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Determination and Evaluation of Fuel Properties of Groundnut (*Arachis hypogaea*, L.) Biofuel Blended with Diesel

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ABSTRACT

Vegetable oils have attracted attention as potential renewable resources for the production of alternatives for petroleum based diesel fuel. This study focused on the evaluation of fuel properties of groundnut oil and its ethyl ester blended with diesel to establish their suitability for use in compression ignition engines. Twenty biodiesel blends (10, 20, 30, 40, 50, 60, 70, 80, 90 and 100%) of groundnut oil and its ethyl ester by volume with Automotive Gas Oil (AGO) were used. The fuel properties of the biodiesel blends such as specific gravity, viscosity, cloud and pour point, flash point, heating value, sulphur content and carbon content were determined according to ASTM standards. Data were analyzed using ANOVA and correlations between fuel properties and blending ratios of groundnut biofuel with AGO were developed. Pure AGO was used as a basis for comparison. Results showed that viscosity of 10 - 30% groundnut ester-AGO blends (5.5 – 5.8 mm^2/s) fell within the limit specified by ASTM standards. The heating values of groundnut biodiesel blends decreased from 38.4 – 30.07MJ/l. Groundnut ethyl-ester had higher cloud point of 7^{o}C compared to -12^{o}C obtained for AGO. The flash points, cloud and pour points of groundnut oil and its ethyl-ester AGO blends were higher than for reference AGO. The specific gravity obtained for all groundnut ester-diesel blends ranged from 0.8 – 0.9 and it fell within limit specified by international standards. All the biodiesel blends had sulphur contents ranging from 9.16 – 13.2% and lower than that of reference AGO. Predictive fuel properties' models gave R^2 of 0.55-0.98. Biodiesel blends with 10 and 20 percent groundnut ethyl ester content were found to have acceptable fuel properties for use as supplementary fuel in compression ignition engines.

Keywords: Renewable, Groundnut ethyl esters, Biodiesel, Compression ignition engine, Fuel.

Introduction

The problems of global warming, frequent heavy rains, rain hurricanes and flood threatening lives arising from the continued use of fossil fuels have generated global interest in developing alternative non-petroleum fuels for engines. The general trend now is to reduce global warming and increase the use of environmental friendly fuels.

Plant oils have attracted attention as potential renewable resources for the production of alternatives for petroleum based diesel fuel also known as Automotive Gas Oil (AGO). Most especially, alcohol esters of vegetable oils known more generically as biodiesel have been proposed as the most promising alternative to petroleum based diesel fuel (Krawczyk, 1996 and Conceicao *et al.*, 2005). Biodiesel can be used in its pure form to fuel any existing diesel engine, and it can be blended with petroleum diesel (Shresta *et al.*, 2005). The physical and chemical properties of biodiesel fuel are similar to petroleum diesel fuel.

There are four primary ways to make biodiesel. They are direct use and/or blending; micro emulsion, thermal cracking (pyrolysis) and transesterification (Ma and Hanna, 1999; Rakopoulos *et al.*, 2006).

In direct use, pure vegetable oil is used to fuel the diesel engine, while in blending, a blend of vegetable oil and AGO is used. The main problem with the direct use of vegetable oils as biodiesel fuel is high viscosities (Rakopoulos *et al.*, 2006). Other problems associated with the direct use of vegetable oils as fuels were oil deterioration and incomplete combustion (Peterson *et al.*, 1983; Frame *et al.*, 1997). The incomplete combustion resulted in carbon deposits and lubricating oil thickening (Ma and Hanna, 1999). The purpose of blending vegetable oil with AGO is to lower the viscosity to make it thinner, so that it flows more freely through the fuel system into the combustion chamber (Ma and Hanna, 1999). It is noteworthy that direct use of vegetable oils and/or the use of blends of the oils has generally been considered to be unsatisfactory and impractical for both direct and indirect diesel engines because of the obvious problems associated with it (Elsbett and Biakowki, 2003). However, the Elsebett engine has been developed for successful direct use of vegetable oils (Elsbett and Biakowki, 2003).

