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Evaluation of rice bran, sesame and moringa oils as feasible sources of biodiesel and the effect of blending on their physicochemical properties

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Globally, the environmental awareness is driving the research towards energy resources that are more beneficial to milieu. Biofuel is considered to be a remarkable option for that. Among the sources of biofuels, vegetable oils are the cheapest, easily available and in abundant quantity. However, some processes are needed to make vegetable oils suitable for engines because vegetable oils have certain detrimental properties. In this study, three potential feedstocks, namely, moringa, sesame and rice bran oils are critically investigated as potential sources for biodiesel production. The work was divided into several steps: firstly, the production of biodiesel from the three feedstocks; secondly, the measurement of the important physical and chemical properties of biodiesels; and finally, the development of mathematical equations with the help of polynomial curve fitting method for biodiesel–diesel and biodiesel–biodiesel blends to predict the most important properties, such as kinematic viscosity, flash point, calorific value, CFPP of the blended biodiesel. The experiment has shown that the three feedstocks can be considered to be feasible sources for biodiesel. It is seen from the experiment that biodiesel blends have notable effect on properties; for instance, the viscosity of the rice bran oil is improved to 5.1631 mm^2 s^{-1} from 5.3657 mm^2 s^{-1}, when mixed with sesame biodiesel at a volume ratio of 3 : 1. Moreover, it is improved to 5.0921 mm^2 s^{-1}, when mixed with moringa biodiesel at a volume ratio of 3 : 1. Moreover, flash point and CFPP of rice bran biodiesel are also improved, when mixed with sesame or moringa biodiesel in any percentage.

1 Introduction

Because of the global concern about the reliability of petrodiesel and their adverse impacts on milieu, the world is converging to renewable sources that are environmentally friendly. Currently, more than 80% energy consumption is derived from fossil fuels. Fossil fuels are primarily dominating because of their high combustion efficiency, fuel adaptability and handling facilities.[1] However, the significant concern about fossil fuels is the generation of toxic pollutants linked to the global warming, climate change and even certain impasse diseases.[2] In turn, this phenomenon has promoted biofuels to be a prominent source of interest, including biodiesel, which is one of the prime renewable energy sources.

Among the renewable feedstock, such as vegetable oils, animal fats and recycled cooking oil, vegetable oils are found to be promising feedstock for biodiesel because of their availability and large scale production ability. Globally, more than 350 oil-bearing crops are identified to be a potential source of biodiesel, which can be classified as edible and non-edible oil.[3]

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Because of the diversity of oil-bearing crops, it is a challenge to select the potential sources for biodiesel. Therefore, myriads of research are ongoing. A number of sources from edible oil are already being used on a large scale in several countries. For instance, canola and soybean are used in USA, palm oil in Malaysia, and rapeseed oil in Europe.[3–5] Sunflower, peanut, coconut, sesame oils are few other examples of edible oils. Other sources from non-edible oils, such as *Jatrapha curcas*, *Sterculia foetida*, *Croton megalocarpus*, *Calophyllum inophyllum*, Karanja, Moringa, and rice bran, have attracted considerable attention for biodiesel[6,7] because the large usage of biodiesel production from edible oils has incurred serious concern on food supply.

1.1 Botanical description of rice bran, moringa and sesame feedstocks

Moringa oleifera is the most widely cultivated tree species in the family of Moringaceae. It grows throughout most of the tropics and is native to sub-Himalayan tracts of north-west India, Africa, Latin America, Pakistan, Bangladesh, and Afghanistan. It is drought tolerant and can survive in arid, harsh and infertile land. The tree can range from 5–10 m in height; it can sometimes even be 15 m. The plant starts bearing pods 6–8 months after planting. The seeds are triangular in shape and contain about 35–45% oil by weight.[1,8–10]

Rice is the seed of the monocot plants *Oryza sativa* (Asian rice) or *Oryza glaberrima* (African rice). Rice is the most important cereal cultivated in the world, which feeds more than half of the people of the world. Rice bran is the by-product of rice milling process. Because of the presence of active lipase and high free fatty acid, about 60–70% of rice bran oil production is non-edible. Rice can be practically grown anywhere, even on a steep hill. It contains about 16–32% oil by weight.[11–13]

