixed with a required amount of ethanol and stirred vigorously. Thereafter, the formed product was swiftly introduced into the oil in the reactor and stirred vigorously with the magnetic stirrer for the set experimental reaction time. After this, 10 ml of distilled water (20 % of initial volume of oil) was added to the mixture and stirred continuously for another 15 min to aid formulation and easy separation of biodiesel. The mixture was thereafter poured inside a separating funnel for 24 h, glycerol which is a heavier liquid settled at the bottom and ethyl ester, which is lighter, was at the top (Plate 3.2). The glycerol was decanted in a container and biodiesel was stored in a sample bottle. A simplified process flow diagram for biodiesel production is shown in Figure 3.1.

Biodiesel product was washed with distilled water at 30% of the ester volume. The mixture was stirred vigorously with mechanical stirrer. The stirring was stopped after 10 min and unreacted ethanol and glycerol that are present are decanted. The washing was done three times to obtain a pure ethyl ester sample. After completion of this procedure, the biodiesel was heated at 100 ºC for 20 min to remove any water present and then stored for further analysis. The percentage of ester yield by ***Parinari polyandra*** was computed using Equation 3.2 as recommended by Oniya (2010).

$$Y = \frac{V_e}{V_r} \times 100\,\% \qquad 3.2$$

Where;

Y = yield of ethyl ester (%)

V_e = volume of ethyl ester produced (m^3)

V_r= volume of raw oil used (m^3)

The petroleum diesel fuel otherwise known as Automotive Gas Oil (AGO) was used as reference fuel in diesel engine. This was obtained from a filling station in Ogbomoso, Nigeria. The samples of biodiesel blends were produced from ***Parinari polyandra*** oil blended with petroleum diesel fuel. The ratios are stated as follow:

i. Biodiesel at 5% of ***Parinari polyandra*** oil and 95% AGO.
ii. Biodiesel at 10% of ***Parinari polyandra*** oil 90% AGO.
iii. Biodiesel at 15% of ***Parinari polyandra*** oil 85% AGO.

iv. Biodiesel at 20% of ***Parinari polyandra*** oil and 80% AGO.

v Biodiesel at 25% of ***Parinari polyandra*** oil and 75% AGO

The ester functional group spectrum of the produced biodiesel was determined using Proton Nuclear Magnetic Resonance. The physical and chemical properties base on America Society for Testing and Material (ASTM D6751) was used to determine acid value, saponification value, iodine value, density, kinematic viscosity, flash point, cloud point and pour point of biodiesel and its blend.

In a bid to optimize the reaction conditions for high biodiesel yields from *Parinari polyandra* oil transesterification, the parameteric effect of temperature, time and catalyst amount were determined on biodiesel yield using Response Surface Methodology (RSM). Seventeen (17) experimental runs, generated from a three-factor two-level Box-Behnken design, were used to produce biodiesel from *Parinari polyandra* oil using ethanol.

A single cylinder, 5 hp diesel engine, with model KM 178 F (A), type Air Cooled diesel Engine , rated power 3.6 kW (3.3 Hp), rated speed 3000 rpm, maximum power 3.68 kw (5 hp), valve clearance -0.10 – 0.15, cooling system Air cooled, lubricating No SAE 10W – 30, Net weigh 40 kg, fuel capacity 3.5 litres made by Kipor Machinery Company was used for performance evaluation of the study. This engine was coupled to a Hydraulic Dynamometer made by AL – Tech BK.

Values for torques, speed, fuel consumption rate and exhaust temperature were recorded from every fuel sample test under different load conditions. Other engine parameters like BTE, BSFC, BP and FEP were computed using the following equations [92].

$$M_f = \frac{8\rho \, X \, 10^{-4}}{t} \quad \text{(Eqn. 5)}$$

Where:

M_f = *Fuel consumption rate (kg/s)*

ρ = *Density of Fuel (kg/m*^{3}*)*

t = *Time taken (s)*

$$P_f = H_g \times M_f \qquad \text{(Eqn. 6)}$$

Where:

P_f = *Fuel equivalent power (W)*

H_g = *Heating value (J/kg)*

M_f = *Fuel consumption rate (kg/s)*

$$P_B = \frac{2\pi NT}{60} \qquad \text{(Eqn. 7)}$$

Where:

P_B = *Brake power (kW)*

N = *Speed (rpm)*

T = *Torque (Nm)*

Also, $P_B = T \times \omega$

Where:

$$\omega = \frac{2\pi N}{60}$$

ω = *angular speed (rad/s)*

$$BSFC = \frac{M_f}{P_B} \qquad \text{(Eqn. 8)}$$

Where:

BSFC = brake specific fuel consumption (kg/kwh)

M_f = *fuel consumption rate (kg/s)*

P_B = *brake power (kW)*

$$\eta_{bth} = \frac{P_B}{P_f} X\ 100 \qquad \text{(Eqn. 9)}$$

Where:

η_{bth} = *brake thermal efficiency (%)*

P_B = *Brake power (kW)*

P_f = *Fuel equivalent power (W)*

Results and Discussion

The oil yield reflected a yield of 53.13% (Table 3). This value seems to be slightly lower than 64 % reported by Afolabi *et al*., (2015) Also, Sand apple seeds have been reported to have an oil yield of 57% through solvent method (Amos *et al*., 2016). It may then be suggested that the variation in the oil yield of sand apple seeds may be due to difference in variety of the fruit, the time of harvest and the experimental conditions.

With a biodiesel throughput range of 72.49 – 95.62 %, highest biodiesel yield of 95.62% was obtained at reaction conditions of 67.5°C, 60 min, 1 wt%; of temperature, time and catalyst amount respectively. Optimal biodiesel yield of 92.75% was predicted at reaction conditions of 61.20 °C temperature, 60 min, and 1 wt% of catalyst amount (Table 4). However, an average biodiesel yield of 91.27% was obtained from validation experiments. The fuel properties (Table 5) of the produced biodiesel were determined and found to be within the standards of ASTM D6751. This is an evidence of the effectiveness of transesterification in the reduction of the viscosity and free fatty acid and has proved further that the biodiesel synthesized from *Parinari polyandra* oil can be used as an engine fuel.

Table 3: Yield from solvent extraction of oil from sand apple seeds (soxhlex method)

Run	**Weight of seed (g)**	**weight of oil (g)**
1	20	10.75
2	20	10.95
3	20	10.60
4	25	12.75
5	25	12.85
6	25	13.35
7	25	13.45

8	20	10.75
9	20	10.60
10	25	13.50
Total	**225**	**119.55**

Table 4: Results of experimental design for transesterification of sand apple oil

Run	Factor A Temperature (℃)	Factor B Time (min)	Response Biodiesel yield (%)	Predicted Value %
1	52.93	90	80	80.58
2	67.07	90	76	74.99
3	65.00	120	78	78.49
4	65.00	60	72	73.13
5	60.00	90	75	77.78
6	60.00	132.43	80	79.1
7	60.00	90	72	73
8	55.00	60	72	73
9	55.00	120	90	89.36
10	60.00	90	78	77.1
11	60.00	90	77	77.78
12	60.00	47.57	70	69.1
13	60.00	90	78	77.78

Table 5: Fuel related properties of the experimental biodiesel samples

Run	Specific gravity	Kinematic viscosity @ 40^{o}C, mm^2/s	Cloud point, ^{o}C	Pour point, ^{o}C	Flash point, ^{o}C	Higher heating value, MJ/kg	Cetane number	Acid value, mgKOH/g	pH	Water (% v/v)
1	0.881	4.66	-1	-6	142	44.9	65.2	0.33	7.43	<0.01
2	0.883	3.69	-2	-5	144	45.2	65.3	0.29	7.33	<0.01
3	0.886	3.71	1	-5	158	45.9	65.3	0.52	7.2	<0.01
4	0.888	3.84	0	-6	156	46.1	65.5	0.48	7.24	<0.01
5	0.886	3.81	-1	-7	168	45.9	65.5	0.51	7.18	<0.01
6	0.885	3.79	-1	-7	152	45.8	65.4	0.48	7.24	<0.01
7	0.888	3.84	1	-6	161	46.2	65.5	0.45	7.18	<0.01
8	0.882	4.33	-1	-5	148	44.8	65.2	0.31	7.21	<0.01
9	0.887	3.89	-2	-7	167	46.0	65.5	0.5	7.14	<0.01
10	0.886	3.78	-3	-7	149`	45.7	65.5	0.42	7.32	<0.01
11	0.883	4.22	-3	-8	142	45.8	65.4	0.37	7.25	<0.01
12	0.885	3.9	-3	-8	172	45.8	65.3	0.43	7.28	<0.01
13	0.881	4.53	-2	-4	148	45.2	65.4	0.28	7.37	<0.01
14	0.885	3.77	-2	-4	160	46.1	65.5	0.49	7.19	<0.01
15	0.881	4.12	-1	-4	145	45.7	65.4	0.28	7.42	<0.01
16	0.882	3.94	-1	-5	148	46.1	65.4	0.33	7.23	<0.01
17	0.881	3.88	-2	-6	152	44.8	65.2	0.31	7.42	<0.01