In micro-emulsion, a colloidal equilibrium dispersion is formed by mixing vegetable oils with solvents such as methanol (Schwab *et al.*, 1987). Though the performance of such micro emulsions has been reported to be as good as that of diesel fuel (Goering *et al.*, 1984), the problem of heavy carbon deposits, incomplete combustion and an increase of lubricating oil viscosity have been reported (Ziejewski *et al.*, 1984).

Thermal cracking (pyrolysis) involves heating vegetable oils or animal fats in the absence of air to produce a variety of biofuels (Sontag, 1979). The initial product of the pyrolysis of vegetable oils or animal fats is a crude oil (Ma *et al.*, 1998). The crude oil can be refined to produce diesel fuel and small amounts of gasoline and kerosene (Ma *et al.*, 1998). The major problems associated with this method include the fact that the equipment for thermal cracking is expensive for modest throughput.

Transesterification involves the reaction of fat or oil with an alcohol to form esters and glycerol as shown in equation 1 (Watt *et al.*, 1997). The esters are used as biodiesel fuel.

$$
\begin{array}{lcccl}
CH_2 - OOC - R_1 & & & R_1 - COO - R^1 & CH_2 - OH \\
| & & & + & | \\
CH - OOC - R_2 & + \; 3R^1OH & \xrightleftharpoons{\text{catalyst}} & R_2 - COO - R^1 & + \; CH - OH \\
| & & & + & | \\
CH_2 - OOC - R_3 & & & R_3 - COO - R^1 & CH_2 - OH \\
\textit{Triglyceride} & + \; \textit{Alcohol} & \rightarrow & \textit{Ester} & + \; \textit{Glycerol}
\end{array}
\quad \text{...eqn 1}
$$

Considerable research had been done on vegetable oils as diesel engine fuel (Ma and Hanna, 1999). That research included palm oil, soybean oil, sunflower oil, coconut oil, rapeseed oil, etc. Shay (1993) and Sheehan *et al.*, (1998) reported that oil from algae, bacteria and fungi have been investigated. Plant oils from these sources have been examined as sources of ester based diesel fuel (Briggs, 2004).

Although, groundnut oil have been found to be potentially suitable for the production of groundnut biodiesel using methanol as the alcohol for transesterification (Yusuf and Sirajo, 2009). No work was reported in literature on the fuel properties of groundnut biodiesel using ethanol as the alcohol for transesterification. In this study, groundnut oil was transesterified with ethanol and the fuel properties of groundnut oil and its ethyl ester blended with AGO were determined in order to establish their suitability for use in compression ignition engines. The regression models for the fuel properties of groundnut biodiesel based on blending ratios with AGO were also developed.

Materials and methods

2.1. Experimental procedures

The groundnut seeds used in this work were bought from *Sabo* market, Ogbomoso, Oyo State, Nigeria. Oil was extracted from the groundnut seeds by mechanical extraction method as outlined in Bamboye and Oniya (2009). The groundnut ethyl ester samples were prepared by treating the groundnut oil with ethanol using potassium hydroxide as catalyst. The process of transesterification to produce ethyl esters was a two-step process as developed by Peterson *et al.* (1996); Saifuddin and Chua (2004). Automotive Gas Oil (AGO) was used as the reference fuel. It was obtained from a petroleum filling station in Ogbomoso, Nigeria.

2.1. Preparation of biodiesel blends

Twenty biodiesel samples were produced by blending groundnut oil and its ethyl-esters with AGO at (10-100%) mix with 10% increment of groundnut biofuel by volume in the following proportions:

B10 = 10 percent groundnut biofuel and 90 percent AGO
B20 = 20 percent groundnut biofuel and 80 percent AGO
B30 = 30 percent groundnut biofuel and 70 percent AGO
B40 = 40 percent groundnut biofuel and 60 percent AGO
B50 = 50 percent groundnut biofuel and 50 percent AGO
B60 = 60 percent groundnut biofuel and 40 percent AGO
B70 = 70 percent groundnut biofuel and 30 percent AGO
B80 = 80 percent groundnut biofuel and 20 percent AGO
B90 = 90 percent groundnut biofuel and 10 percent AGO
B100= 100 percent groundnut biofuel and 0 percent AGO

2.2 Analysis of the samples

The extracted groundnut oil blended with AGO, groundnut ethyl ester blended with AGO and the reference AGO were evaluated for their fuel properties such as specific gravity, viscosity, cloud and pour point, flash point, heating value, sulphur content, carbon content, iodine value, peroxide value, saponification value and free fatty acid which were determined according to ASTM standards.