Sesame (*Sesamum indicum* L) is an oil seed herbaceous crop of the Pedaliaceae family, primarily found in tropical and subtropical areas. It is an annual plant growing 50 to 100 cm tall with opposite leaves 4–14 cm long. The flowers are yellow, tubular with a four-lobed mouth. The flower may vary in color with some being white, blue or purple. The tree is originated in Africa, Turkey, India, China, Sudan, Burma, Tunisia, Egypt, Thailand, Mexico, Guatemala, Afghanistan, Pakistan, and Bangladesh. The oil content is about 57–63%.[14,15]

The pictorial view of the feedstocks is shown in Fig. 1.

1.2 Objectives of this paper

Recently, many studies have been undertaken concerning the production and properties of edible and non-edible oils.[6,16–23] Some authors have discussed the production of biodiesel from *Moringa oleifera*,[24–26] rice bran[12,27,28] and sesame.[14,29] However, there is no published report on the comparison of the physico-chemical properties of these feedstocks. The comparative evaluation of properties is inevitable for the maximum usage of biodiesel and optimization of biodiesel blends because research has shown that the blended biodiesel with two or more feedstocks provides better performance.[30–32] Therefore, the primary objective of this study is to produce biodiesel from crude rice bran, sesame and moringa oil and critically analyze the physico-chemical properties of rice bran, sesame and moringa biodiesel, as potential sources for biodiesel. Then, the biodiesel–diesel and biodiesel–biodiesel blending is suggested to improve some of the main properties, such as kinematic viscosity, calorific value, flash point, and CFPP. In this paper the polynomial curve fitting method is suggested to predict the properties of the blended biodiesel.[6,33]

2 Materials and method

2.1 Materials

The crude moringa and sesame oils were purchased from Delhi, India. Rice bran oil was obtained from the local markets of Bangladesh. Other chemicals, such as methanol, H_2SO_4, KOH, Na_2SO_4, and qualitative filter paper of 150 mm size, were obtained from Malaysia. Biodiesel production was conducted in the scale of 1 L batch reactor.

2.2 Biodiesel production

2.2.1 Production of biodiesel from moringa and rice bran oils. Crude moringa and rice bran oil were poured into a reactor and heated at 60 °C. After reaching the temperature, the oils were reacted with 25% (v/v oil) methanol and 1% (m/m of oil) KOH. The reaction mixture was maintained at 60 °C for 2 h with stirring at the speed of 400 rpm. After the completion of the reaction, the produced biodiesels were poured in a separation funnel for 12 h to separate glycerol from biodiesel. The lower layer, which contained impurities and glycerin, was drained off.

2.2.2 Production of biodiesel from sesame oil

2.2.2.1 Esterification process. This process is primarily employed to reduce the acid value of the feedstock prior to the transesterification process. In this process 50% (v/v oil) methanol was reacted with refined sesame oil. 1% (v/v oil) sulfuric acid (H_2SO_4) was added to the preheated oil at 60 °C for 3 h with stirring at the speed of 400 rpm in a glass reactor. After completing the reaction time the product was poured in a

