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Provenance variation in *Mesua ferrea* oil: A promising tree-borne oilseed for biodiesel production

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Abstract
Mesua ferrea is a promising tree-borne oilseed for biodiesel production. In recent years, there have been growing concerns about the utility of tree-borne oilseeds as an alternative source of energy. The potential of Mesua seeds as feedstock for biodiesel production was not exploited and only very little research has been carried out. The present study was conducted in different locations to identify the provenance variation in *Mesua ferrea* seed oil. The *Mesua ferrea* oil was analysed for different qualitative and quantitative parameters. The results showed that highest oil yield was noticed in the Sagara of Shivamogga and the highest acid, iodine and saponification value were recorded in Tanimani, Megaravalli-1 and Sampaje respectively. The highest calorific value and viscosity were observed in Megharavalli-1 and the highest density was observed in Tanimani. The GC-MS chromatogram of the oil indicated the presence of 5 to 10 compounds, of which 4 to 5 were identified as the major compounds viz., oleic acid range from 45.25-52.32 percent, linoleic acid range from 15.54-28.43 percent, palmitic acid range from 16.29-20.43 percent, stearic acid range from 7.34-14.9 percent and arachidic acid range from 0.50-1.32 percent. The properties of *Mesua ferrea* biodiesel decreased with transesterification compared to *Mesua ferrea* oil. The oil and biodiesel properties of *Mesua ferrea* were within the international standards of ASTM and BIS. So that the seeds from the *Mesua ferrea* tree can be used as an alternative source for biodiesel production.

Keywords: Provenance, renewable, tree borne oil seed, biofuel, biodiesel, biochemical, fatty acids

Introduction

The globalisation, urbanisation and industrialization cannot even be thought of without "Energy" and meanwhile industrial revolution on inventory of fossil fuel consisting of coal, oil and natural gas has reached the top list in meeting the energy demands of humans. However, continuous decline in these geological reservoirs, combined with the global energy demands and environmental issues has triggered academic and commercial research into new routes to renewable, reliable, accessible, cost-effective and carbon-neutral energy sources to meet the current and potential energy needs of a growing global population. (Lee *et al*., 2014; Nigam and Singh, 2011) [26, 30]. A vital source of renewable energy is biofuels, biofuels are categorised as either liquid (bioethanol, biodiesel) or gaseous (*e.g.*, methane) in the transport sector. Biofuels are renewable fuels from organic feed stocks. The interesting fact about biofuels is that they can be produced by simple chemical reactions from plant sources. Bioethanol and biodiesel are currently the most potential liquid biofuels in transport sector and because of their simplicity of production and cost advantages, these renewable fuels can replace the existing fossil fuels (gasoline and diesel) (Balat and Balat, 2008) [7].

Worldwide, the transportation segment accounts for about 28 percent of the energy consumption and demand keeps going up. Currently, biofuels contribute approximately 3 percent of the energy used in transport sector worldwide. Since 2005, biofuel production has tripled and in 2014 it achieved 74 mega tonnes. Biofuel’s contribution in road transport segment was four percent in 2016. The biofuel production may increase to 159 billion litres by 2022 according to a report from IEA (2017) (Dewangan *et al.*, 2018) [13]. Biodiesel is a strong substitute, clean-burning fuel made from renewable resources. It can be used for diesel engines with slight modifications. Biodiesel is biodegradable and free from sulphur content. The usage of biodiesel will minimise air pollutants such as carbon monoxide, hydrocarbons and particulate matter. These biodiesels have a higher cetane number so that the ignition efficiency is enhanced even when combined with petroleum diesel.

In order to address this devastating phenomenon, suggestions and studies were made regarding biodiesel production using alternative resources which are non-edible oils.

Non-edible oils such as *Madhuca indica*, *Jatropa curcus*, *Mesua ferrea*, and *Pongamia pinnata* are fit for the production of biodiesel (Meher *et al*., 2006) [28]. In recent years, there are growing concerns about the utility of tree-borne oilseeds as an alternative source of energy. The potential of Mesua seeds as feed stock for biodiesel production was not exploited and only very little research has been carried out. The present investigation mainly to study the influence of geographical location on qualitative and quantitative analysis of Mesua oil; biodiesel production and evaluation of quality parameters of biodiesel.