Results and discussion

The summary of fuel properties of groundnut biodiesel samples are presented in Tables 1 – 2. The regression models for the fuel properties of groundnut biodiesel based on blending ratios with AGO are presented in Table 3.

3.1 Viscosity

The viscosity increased with increase in the blend of groundnut oil, and its ethyl esters with AGO from B10 to B100. It was observed that the viscosities of up to B80 increased from 4.5 – 23.50 mm^2/s and were within the range of 4-D grade AGO which is specified by American Society for Testing and Materials Standards (1995) as 5.5 – 24.0mm^2/s for all the biodiesel samples. This implies that those biodiesel fuels produced from groundnut oil up to B80 had enhanced fluidity as fuel for diesel engines and that real spray would generate across the combustion chamber and this would be properly mixed with air. The same trend was observed by Rao *et al*, (2008) and Prasadl, *et al*. (2009) for blends of jatropha methyl ester with AGO and blends of castor oil with AGO respectively, whose viscosity increased as the percentage of biofuel increased in the blends.

The viscosities of groundnut ethyl ester-AGO blends up to B30 ranged from 5.5 – 5.8 mm^2/s and were within the preliminary technical specification standard of U.S.A. for biodiesel fuels and the limit specified by ASTM D445 which ranged from 1.9 – 6.0 mm^2/s. The viscosities of all the other blends were more than the limit specified. Also, the viscosities of blends of groundnut ethyl ester with AGO of more than B30 gives wide variation from the reference AGO. Therefore, blends of not more than 30% of groundnut ethyl ester with AGO will give the best performance in diesel engine without modifying the engine. Similarly, Ajav and Akingbehin (2002) reported that 5-20 % blend of ethanol with AGO have acceptable fuel properties for use as supplementary fuel in farm engines. It is noteworthy that the viscosities of the vegetable oils and consequently their esters can be much more improved if the oil was refined through degumming, neutralization and bleaching process immediately after extraction (Akpan, *et al.,* 2006).

An exponential relationship was obtained for the regression model of viscosity of groundnut ethyl ester at various blends with AGO, while a quadratic relationship was obtained for the regression model of viscosity of groundnut oil at various blends with AGO. The models gave R^2 of 0.91-0.98 and can be used to predict accurately the viscosity of the biofuels at any blend percentage with AGO.

3.2 Specific gravity

The specific gravity of all the groundnut biodiesel samples ranged from 0.83 – 0.88 and were close to the values obtained for the reference AGO which was 0.86. The closeness of the value of specific gravity of the biodiesel samples to that of AGO indicated good ignition property. Similarly, the specific gravity of blends of jatropha methyl ester with AGO from B50 to B100 and raw castor oil with AGO from B25 to B100 increased from 0.85 – 0.88 and 0.86 - 0.96 respectively (Rao *et al.,* 2008 and Prasadl *et al.,* 2009).

The correlation developed for specific gravity of groundnut oil-AGO blends were linear relationships. The regression models gave R^2 of 0.88 – 0.96 and can be used to predict accurately the specific gravity of the biofuels at any blend percentage with AGO.