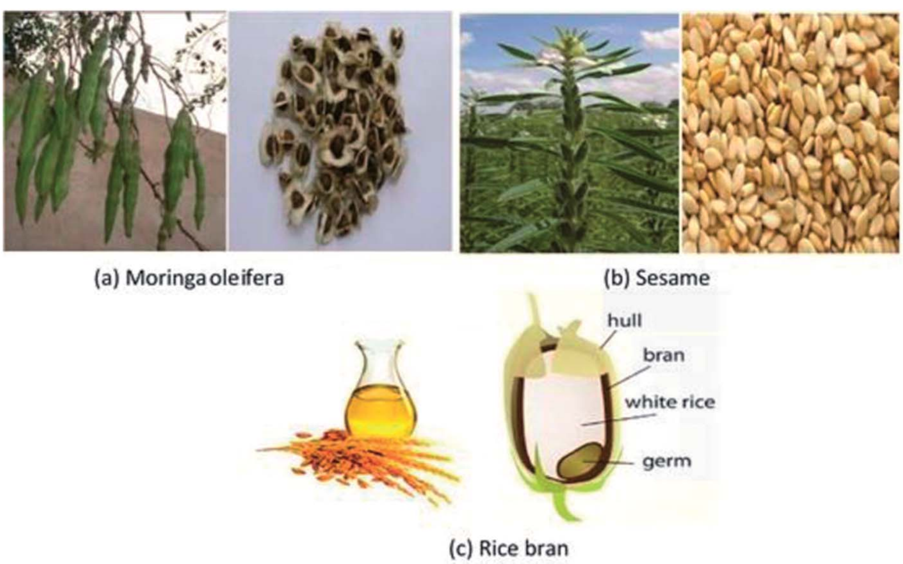

Fig. 1 Feedstocks.

Table 1 List of equipment used in the characterization of fuels[a]

Property	Equipment	Manufacturer	Standard method	ASTM D6751 limit	Accuracy
Kinematic viscosity at 40 °C	SVM 3000-automatic	Anton Paar, UK	D 445	1.9–6.0	±0.35%
Dynamic viscosity at 40 °C	SVM 3000-automatic	Anton Paar, UK	D7042	n.s.	±0.35%
Viscosity index	SVM 3000-automatic	Anton Paar, UK	D 2270		
Density at 40 °C	SVM 3000-automatic	Anton Paar, UK	D 7042	n.s.	0.0005 g cm^{-3}
Density at 15 °C	DM40 LiquiPhysics™ density meter	Mettler Toledo, Switzerland	D 4052		±0.1 kg m^{-3}
Flash point	Pensky-martens flash point – automatic NPM 440	Normalab, France	D 93	130 min	±0.1 °C
Oxidation stability	873 Rancimat-automatic	Metrohm, Switzerland	D 675	3 h min	±0.01 h
Higher heating value (HHV)	C2000 basic calorimeter-automatic	IKA, UK	D 240	n.s.	±0.1% of reading
Cloud point	Cloud and pour point tester-automatic NTE 450	Normalab, France	D 2500	Report	±0.1 °C
Pour point	Cloud and pour point tester-automatic NTE 450	Normalab, France	D 97		±0.1 °C
CFPP	Cold filter plugging point–automatic NTL 450	Normalab, France	D 6371	n.s.	
Acid value	G-20 rondolino automated titration system	Mettler Toledo, Switzerland	D 664	0.5 max	±0.001 mg KOH per g

[a] n.s. ≡ not specified in ASTM test method.

Table 2 Physicochemical properties of crude oils[a]

Property	Unit	CRBO	CMOO	CSO
Kinematic viscosity at 40 °C	$mm^2 s^{-1}$	52.225	32.004	34.087
Dynamic viscosity at 40 °C	mPa s	47.364	29.003	30.905
Density at 15 °C	kg m^{-3}	924.3	923.4	923.6
Specific gravity at 15 °C	—	0.9251	0.9242	0.9244
Density at 40 °C	kg m^{-3}	906.9	906.3	906.6
Kinematic viscosity at 100 °C	$mm^2 s^{-1}$	10.393	7.6569	7.6364
Acid value	mg KOH per g	1.314	0.8670	13.56
Oxidation stability	h	4.40	41.75	9.795
Cloud point	°C	0	−7	−3
Pour point	°C	0	−7	−4
CFPP	°C	16	9	44
Higher heating value (HHV)	MJ kg^{-1}	39.548	39.868	39.386
Viscosity index	—	192.8	222	202.9
Refractive index	—	1.4718	1.4728	1.4709
Transmission	%T	87.1	85.9	78.4
Absorbance	ABS	0.06	0.066	0.106
Flash point	°C	300.5	263.5	280.5

[a] CRBO ≡ crude rice bran oil, CMOO ≡ crude moringa oleifera oil, CSO ≡ crude sesame oil.

separating funnel to separate the excess of alcohol and sulfuric acid. The upper layer containing impurities was separated; the lower layer was placed into a rotary evaporator and heated at 95 °C under vacuum condition to remove ethanol and water content.