The ^{1}H NMR spectrum of the produced biodiesel is shown in Figure 3. The NMR spectra showed a neat and clearer signal separation of the functional alcohol group, the carboxylic and fatty acid ester. The chemical shift from δ 5.255 – 5.371 ppm represents the olefinic protons. The ethoxy protons of the ester of the biodiesel are represented in the double signals between δ 4.054 and 4.107 ppm. The fatty and carboxylic acid functional groups of the biodiesel are accumulated in the multiplet between δ 0.834 and 2.745 ppm.

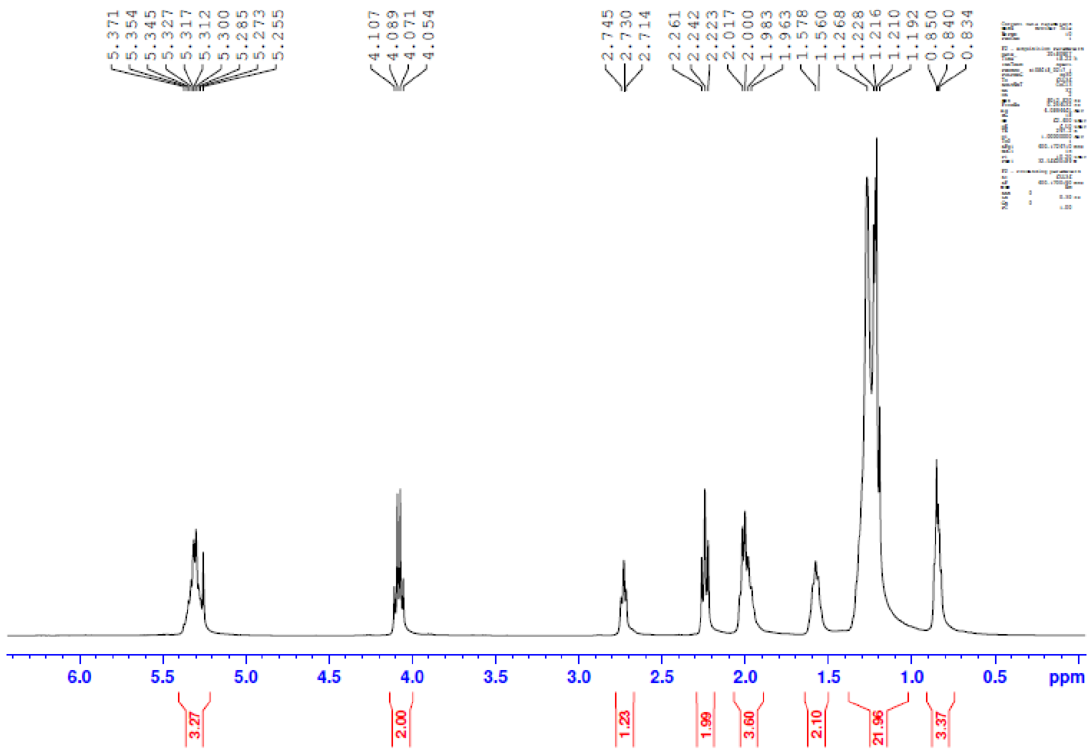

Figure 3: ^{1}H NMR spectrum of *Parinari polyandra* seed oil biodiesel

Another sets of reaction parameter were applied in biodiesel production study from *Parinari polyandra* oil [22]. A Central Composite Design was used to optimize biodiesel yields from *Parinari polyandra* oil transesterification using potassium hydroxide as catalyst. Ethanol was also used because of its lesser toxicity and higher energy content per gallon than methanol. The experiments were conducted within the range of 60 - 65 ^oC temperatures, 60 - 120 min reaction time, and alcohol to oil ration 3:1 - 6:1 mol. A catalyst concentration of 1 % by weight of oil was used throughout the experiment. Maximum biodiesel yield of 94.6% was obtained at reaction conditions of 65 ^oC temperature, 120 min reaction time and 6:1 alcohol to oil molar ratio. Analysis of Variance (ANOVA) showed that all the reaction parameters were of significant effect ($p<0.05$) on biodiesel yield. Optimization studies, such as this, have led to establishment of validated data which have continued to be of background help to upcoming researchers in biodiesel production for resource efficiency and cleaner production. A summary of all the fuel properties determined from the aforementioned transesterification processes of *Parinari polyandra* oil is given in Tables 6 and 7.

Table 6: Fuel properties of *Parinari polyandra* biodiesel samples compared with ASTM 6751 standard

Fuel properties	1% KOH [22]	1% KOH [82]	2% RHA [82]	4% CPA [82]	ASTM D6751 standard
Density (g/cm^3)		0.895	0.697	0.807	
Specific gravity (40 °C)	0.899	0.862	0.609	0.705	0.87 to 0.98
Viscosity (40 °C) (cSt)	3.905	-	-	-	1.90 to 6.0