3.3 Heating value and carbon content

The heating values of groundnut biodiesel blends decreased from 38.4 – 30.07MJ/l. These values were slightly lower than the values obtained for the reference AGO of 44.68MJ/l. These results were comparable to the values reported by Yusuf and Sirajo (2009) and Barminas *et al*. (2001) for tigernut oil (34.6MJ/l), jatropha oil(34.7MJ/l), soybean oil (34.7MJ/l) and groundnut methyl ester (25.5 – 40.81MJ/l). Therefore, all the groundnut biodiesel blends have potentials to power a diesel engine. The heating values of groundnut biodiesel blends decreased as the percentage of raw groundnut oil and groundnut oil ester increased in the blends. This was because the carbon content of the biodiesel blends decreased as the raw groundnut oil and groundnut ethyl ester increased in the blends. Ajav and Akingbehin (2002) reported the same trend of decreasing heating value as the percentage of ethanol increased in the blends of ethanol with AGO. A similar trend was reported for blends of jatropha methyl ester and AGO (Rao *et al.,* 2008).

The correlations developed for heating value and carbon content of groundnut oil-AGO blends were linear, while the correlation developed for heating value of groundnut ethyl ester-AGO blends was exponential. A polynomial relationship was obtained for the carbon content of groundnut ethyl ester-AGO blends. The regression models gave R^2 of 0.77 – 0.96 and can be used to predict accurately the heating value and carbon content of the biofuels at any blend percentage with AGO.

3.4 Cloud, pour and flash points

The flash points, cloud and pour points of groundnut oil and its ethyl-ester diesel blends were higher than for reference AGO. The higher flash points of the biodiesel fuels would ensure safety during storage, while the higher cloud and pour points of the blends may involve some complication for their use in diesel engine during cold weather (Rakopoulos *et al.*, 2006). These results were consistent with the general report that biodiesel fuels have higher pour points than AGO (Peterson *et al*., 1990 and Alamu *et al*., 2007). The results of the flash points were comparable to the values obtained for tigernut oil, tigernut ethyl ester, jatropha oil, jatropha ethyl ester, sunflower methyl ester and groundnut methyl ester which were 228ºC, 200ºC, 240ºC, 191ºC, 177ºC and 98ºC respectively (Barminas *et al*., 2001; Moreno *et al*., 1999; Yusuf and Sirajo, 2009). The results of the cloud and pour points were comparable to the values obtained for sunflower methyl ester, rapeseed methyl ester, soybean ethyl ester and rapeseed ethyl ester whose cloud points were 2ºC, -4ºC, 9ºC and -2ºC while the pour points were -1ºC, -10ºC, 3ºC and -15ºC respectively (Rao *et al.*, 2008; Rahman *et al.*, 2010; Antolin *et al.*, 2002; Labeckas and Slavinskas, 2006; Rakopoulos *et al.*, 2006; Ramesh *et al*., 2002).

The cloud points, the pour points and the flash points increased as the percentage of raw vegetable oil and vegetable oil ester increased in the blends. A quadratic relationship was obtained for the regression model of cloud point and flash point of groundnut ethyl ester at various blends with AGO. The correlation developed for pour point of groundnut oil-AGO blends was linear. Also, the correlations developed for flash point of loofah ethyl ester were logarithmic. The regression models gave R^2 of 0.76 – 0.98 and can be used to predict accurately the cloud, pour and flash points of the biofuels at any blend percentage with AGO.

The flash points of 90% groundnut oil blended with AGO, raw groundnut oil and pure groundnut ethyl ester which ranged from 160 - > 280^0C were close to the European Union biodiesel standard of 130^0C minimum.

3.5 Cetane number

The cetane number of groundnut ester were within the range of the cetane number of dominating fatty acid constituents. This agreed with the findings of Bamgboye and Hansen (2008) who reported that the cetane numbers of esters of soybean, rapeseed, sunflower, cottonseed, peanut, palm oil, lard, tallow and canola oils were within the range of the cetane number of the dominating fatty acid constituents. The cetane numbers of groundnut biodiesel were also close to the values reported by Bamgboye and Hansen (2008) and Moreno *et al.* (1999) for esters of soybean oil (45 - 60), rapeseed oil (44 – 59), sunflower oil (50 – 61.2), cottonseed oil (45 – 55), peanut oil (54), palm oil (58 – 70), lard (63.6), tallow (58 – 64.8) and canola oil (53.9 – 55). The cetane number of groundnut biodiesel obtained as 53.8 agreed with the biodiesel standard of 49 minimum specified by the Technical Standard of the European Union.