2.2.2.2 Transesterification process. This process is same as that in Section 2.2.1.

2.2.3 Post-treatment process. Methyl ester in the upper layer from the previous process was washed several times with warm distilled water at 55–60 °C to remove impurities and glycerol. Then, the upper layer was poured in a control rotary evaporator to eliminate water and methanol. Methyl ester was then dried using Na_2SO_4 and finally filtered using qualitative filter paper.

2.3 Measurement of physico-chemical properties of crude oil and their biodiesel

The physico-chemical properties of crude oils and their biodiesel were tested according to the ASTM method. These properties include kinematic viscosity, density, calorific value, viscosity index, CFPP, cloud point, pour point, flash point and oxidation stability with some non-ASTM properties, such as absorbance, transmission and refractive index. Table 1 shows the test methods and ASTM standard.

2.4 Blending of biodiesel

The blending of biodiesel–diesel and biodiesel–biodiesel was done using a homogenizer at 2000 rpm. The effect of biodiesel blending ratios of 1 : 1 and 1 : 3 were studied for certain properties. These include kinematic viscosity, calorific value, flash point and CFPP. For this purpose, the polynomial curve fitting method was used to predict the properties of biodiesel–diesel blends and biodieselbiodiesel blends. Mathematically, a polynomial of order k in X is expressed as follows: $Y = C_o + C_1X + C_2X^2 + \ldots + C_kX^k$, where X is the variable as a function of available data, and Y is the predicted value.

3 Results and discussion

3.1 Characterization of crude oils

The properties of crude oils are presented in Table 2. The findings from the table show that both sesame and moringa oils possess almost the same kinematic viscosity of 34.087 mm^2 s^{-1} and 32.004 mm^2 s^{-1}, respectively, while rice bran possesses the highest viscosity of 52.225 mm^2 s^{-1}. The acid value of rice bran and moringa oil is about 1 mg KOH per g (1.314 and 0.8670), while sesame oil has a considerable high acid value of 13.56 mg KOH per g. Rice bran oil possesses the highest flash point of 300.5 °C, whereas moringa and sesame oil have flash points of 263.5 °C and 280.5 °C, respectively. All the three oils have the same refractive index of about 1.47, whereas sesame possesses the highest absorbance of 0.106.

3.2 Characterization of biodiesels

The measured physical and chemical properties for rice bran, sesame and moringa biodiesel are presented in Table 3. The findings show that the kinematic viscosity of sesame and moringa biodiesel satisfy both ASTM and EN standards which are 4.3989 mm^2 s^{-1} and 4.1264 mm^2 s^{-1}, respectively; however rice bran oil satisfies only the ASTM standard which is 5.3657 mm^2 s^{-1}. The densities of all the biodiesels are slightly higher (about 3.5%) than diesel. The calorific values of all the biodiesels are about 40 MJ kg^{-1}, which is around 12% less than diesel. The flash points of the three feedstocks are 174.5, 208.5 and 176.5 °C, respectively, which also satisfy the ASTM and EN standards.

3.3 Effect of blending on physicochemical properties

3.3.1 Effect of biodiesel–diesel blending. In this study, higher heating value, flash point, and CFPP are plotted against kinematic viscosity. Mathematical equations are formed using the polynomial equation with the help of Fig. 2(a–c), 3(d–f) and 4(g–i). Moreover, the equations are shown in Table 4(a). The kinematic viscosity, higher heating value, flash point and CFPP can easily be calculated by these equations.

3.3.2 Effect of biodiesel–biodiesel blending. In this study, kinematic viscosity, flash point and CFPP were analyzed. Using Fig. 5(j–l) and 6(m–o), the equations are formed. The equations are shown in Table 4(b).

3.3.2.1 Effect of biodiesel–biodiesel blend on kinematic viscosity. Blending has a considerable effect on kinematic viscosity. For sesame–rice bran biodiesel blend with (3 : 1) ratio, the viscosity of rice bran oil improved from 5.3657 mm^2 s^{-1} to 5.1631 mm^2 s^{-1}. The equation, $Y = -7 \times 10^{-6}Z^2 + 0.0105Z + 4.3928$, $(0 \geq Z \leq 100)$ helps to predict the kinematic viscosity at any percentage of rice bran methyl ester (Z).