Pour point (°C)	1.05	-	-	-	-15 to 13
Acid value (mgKOH/g)	0.52	0.613	0.464	0.298	0.80 (max)
pH	7.42	-	-	-	7 to 9
Cloud point (°C)	4.78	-	-	-	-3.15 to 11.85
Flash point (°C)	165.5	175	150	165	>120
Cetane number	54.3	-	-	-	>45

KOH: potassium hydroxide; RHA: Risk Husk Ash; CPA: Cocoa Pod Ash

Table 7: Fuel properties of *Parinari polyandra* biodiesel blends

Fuel properties	B5D95	B10D90	B15D85	B20D80	AGO
Kinematic viscosity @ 40 ℃	3.5	4.3	5.1	4.7	2.95
Specific gravity @ 15 ℃	0.9064	0.9112	0.9102	0.9107	0.86
Heating value (MJ/kg)	44.09	43.79	43.46	43.17	44.41
Flash point(℃)	90	69	67	65	74
Cloud point (℃)	-4	-4.5	-5	-3	-11.9
Pour point (℃)	-7.5	-8	-9	-7	-15.4
Sulphur content (%)	0.006	0.009	0.014	0.016	< 0.01
Fire point (℃)	97	83	76	74	78
Cetane number	49.5	50.8	51.6	52.45	48

From the results obtained as shown in Tables 8 - 12, the diesel engine produced lower BTE when biodiesel blends were used to run the engine compared to when diesel fuel was used. This has shown that the biodiesel blends are better in terms of the index of flammability because of its high cetane number and high oxygenated nature than that of diesel fuel. The torque developed by the engine increased in the engine load for all the fuels.

The exhaust gas temperature was found to increase as the load increased. There was a constant steady increase in exhaust gas temperature from B5 except for slight decrease from 75% to 100% load condition when B20 was used. The results obtained are comparable with the reports of Naga Prasad et al. [93] that exhaust temperature increases with increase in operating load for all the blends of neat castor oil with AGO. The fuel consumption rate increased as the loading rate increased. Though this increase can be explained in term of the increasing mechanical and pumping losses that accompany the increasing speed of the engine, biodiesel has also been found to generally contain lower energy per volume compared to diesel fuel. The obtained results are similar to the reports of Adaileh and Alqdah [94] who found that the fuel consumption of a diesel engine fueled by WCO biodiesel blends increased as the load condition and biodiesel content in the fuel increases.