3.6 pH value

The pH of all the biofuels were higher but are close to that of AGO obtained as 2.8. It is noteworthy that the acidic nature of the biofuels was due to the presence of free fatty acid while that of AGO was due to the sulphur content.

3.7 Ash content

The ash contents of groundnut oil, its ethyl esters and their blends with AGO were lower compared to AGO obtained as 0.12. Since the ash content is a measure of the amount of metal contained in the fuel, therefore this result indicated that the use of groundnut biofuels would reduce injector nozzle clogging, combustion deposits and injector system wear compared to AGO which had higher ash content. The use of the biodiesel fuels would not constitute a corrosion problem in the injection system and pressure chamber of a diesel engine. The results were consistent with the values of ash contents obtained for jatropha oil, rapeseed methyl ester, sunflower methyl ester and jatropha methyl ester obtained as 0.03, 0.007, 0.004 and 0.013 respectively (Rahman, *et. al.,* 2010; Labeckas and Slavinskas, 2006 and Moreno, *et. al.,* 1999).

A set of quadratic relationships were obtained for the regression models of ash content of groundnut oil and groundnut ethyl ester at various blends with AGO. The regression models for groundnut oil-AGO blends gave R^2 of 0.81 – 0.95, while those of groundnut ethyl ester-AGO blends gave R^2 of 0.53- 0.95, which implies that the models can be used to predict accurately the ash content of the biofuels at any blend percentage with AGO.

3.8 Sulphur Content

All the groundnut biodiesel blends had sulphur contents ranging from 9.16 – 13.2% which are lower than that of reference AGO, therefore sulphur dioxide emissions are expected to be considerably reduced in a diesel engines using the biofuels. The sulphur contents of the biofuels decreased as the percentage of raw vegetable oil and vegetable oil ester increased in the blends.

The correlations developed for sulphur content of groundnut oil-AGO blends and groundnut ethyl ester-AGO blends were linear. The regression models based on blending ratios gave R^2 of 0.86 – 0.93 and can be used to predict accurately the sulphur content of the biofuels at any blend percentage with AGO.

3.9 Saponification value

The same saponification value (0.17 mgKOH/g) was obtained for groundnut oil, groundnut ethyl ester and AGO. These results showed that the groundnut biofuels and AGO would behave similarly in the same chemical reaction.

A quadratic relationship was obtained for the regression model of saponification value of raw groundnut oil and groundnut ethyl ester at various blends with AGO. The regression models for groundnut biofuels gave R^2 of 0.60 – 0.61 which means that the correlation developed can be used to estimate the saponification value of the biofuels at any blend percentage with AGO.

3.10 Iodine value

A set of quadratic relationship was obtained for the regression models of iodine value of groundnut oil and groundnut oil ethyl ester with AGO. The regression models for groundnut biofuel gave R^2 of 0.59 – 0.65 which means that only the correlation developed for loofah biofuels can be used to predict accurately the iodine value of the biofuels at any blend percentage with AGO.

3.11 Peroxide value and free fatty acid

The regression models gave R^2 of 0.76 – 0.98, except those of peroxide value and free fatty acid of groundnut biofuels and groundnut ethyl ester, free fatty acid which gave R^2 of 0.57- 0.78, which means that only the correlation developed for loofah biofuels can be used to predict accurately the peroxide value and free fatty acid of the biofuels at any blend percentage with AGO.

Conclusions

In this study, the viscosity of 10% - 30% groundnut ester-AGO blends (5.5 – 5.8 mm^2/s) fell within limit specified by ASTM standard. Generally, it was found that groundnut oil, its ethyl esters and ethyl ester-AGO blends would have good combustion characteristics and good ignition quality similar to that of AGO. The higher flash points of groundnut biodiesel fuels than that of AGO would ensure safety during storage, while the higher cloud and pour points of the biodiesel fuels may involve some complication for their use in diesel engine during cold weather. The use of groundnut biodiesel would reduce injector nozzle clogging, combustion deposits and injector system wear compared to AGO which had higher ash content. Also, the use of groundnut biodiesel would not constitute a corrosion problem in the injection and piston chambers of the diesel engine.