Moreover, for the moringa–rice bran blend, the kinematic viscosity of rice bran also improved from 5.3657 mm^2 s^{-1} to 5.0921 mm^2 s^{-1}. The equation, $Y = -2 \times 10^{-5}Z^2 + 0.0147Z + 4.1162$, $(0 \geq Z \leq 100)$ helps to predict the viscosity at any percentage of rice bran methyl ester (Z).

3.3.2.2 Effect of biodiesel–biodiesel blend on flash point. For both sesame–rice bran and moringa–rice bran, the flash point deflects about 3% from pure rice bran biodiesel with a ratio of 3 : 1 by volume. Flash point improved to 175.5 °C for moringa–

Table 3 Physicochemical characteristics of biodiesel[a]

Properties	Unit	SME	RBME	MOME	ASTM D6751	EN 14214	Diesel
Kinematic viscosity at 40 °C	mm^2 s^{-1}	4.3989	5.3657	4.1264	1.9–6.0	3.5–5.0	3.1818
Dynamic viscosity at 40 °C	mPa s	3.8136	4.6581	3.5781	n.s.	n.s.	2.6474
Density at 15 °C	Kg m^{-3}	884.8	886.9	885.8	n.s.	860–900	849.1
Specific gravity at 15 °C		0.8856	0.8877	0.8858	n.s.	n.s.	1.2723
Density at 40 °C	Kg m^{-3}	866.9	868.1	867.1	n.s.	n.s.	832.1
Kinematic viscosity at 100 °C	Mm^2 s^{-1}	1.7236	1.9609	1.6655	n.s.	n.s.	1.2723
Oxidation stability	h	1.135	1.61	12.64	>3	>6	58.51
Cloud point	°C	1	0	0	Report	n.s.	3
Pour point	°C	1	−3	−1	n.s.	n.s.	0
CFPP	°C	−1	2	−2	n.s.	n.s.	4
Higher heating value	MJ kg^{-1}	39.996	39.957	39.888	n.s.	n.s.	45.315
Viscosity index (VI)		229.0	187	244.9	n.s.	n.s.	133.2
Refractive index		1.4540	1.4541	1.4553	n.s.	n.s.	N/D
Transmission	%T	86.5	82.4	87.55	n.s.	n.s.	N/D
Absorbance	Abs	0.063	0.08	0.058	n.s.	n.s.	N/D
Flash point	°C	208.5	174.5	176.5	>130	>120	73.5

[a] n.s. ≡ not specified in ASTM test method, SME ≡ sesame methyl ester, MOME ≡ moringa oleifera methyl ester, RBME ≡ rice bran methyl ester.

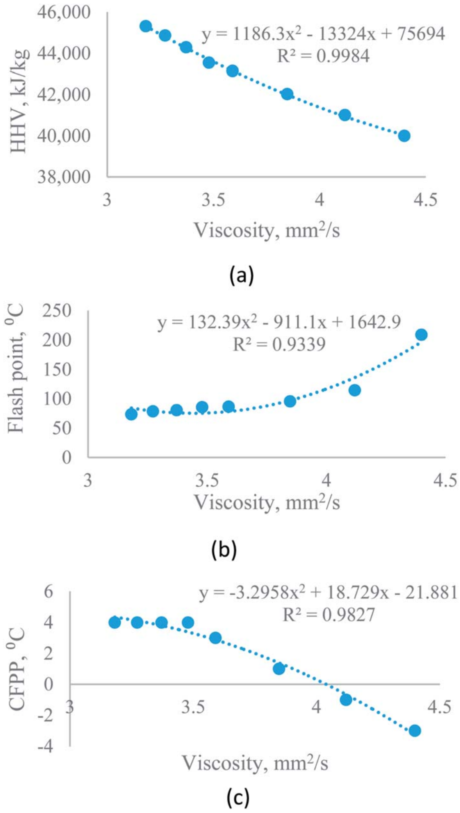

Fig. 2 Sesame methyl ester–diesel blend (a, b and c).