Materials and Method

Study area

The present study was carried out in four southern districts of Karnataka, *viz*., Shivamogga, Chikkamagalur, Kodagu and Bengaluru. A major part of Shivamogga district lies in the Malnad region of Karnataka and spreads over an area of 8465 Sq. km. It lies between the latitudes 13° 27' and 14° 39' N and between the longitudes 74° 38' and 76° 04' E at an altitude of 640 m above the sea level. The average annual rainfall is around 1813.9 mm. Kodagu district with an area of 4,102 Sq. e km is one of the district in Karnataka. It is located in the south western fragment of Karnataka state between 11° 56' and 11° 52' north latitude and between 75° 22' and 76° 12' east longitude. It is a high precipitation area with the lowest elevation of 120 m above the sea level. The average rainfall received is around 2,598 mm. Chikkamagalur district is between 12° 54' and 13° 53' north latitude and between 75° 04' and 76° 21' east longitude at an altitude of 630 m above the sea level. The total area of the district is around 7,201 Sq. km with an average rainfall of about 1925 mm annually. Bengaluru is at an average elevation of 900 m (2,953 ft.). It is located at 12.97° N 77.56° E and covers an area of 741 Sq. km with an average rainfall of about 986.9 mm annually.

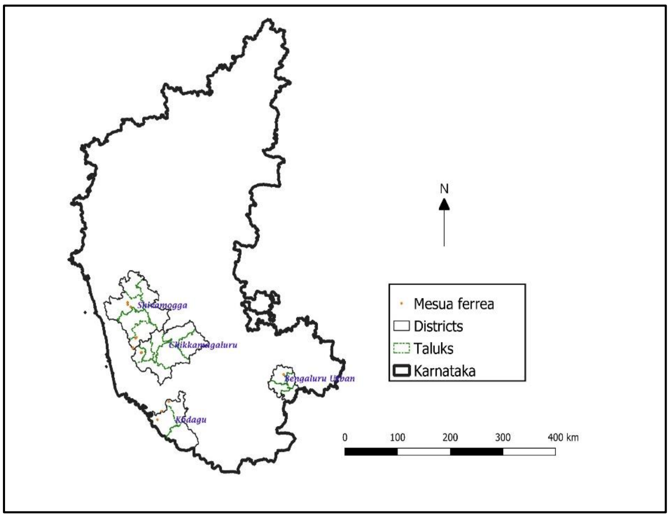

Fig 1: Map showing the GPS location of sampling sites of *Mesua ferrea* L. in Chikkamagalur, Shivamogga, Kodagu and Bengaluru districts of South Western Karnataka.

Sample collection

The ripe seeds of *Mesua ferrea* L. fruits were collected from a wide range of distribution along the South Western Ghats of Karnataka (Selected provenances) during September to November 2019. For each place, approximately one kilogram of fully matured seeds was collected from and filtered, then subjected for further analysis. The percent conversion was determined based on the material balance of the reaction and combined glycerin present in the biodiesel by iodometric titration (AOCS 1991) [4].

Quality analysis of Mesua biodiesel

The acid value, saponification value and iodine value were determined by standard methods (Jayaraman, 1981) [18]. The biodiesel properties were measured as per American Society for Testing and Materials (ASTM) methods as follows: kinematic viscosity (ASTM D445), flash point (ASTM D93), cloud and pour point (ASTM D2500 and ASTM D97). The total FAME content ester in the product was measured by GC analysis according to the EN14103 test method and bomb calorimeter was used to determine the calorific value of the biodiesel.

Statistical Analysis

The experimental data thus obtained during the course of investigation were subjected to statistical analysis by applying the technique of one-way analysis of variance (ANOVA) to test the significance of overall differences among the treatments (Gomez and Gomez, 1984) [15].

Results and Discussion

Qualitative and quantitative analysis of oil

Oil content

The oil content varied from 63.30 to 79.46 percent (Table 1). The highest oil content was recorded in the kernels from Sagara (79.46 percent) and the least oil content was recorded in Tanimani (63.30 percent). The oil content of Mesua in Chikkamagalur, Shivamogga, Kodagu and Bengaluru districts varied from 73.17 to 77.25 percent, 66.65 to 79.46 percent, 63.73 to 65.73 percent and 74.78 to 79.39 percent respectively. Seed oil content variation is more widely reported in a wide variety of trees borne oil seed (Kaura *et al*., 1998) [22] and Panpraneecharoen *et al*., (2014) [31] reported Pongamia oil yield variation in three different provenances. The variations found in the oil content was greatly influenced by the environmental factors such as soil conditions or differences in maturation stage of the seeds (Rahangdale *et al*., 2014) [32].