Table 1. Fuel properties of blends of groundnut oil with AGO

BLENDS	AGO	B10	B20	B30	B40	B50	B60	B70	B80	B90	B100
Kinematic viscosity @ 40^{0}C (mm²/s).	2.95	6.45	10.75	9.6	11.35	13.05	16.5	20	23.5	34.5	39.2
Lower heating value(MJ/l)	44.7	37.4	36.83	36.6	36.6	34.6	34.4	33.7	32.9	32.9	31.6
pH	2.8	2.8	2.4	2.6	3	2.5	2.7	3.1	3.1	2.3	3.4
Specific gravity @ 15°C	0.86	0.8	0.81	0.82	0.824	0.85	0.86	0.88	0.88	0.88	0.9
Cloud point(°C)	-12	6	6	6	6	7	7	7	7	7	8
Pour point(°C)	-16	2	2	2	2	2	3	3	3	3	3
Ash content(%)	0.12	0.003	0.004	0.004	0.006	0.008	0.01	0.01	0.01	0.01	0.01
Flash point(°C)	74	65	70	70	95	98	120	110	123	160	>280
Sulphur content(%)	61.8	12.8	11	11.01	11.01	10.6	10.3	10.18	10.1	9.85	9.8
Carbon content(%)	13.4	24.8	21.4	20.6	20.6	18.6	16.6	13.6	13.1	12.6	11.6
Iodine value (wijis)	0.21	0.05	0.043	0.044	0.047	0.053	0.06	0.061	0.06	0.08	0.41
Peroxide value (Meq/KOH)	0.14	0.04	0.041	0.04	0.045	0.051	0.05	0.055	0.06	0.07	0.13
Saponification value (MgKOH/g)	0.17	0.012	0.011	0.012	0.014	0.015	0.01	0.016	0.02	0.02	0.17
Free fatty acid(%)	8	2	2.3	2.4	2.5	2.3	2.4	2.9	2.9	2	11.2

Table 2. Fuel properties of blends of groundnut oil ethyl ester with AGO

BLENDS	AGO	B10	B20	B30	B40	B50	B60	B70	B80	B90	B100
Kinematic viscosity @ 40^{0}C (mm²/s).	2.95	5.5	5.7	5.8	10	10.8	11.2	13	13.6	21	16.8
Lower heating value(MJ/l)	44.7	38.4	34.9	33.7	33.6	33.4	32.6	32.5	31.6	31.5	30.1
pH	2.8	2.4	2.6	2.8	3.3	2.6	2.6	3.2	3.7	3.2	2.9
Specific gravity @ 15°C	0.86	0.84	0.85	0.84	0.84	0.85	0.83	0.82	0.84	0.88	0.85
Cloud point(°C)	-12	6	5.81	5.9	6.1	6.5	6.8	7.1	7.3	7.31	7.4
Pour point(°C)	-15.4	2.47	2.6	2.69	3	3.1	3.2	3.5	3.64	3.68	3.7
Ash content(%)	0.12	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Flash point(°C)	74	85	81	86.5	95.5	92	90	104	112	125	200
Sulphur content(%)	61.8	11.9	11.4	10.6	11.4	10.6	10.2	10.1	9.85	9.8	9.73
Carbon content(%)	13.4	12.6	18.4	16.9	16.5	15.8	15.5	14.5	12.6	11.2	10.4
Iodine value (wijis)	0.21	0.05	0.05	0.05	0.06	0.06	0.05	0.06	0.06	0.06	0.34
Peroxide value (Meq/KOH)	0.14	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.5	0.13
Saponification value (MgKOH/g)	0.17	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.02	0.17
Free fatty acid(%)	8	2	2.2	2.2	2.1	2	2.2	2.1	2.6	2.4	7