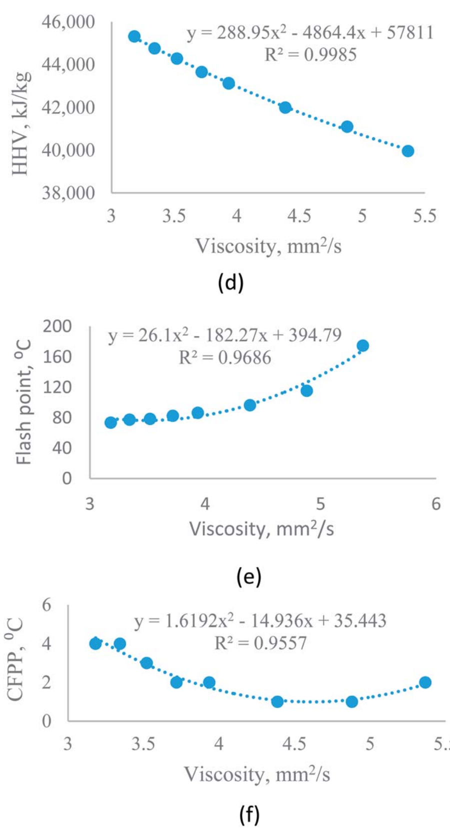

Fig. 3 Rice bran methyl ester–diesel blend (d, e and f).

rice bran biodiesel and 198.5 °C for sesame–rice bran biodiesel at a ratio of 3 : 1 by volume, where the flash point of moringa is 176.5 °C, for rice bran is 174.5 °C and for sesame biodiesels is 208.5 °C. The following equations were used to predict the flash point of sesame–rice bran and moringa–rice bran biodiesel blends for any percentage of rice bran methyl ester ($0 \geq Z \leq 100$):

$$Y = -0.0009Z^2 - 0.2283Z + 207.23 \quad (1)$$

$$Y = 1 \times 10^{-5}Z^2 - 0.0207Z + 176.47 \quad (2)$$

3.3.2.3 Effect of biodiesel–biodiesel blend on cold filter plugging point. The cold filter plugging point (CFPP) can be easily predicted for sesame–rice bran and moringa–rice bran biodiesel blend using eqn (3) and (4) with condition ($0 \geq Z \leq 100$). CFPP of sesame–rice bran blended biodiesel improved to −1 °C at 1 : 1 ratio by volume, where CFPP of rice bran is 2 °C.

$$Y = 0.0001Z^2 + 0.0406Z - 3.0571 \quad (3)$$

$$Y = 0.0005Z^2 - 0.0057Z - 2.0286 \quad (4)$$

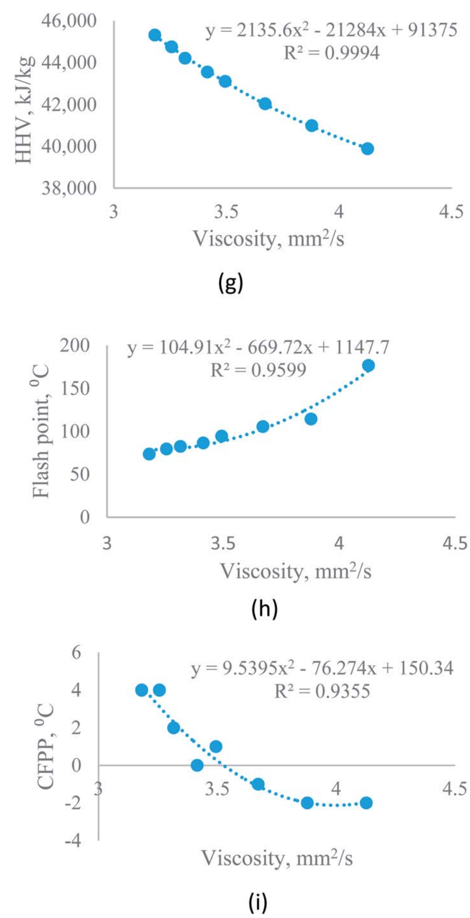

Fig. 4 Moringa methyl ester–diesel blend (g, h, i).