Table 1: Oil yield (%) in *Mesua ferrea* L. kernels

Site number	District	Place of sample collection	Oil yield (%)
1	Chikkamagalur	Sringeri-1	77.25
2		Sringeri-2	73.17
3	Shivamogga	Sagara	79.46
4		Megaravalli-1	78.54
5		Megaravalli-2	77.87
6		Ikkeri-2	78.88
7		Ikkeri-1	66.65
8		Heggodu	73.52
9	Kodagu	Tanimani	63.30
10		Sampaje	65.73
11	Bengaluru	GKVK	74.78
12		Lalbagh	79.39
		S.Em ±	0.23
		CD @ 5%	0.66

Higher temperatures at fruit development also seems to have role in improved oil content and the amount of saturated fatty acids. In contrast, higher mean annual rainfalls and lower seasonal temperatures have induced lower oil contents in argan seed oil (Aabd *et al*., 2013) [1]. These findings support the present research that oil content is mainly affected by environment conditions as compared to the genetic makeup. The present study also recorded highest coefficient of variation for seed oil content suggesting that the provenance with higher oil content will have greater significance for the selection and development of high oil yielding trees for biodiesel production.

Chemical properties of Mesua oil

The quality of oil is expressed in terms of the fuel properties such as the acid value, iodine value, saponification value and other properties of *Mesua* oil. The acid value, iodine value, saponification value in the present study varied from 10.69 to 24.70 mg KOH/g, 76.29 to 109.41 gI_2/100 g, 178.16 to 236.29 mg KOH/g. Among the different locations, Tanimani of Kodagu district was recorded the highest acid value (24.70 mg KOH/g) and the lowest acid value (10.69 mg KOH/g) was recorded in Sringeri-2 of Chikkamagalur, Sampaje recorded the highest saponification value (236.29 mg KOH/g) and the least saponification value (178.16 mg KOH/g) was recorded in Sringeri-2 (Table 2).

Table 2: Chemical properties of *Mesua ferrea* oil

District	Place of sample collection	Acid value (mg KOH/g)	Iodine value (gI_2/100 g)	Saponification value (mg KOH/g)
Chikkamagalur	Sringeri-1	17.44	76.29	184.50
	Sringeri-2	10.69	84.71	178.16
Shivamogga	Sagara	20.04	79.52	219.47
	Megaravalli-1	16.63	109.41	210.70
	Megaravalli-2	18.33	96.50	211.82
	Ikkeri-1	22.44	76.75	208.46
	Ikkeri-2	11.40	86.53	208.43
	Heggodu	13.31	89.10	219.86
Kodagu	Tanimani	24.70	97.13	231.71
	Sampaje	23.87	94.42	236.29
Bengaluru	GKVK	20.60	96.42	189.61
	Lalbagh	10.71	99.70	227.03
S.Em ±		0.17	1.47	2.64
CD @ 5%		0.51	4.29	7.71

Earlier studies on *Mesua ferrea* L. with regard to acid value varied from 9.64 to 11.87 mg KOH/g for different locations of Bangladesh (Sayeed *et al*., 2004) [33]. Low acid value indicated single stage process for biodiesel production. If the acid values are more than 3 mg KOH/g it requires pre-treatment of oil prior to biodiesel production (Kumar *et al*., 2013) [24]. The iodine value of *Mesua ferrea* oil was found below 120 gI_2/100 g suggesting that these oils are suitable for biodiesel production. Similar results also found with research conducted by Sayeed *et al.* (2004) [33] in different locations of Bangladesh. Azam *et al*. (2005) [6] have reported that the saponification value of *M. ferrea* was 201 mg KOH/g and in another study the saponification value for *M. ferrea* L. oil varied from 193.03 to 206.40 mg KOH/g (Sayeed *et al*., 2004) [33]. These studies are in confirmation with the results obtained in the present study. The variations in the saponification values may be due to variations in the fatty acid profile. However, the effect of environmental factors cannot be ruled out.