Table 3. Regression models for fuel properties based on blending ratios of groundnut biofuels

Property	Regression models	R^2	Biofuels
Kinematic viscosity at 40^{0}C (mm²/s).	$y = 3.968e^{0.147x}$	$R^2 = 0.91$	Groundnut ethyl ester.
Kinematic viscosity at 40^{0}C (mm²/s).	$y = 0.450x^2 - 2.466x + 11.76$	$R^2 = 0.98$	Groundnut oil.
Heating value(MJ/L).	$y = -0.651x + 38.98$	$R^2 = 0.96$	Groundnut oil.
Heating value(MJ/L).	$y = 40.58x^{-0.11}$	$R^2 = 0.92$	Groundnut ethyl ester.
Specific gravity at 15°C.	$y = 0.011x + 0.778$	$R^2 = 0.96$	Groundnut oil.
Cloud point(°C)	$y = 0.017x^2 - 0.083x + 6.331$	$R^2 = 0.87$	Groundnut oil.
Cloud point(°C)	$y = -0.006x^2 + 0.310x + 4.897$	$R^2 = 0.97$	Groundnut ethyl ester.
Pour point(°C)	$y = 0.056x + 2.218$	$R^2 = 0.95$	Groundnut oil.
Pour point(°C)	$y = 0.017x^2 - 0.083x + 6.331$	$R^2 = 0.96$	Groundnut ethyl ester
Flash point °C	$y = 50.83e^{0.137x}$	$R^2 = 0.86$	Groundnut oil.
Flash point °C	$y = 2.261x^2 - 15.82x + 107.0$	$R^2 = 0.84$	Groundnut ethyl ester
Sulphur content(%)	$y = 12.43x^{-0.10}$	$R^2 = 0.93$	Groundnut oil
Sulphur content(%)	$\mathbf{y = -0.235x + 11.85}$	$R^2 = 0.86$	Groundnut ethyl ester
Ash content(%)	$\mathbf{y = 6E\text{-}05x^2 - 0.000x + 0.01}$	$R^2 = 0.53$	Groundnut ethyl ester.
Ash content(%)	$\mathbf{y = -8E\text{-}05x^2 + 0.001x + 0.000}$	$R^2 = 0.95$	Groundnut ethyl ester.
Carbon content(%)	$\mathbf{y = -1.46x + 25.38}$	$R^2 = 0.96$	Groundnut oil.
Carbon content(%)	$\mathbf{y = -0.191x^2 + 1.510x + 13.49}$	$R^2 = 0.77$	Groundnut ethyl ester
Iodine value (wijis)	$\mathbf{y = 0.008x^2 - 0.066x + 0.146}$	$R^2 = 0.65$	Groundnut oil
Iodine value (wijis)	$\mathbf{y = 0.006x^2 - 0.052x + 0.131}$	$R^2 = 0.59$	Groundnut ethyl ester
Peroxide value (meq/KOH)	$\mathbf{y = 0.001x^2 - 0.010x + 0.056}$	$R^2 = 0.78$	Groundnut oil
Peroxide value (meq/KOH)	$\mathbf{y = 0.001x^2 - 0.016x + 0.074}$	$R^2 = 0.57$	Groundnut ethyl ester
Saponification value (mgKOH/g)	$\mathbf{y = 0.003x^2 - 0.029x + 0.057}$	$R^2 = 0.6$	Groundnut oil
Saponification value (mgKOH/g)	$\mathbf{y = 0.003x^2 - 0.028x + 0.054}$	$R^2 = 0.61$	Groundnut ethyl ester
Free fatty acid(%)	$\mathbf{y = 0.179x^2 - 1.467x + 4.431}$	$R^2 = 0.55$	Groundnut oil
Free fatty acid(%)	$\mathbf{y = 0.109x^2 - 0.913x + 3.476}$	$R^2 = 0.64$	Groundnut ethyl ester

Key: y = Fuel property; x = percentage of groundnut biofuel in the blend.

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