Table 4 Mathematical Equation for various properties of blended biodiesel

Property	Biodiesel blends	Mathematical equation	R^2	Variable
(a): Biodiesel–diesel blends				
Higher heating value *vs.* kinematic viscosity at 40 °C	Sesame–diesel	$y = 1186.3x^2 - 13324x + 75694$	$R^2 = 0.9984$	X = percentage of biodiesel, varies from 0 to 100
	Rice bran–diesel	$y = 288.95x^2 - 4864.4x + 57811$	$R^2 = 0.9985$	
	Moringa–diesel	$y = 2135.6x^2 - 21284x + 91375$	$R^2 = 0.9994$	
Flash point *vs.* kinematic viscosity at 40 °C	Sesame–diesel	$y = 132.39x^2 - 911.1x + 1642.9$	$R^2 = 0.9339$	
	Rice bran–diesel	$y = 26.1x^2 - 182.27x + 394.79$	$R^2 = 0.9686$	
	Moringa–diesel	$y = 104.91x^2 - 669.72x + 1147.7$	$R^2 = 0.9599$	
CFPP *vs.* kinematic viscosity at 40 °C	Sesame–diesel	$y = -3.2958x^2 + 18.729x - 21.881$	$R^2 = 0.9827$	
	Rice bran–diesel	$y = 1.6192x^2 - 14.936x + 35.443$	$R^2 = 0.9557$	
	Moringa–diesel	$y = 9.5395x^2 - 76.274x + 150.34$	$R^2 = 0.9355$	
(b): Biodiesel–biodiesel blends				
Kinematic viscosity at 40 °C	Sesame–rice bran	$Y = -7 \times 10^{-6}Z^2 + 0.0105Z + 4.3928$	$R^2 = 0.9988$	Z = percentage of rice bran biodiesel, varies from 0 to 100
	Moringa–rice bran	$Y = -2 \times 10^{-5}Z^2 + 0.0147Z + 4.1162$	$R^2 = 0.9984$	
Flash point	Sesame–rice bran	$Y = -0.0009Z^2 - 0.2283Z + 207.23$	$R^2 = 0.9734$	
	Moringa–rice bran	$Y = 1 \times 10^{-5}Z^2 - 0.0207Z + 176.47$	$R^2 = 0.9974$	
CFPP	Sesame–rice bran	$Y = 0.0001Z^2 + 0.0406Z - 3.0571$	$R^2 = 0.9867$	
	Moringa–rice bran	$Y = 0.0005Z^2 - 0.0057Z - 2.0286$	$R^2 = 0.9949$	

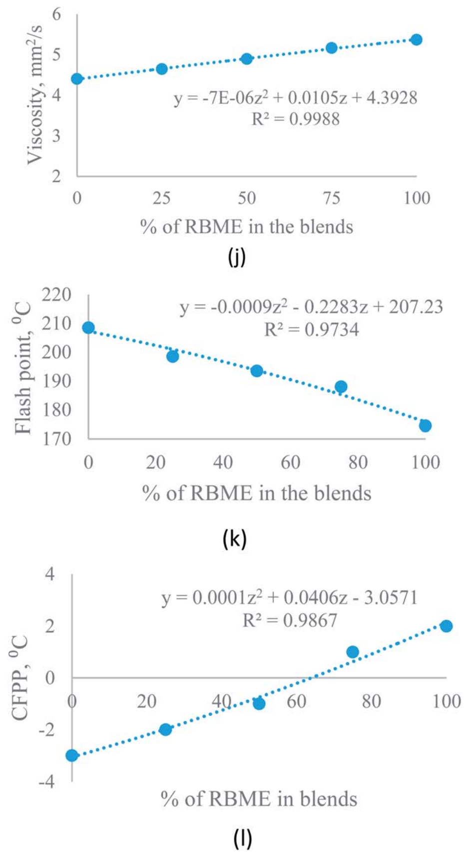

Fig. 5 Sesame–rice bran biodiesel blends (j, k and l).