Physical properties of Mesua oil

The kinematic viscosity is the resistance offered to the flow of a fluid under gravity and is determined by measuring the amount of time taken for a given quantity of oil to pass through the orifice of a specified size. The oil from Megaravalli-1 was more viscous (47.44 mm^2/s) and Sagara recorded low viscosity (42.52 mm^2/s). The viscosity of *M. ferrea* in Chikkamagalur, Shivamogga, Kodagu and Bengaluru districts varied from 45.84 to 45.87 mm^2/s, 42.52 to 47.44 mm^2/s, 43.73 to 46.87 mm^2/s and 44.21 to 45.14 mm^2/s, respectively (Table 3). The highest viscosity of *M. ferrea* L. oil (47.44 mm^2/s) was significantly high compared to the values obtained from the previous studies. Bora *et al*. (2014) [9] have reported a viscosity of 26.20 mm^2/s. Similar findings have also been presented by Bora *et al*. (2016) [10] in *Mesua*. These variations in the viscosity could be due to the varied levels of fatty acid composition and other constituents in the oil. Since, the viscosity of oil was very high, it cannot be used in engines directly. The viscosity of oil needs to be reduced by the techniques like transesterification (Kumar *et al*., 2013) [24].

The calorific value (the heat of combustion) is the amount of heat energy released by the combustion of unit weight of fuel. The calorific value varied from 38.85 to 39.28 MJ/kg (Table 3). Among the locations Sringeri-2 recorded the highest calorific value (39.28 MJ/kg) and the least calorific value was recorded in Sampaje (38.85 MJ/kg). The calorific value was significantly influenced by different locations. Devi *et al*. (2018) [12] reported a calorific value of 39.56 MJ/kg in Mesua, the results in the present investigation were in good agreement with the previous studies. The density of oil is the ratio of the mass of oil to its volume. The density of *M. ferrea* L. oil varied significantly as influenced by different locations. The density varied from 916.90 to 930.70 kg/m^3 (Table 3). Tanimani recorded more density (930.70 kg/m^3) and Sringeri-1 recorded the least density of 916.90 kg/m^3. The results obtained in the present study for Mesua was in good agreement with the previous study (Bora *et al*., 2014) [9] who reported 930.0 kg/m^3.

Table 3: Physical properties of *Mesua ferrea* L. oil

District	Place of sample collection	Calorific value (MJ/kg)	Viscosity (mm^2/s)	Density (kg/m^3)
Chikkamagalur	Sringeri-1	39.11	45.87	916.90
	Sringeri-2	39.28	45.84	917.90
Shivamogga	Sagara	39.07	42.52	918.20
	Megaravalli-1	38.98	47.44	926.50
	Megaravalli-2	38.92	43.23	923.70
	Ikkeri-1	38.95	46.13	920.50
	Ikkeri-2	39.21	45.79	920.60
	Heggodu	39.08	45.05	920.40
Kodagu	Tanimani	38.93	46.87	930.70
	Sampaje	38.85	43.73	925.20
Bengaluru	GKVK	38.96	45.14	919.50
	Lalbagh	39.16	44.21	917.60
S.Em ±		0.016	0.006	0.057
CD @ 5%		0.048	0.017	0.168

Fatty acid profile composition of *Mesua ferrea* L. oil

The quality of oil is the function of fatty acid composition. The palmitic, stearic, oleic, linoleic, linolenic and arachadic fatty acid compositions were found to be statistically significant. The result shown in table 4, revealed that the major fatty acid was oleic acid in a concentration range of 45.25-52.32 percent, followed by palmitic acid with 16.29-20.43 percent, linoleic acid with 15.54-28.43 percent, stearic acid with 7.34-14.93 percent, arachidic acid with a range of 0.50-1.32 percent and linolenic acid with a range of 0.33-1.16 percent. The above findings were in conformity with the previous researchers (Bora *et al*., 2014; Kushwah *et al*., 2008) [9, 25].

Table 4: Fatty acid methyl esters profile of *M. ferrea* oil

District	Location of sample	Palmitic acid (C_{16}:0) wt%	Steric acid (C_{18}:0) wt%	Oleic acid (C_{18}:1) wt%	Linoleic acid (C_{18}:2) wt%	Arachadic acid (C_{20}:0) wt%	Linolenic acid (C_{18}:3) wt%
Chikkamagalur	Sringeri-1	16.63	11.82	51.64	18.62	0.75	0.58
	Sringeri-2	19.36	14.75	47.38	18.26	0.63	0.33
Shivamogga	Sagara	18.57	14.93	45.88	17.28	0.83	1.16
	Megravalli-1	17.49	13.28	49.38	19.38	0.53	0.89
	Megravalli-2	17.90	8.89	46.47	21.86	0.93	0.69
	Ikkeri-1	17.17	10.32	52.32	19.16	0.73	0.43
	Ikkeri-2	19.52	10.02	45.79	23.30	0.69	0.52
	Heggodu	20.43	9.55	45.94	22.68	0.65	0.55
Kodagu	Tanimani	16.29	8.05	50.51	22.83	1.32	0.62
	Sampaje	17.60	8.65	50.71	22.80	0.62	0.73
Bengaluru	GKVK	17.88	7.34	45.25	28.43	0.55	0.65
	Lalbagh	20.24	10.04	52.80	15.54	0.50	0.79
S.Em ±		0.13	0.09	1.09	0.16	0.02	0.02
CD @ 5%		0.40	0.26	3.19	0.47	0.06	0.07