The BSFC of the engine was found to increase as the proportion of *Parinari polyandra* biodiesel increased in the blend, but there was a gradual decrease in the value of BSFC at increased load conditions when biodiesel blends and AGO were used to run the engine. This performance results are in agreement with that of Saravanan et al. [95] who found that BSFC developed by a diesel engine fueled by rice bran biodiesel blends increased as the percentage of rice bran ester increased in the blends. This decrease can be further explained by the noticeable decrease in heating values of blended fuel as biodiesel content increased. Lower BSFC of diesel may be attributed to its lower viscosity and higher heating value [22]. The BTE, was reported as a very important parameter necessary for the evaluation of engine performance [96]. The BTE of the tested diesel engine was found to increase as the load increased. The BTE of the engine was also found to be higher on pure diesel than biodiesel blends. This was due to smoother lubricating quality, high CN and high oxygenated nature of the blends as compared to diesel fuel. Usta [97] similarly reported that the BTE of a diesel engine was enhanced when it was run on tobacco oil biodiesel. The B5D95, which contained 5% biodiesel fuel, was found to have BTE values that are close to that of AGO. These results suggest that the thermal efficiency of diesel engine can be improved by adding 5% of *Parinari polyandra* biodiesel on volumetric basis. Based on the results obtained, more thermal efficiency can however be achieved from fuel blends which are not more than 20%.

Conclusively, *Parinari polyandra* biodiesel blends demonstrated similar performance characteristics to conventional diesel when used in recommended percentages. The obtained results can recommend *Parinari polyandra* biodiesel as an engine fuel which can serve as an alternative to supplement diesel usage in the present and also serve as a substitute in the future complete transition plan to biofuels. However, the exhaust emissions characteristics were not provided as this would have been additional information to support its environmental friendliness and impact. Getting more information on the emission data of *Parinari polyandra* will help researchers in identifying if its combustion offers an opportunity to help reduce the carbon based GHG emissions and create the clean world we all so much desire. Though, it can be deduced logically from previous reports that the combustion of biodiesel has consistently led to reduction of harmful exhaust emissions.

Table 8: Performance test on 5 Hp diesel engines using B5D95

Parameters	**No load**	**25 % load**	**50 % load**	**75 % load**	**100 % load**
Torque (Nm)	6.60	6.95	7.60	8.10	8.50
Speed (rpm)	2950	2950	2950	2945	2945
Exhaust-Gas Temperature (^oC)	385	401	475	550	660
Fuel-Consumption Rate (kg/s)	2. 925 x 10^{-6}	2.998 x 10^{-6}	3.108 x 10^{-6}	3.258 x 10^{-6}	3.442 x 10^{-6}
Brake power (kW)	2.04	2.15	2.35	2.50	2.62
Brake Specific Fuel Consumption (g/kWh)	5.16	5.02	4.76	4.69	4.73
Fuel-Equivalent Power (W)	2.65	2.72	2.82	2.95	3.12
Brake-Thermal Efficiency (%)	76.98	79.04	83.33	84.74	83.97

Table 9: Performance test on 5 Hp diesel engines using B10D90

Parameters	**No load**	**25 % load**	**50 % load**	**75 % load**	**100 % load**
Torque (Nm)	6.00	6.40	7.00	7.45	7.90
Speed (rpm)	2900	2900	2900	2895	2895
Exhaust Gas Temperature (^oC)	350	390	440	510	600
Fuel Consumption Rate (kg/s)	3.092×10^{-6}	3.158×10^{-6}	3.258×10^{-6}	3.425×10^{-6}	3.583×10^{-6}
Brake power (kW)	1.82	1.94	2.13	2.26	2.4
Brake-Specific Fuel Consumption (g/kWh)	6.12	5.86	5.51	5.46	5.38
Fuel-Equivalent Power (W)	2.82	2.88	2.97	3.12	3.26
Brake-Thermal Efficiency (%)	64.54	67.36	71.72	72.43	73.62

Table 10: Performance test on 5 Hp diesel engines using B15D85

Parameters	**No load**	**25 % load**	**50 % load**	**75 % load**	**100 % load**
Torque (Nm)	5.70	6.20	6.90	7.15	7.50
Speed (rpm)	2850	2850	2850	2845	2845
Exhaust-Gas Temperature (^oC)	345	380	430	500	580