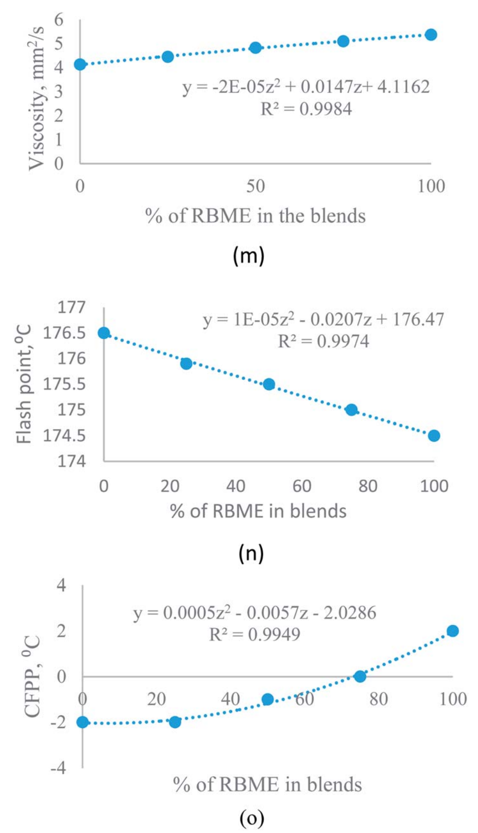

Fig. 6 Moringa–rice bran biodiesel blends (m, n, and o).

3.4 Validation of mathematical equations for biodiesel blends

The equation developed using the polynomial curve fitting method for various biodiesel blend percentages are validated with the experimental data shown in Table 5. The variation of data is calculated using eqn (5).[34] Viscosity variation with experimental data for each blend is found below 0.5% and not more than 5.5%, when it is used for flash point calculation. The variation of CFPP is considerably larger, about 20%.

Table 5 Data comparison for the equation validation of various biodiesel blends

Blend	Property	Biodiesel blend	Experimental data	Data from equation	Variation %
Rice bran + diesel	Higher heating value	B20	44.206	44 279.29	0.14
		B60	42.042	42 019.61	
	Flash point	B20	82.5	80.486	3.79
		B60	105.5	102.98	
	CFPP	B20	2	2.469	9.27
		B60	−1	−0.8839	
Sesame + diesel	Higher heating value	B20	44.291	44 256.29	0.13
		B60	42.026	41 989.75	
	Flash point	B20	80.5	76	5.45
		B60	95.5	97.278	
	CFPP	B20	4	3.8	19.24
		B60	−1	−1.3882	
Moringa + diesel	Higher heating value	B20	44.278	44 263.7	0.10
		B60	41.995	42 031.71	
	Flash point	B20	78.5	76.59	3.99
		B60	96.5	97.49	
	CFPP	B20	3	2.9248	19.30
		B60	1	1.0784	
Sesame + rice bran	Kinematic viscosity	B25	4.6421	4.65	0.23
		B50	4.8933	4.9	
	Flash point	B25	198.5	200.935	0.94
		B50	193.5	193.56	
	CFPP	B25	−2	−1.9796	22.76
		B50	−1	−0.7771	
Moringa + rice bran	Kinematic viscosity	B25	4.4417	4.471	0.46
		B50	4.8216	4.8	
	Flash point	B25	175.9	175.9587	0.03
		B50	175.5	175.45	
	CFPP	B25	−2	−1.8586	16.36
		B50	−1	−1.0636	

$$\text{Variation}(\%) = \frac{100}{N}\sum_{1}^{N}\left|\frac{\text{Data}_{\text{exp}} - \text{Data}_{\text{equa}}}{\text{Data}_{\text{exp}}}\right|, N = \text{No. of data} \quad (5)$$

4 Conclusion

Biodiesel is one of the best potential alternatives of petro-diesel because it has profitable benefit, though it has some disadvantages, such as high kinematic viscosity, density, low volatility and heating value. This article deals with the production and characterization of biodiesel from three potential feedstocks, *viz.*, rice bran, moringa and sesame oil. Moreover, the experimental validation of physicochemical properties of biodiesel–diesel and biodiesel–biodiesel blends is studied. By applying the curve fitting method, equations are developed for predicting important properties, which show very close-fit to the experimental data. This will help future research, such as the optimization of blending percentage, engine combustion and performance and emission analysis.

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