Fuel Consumption Rate (kg/s)	3.292×10^{-6}	3.425×10^{-6}	3.658×10^{-6}	3.758×10^{-6}	3.925×10^{-6}
Brake-power (kW)	1.70	1.85	2.06	2.13	2.23
Brake-Specific FuelConsumption (g/kWh)	6.97	6.66	6.39	6.35	6.34
Fuel-Equivalent Power (W)	2.99	3.11	3.32	3.42	3.57
Brake-Thermal Efficiency (%)	56.86	59.48	62.05	62.28	62.46

Table 11: Performance test on 5 Hp diesel engines using B20D80

Parameters	**No load**	**25 % load**	**50 % load**	**75 % load**	**100 % load**
Torque (Nm)	5.10	5.80	6.40	6.95	7.20
Speed (rpm)	2850	2850	2850	2845	2845
Exhaust-Gas Temperature (^{o}C)	300	350	385	435	400
Fuel-Consumption Rate (kg/s)	3.667×10^{-6}	3.767×10^{-6}	3.925×10^{-6}	4.0×10^{-6}	4.167×10^{-6}
Brake power (kW)	1.52	1.73	1.91	2.07	2.15
Brake-Specific Fuel Consumption (g/kWh)	8.68	7.84	7.40	6.96	6.98
Fuel-Equivalent Power (W)	3.33	3.43	3.57	3.64	3.79
Brake-Thermal Efficiency (%)	45.64	50.44	53.50	56.87	56.73

Table 12: Performance test on 5 Hp diesel engines using B25D75

Parameters	No load	25 % load	50 % load	75 % load	100 % load
Torque (Nm)	4.75	5.00	5.50	6.10	6.50
Speed (rpm)	2800	2800	2800	2800	2795
Exhaust-Gas Temperature (^oC)	270	300	340	375	400
Fuel-Consumption Rate (kg/s)	4.425×10^{-6}	4.5×10^{-6}	4.6×10^{-6}	4.767×10^{-6}	5.0×10^{-6}
Brake power (kW)	1.39	1.47	1.61	1.79	1.90
Brake Specific Fuel Consumption (g/kWh)	11.46	11.02	10.29	9.59	9.47
Fuel-Equivalent Power (W)	3.99	4.06	4.15	4.30	4.51
Brake-Thermal Efficiency (%)	34.84	36.21	38.79	41.63	42.13

8. Conclusion

A comprehensive appraisal of African ***Parinari polyandra*** oil as a novel feedstock for biodiesl production was carried out. The oil extraction and biodiesel production processes were discussed. Feasible application of the oil was also highlighted. The application of the biodiesel in a diesel engine via a laboratory experimental test was discussed, and this has shown that it is a promising feedstock for diesel engine fuel production. Notable conclusions, which were derived from the study, are summarized as follows:

i. It can be deduced from the study that *Parinari polyandra* is one of the untapped promising feedstocks for biodiesel production in Africa. The full exploitation and utilization of this plant seed oil will help contribute immensely to the development of biodiesel industries in Africa and help reduce unemployment while providing income earner opportunities for farmers in the rural areas.

ii. *Parinari polyandra* is a promising feedstock with relative high oil yield suitable for biodiesel and oleochemical industries. Few optimization studies have been carried out to study the effects of reaction parameters on the quality and quantity of oil yield. The average oil yield extracted so far has been within 40% and 60%.

iii. The oil used for biodiesel production found to have similar properties to that of fossil diesel. Biodiesel production were carried out in different studies involving the use of homogeneous and heterogeneous catalysts. All these were effective as biodiesel yields higher than 90% were obtained from the transesterification of the oil.

iv. The extracts of *Parinari polyandra* have been used as herbal recipes and they contain chemical components that have medicinal properties which can be used as pain and inflammatory relievers, fertility boosts, antidiabetic, anti-hyperlipedimia and anticholesterolemia potentials.

v. Not so much studies were found on the application of the biodiesel as engine fuel. The performance evaluation was carried out in a study and it was found that the engine performance improved on blended fuel with no modification of the engine. The performance characteristics of the diesel engine showed similar characteristics to the values obtained from running the engine on AGO. No report was found on emissions characteristics.

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