Comparison of fatty acid profiles of *Mesua ferrea* L. oil with various non-edible oils

The fatty acid composition of *Mesua ferrea* L. oil has been compared with the other non-edible oils like pongamia and neem (Table 5). The saturated fatty acids of *M. ferrea* oil were comparable (C_{16}:0 16.29-20.43%, C_{18}:0 7.34 -14.90%) with saturated fatty acids of mahua oil (C_{16}:0 16-28.20%, C_{18}:0 20-25.10%) (Ghadge and Raheman, 2006) [14]. In unsaturated fatty acids, the linoleic acid of *M. ferrea* L. oil (C_{18}:2 15.54-28.43%) was comparable to pongamia oil (C_{18}:2-10.8-18.3%) (Karmee and Chadha, 2005) [21]. The composition of *M. ferrea* oil revealed higher oleic acid. Similar findings are also reported in other oils *viz*., pongamia, mahua in the previous studies (Karmee and Chadha, 2005; Ghadge and Raheman, 2006; Azam *et al*., 2005) [21, 14, 6]. The fatty acid composition of *M. ferrea* oil was in good agreement with the previous studies (Kushwah *et al*., 2008) [25]. These biochemical properties of *M. ferrea* oil were improved by transesterification. The results showed that *M. ferrea* is a potential source of oil and hence the seeds could be a feasible option for biodiesel production.

Table 5: Comparison of fatty acid profiles of *M. ferrea* L. oil with various non-edible oils

Fatty acids	*M. ferrea* L.[a]	*M. ferrea* L.[b]	Pongamia[c]	Mahua[d]
Palmitic acid (C_{16}:0)	16.29-20.43	10.87	3.70-7.90	16-28.20
Stearic acid (C_{18}:0)	7.34-14.90	14.19	2.40-8.00	20-25.10
Oleic acid (C_{18}:1)	45.25-52.32	55.93	44.50-71.30	41-51
Linoleic acid (C_{18}:2)	15.54-28.43	13.68	10.80-18.30	8.9-13.70
Linolenic acid (C_{18}:3)	0.33-1.16	3.39	-	-
Arachidic acid (C_{20}:0)	0.50-1.32	2.92	2.20-4.70	0-3.30

[a] Present study- Range of fatty acid composition in different provenance; [b] Kushwah *et al*. (2008) [25]; [c] Karmee and Chadha (2005) [21]; [d] Ghadge and Raheman (2006) [14].

Oleic to linoleic acid ratio

The oleic/linoleic acid ratio indicated stability of the oil. It was found to be significantly influenced by different provenances and varied from 1.59 to 3.39 in the selected locations (Table 6). Among the different locations, Lalbagh had high O/L ratio (3.39) and the least O/L ratio was observed in GKVK (1.59). The higher O/L ratio indicated higher stability. The above findings are in conformity with the previous studies (Mukta *et al*., 2009; Panpraneecharoen *et al*., 2014) [31].

Biodiesel production yield

Biodiesel production was carried out by using samples collected from Sringeri location and analyzed for its quality parameters and yield. The estimation of yield of biodiesel can be done after transesterification process. The methyl ester yield relative to the initial sample weight of Mesua oil was calculated. Biodiesel yield obtained from the present study was 96.70 percent**.** Mamilla *et al*. (2012) transesterified palm oil using NaOH as catalyst and methanol to form biodiesel. The conversion was to the extent of 92 percent at 60 ºC. The quality parameters obtained from the present investigation was within the standard limits prescribed by ASTM.

Table 6: Oleic to linoleic acid ratio of *M. ferrea* oil

District	Location of sample	O/L ratio
Chikkamagalur	Sringeri-1	2.77
	Sringeri-2	2.59
Shivamogga	Sagara	2.65
	Megravalli-1	2.55
	Megravalli-2	2.13
	Hikkeri-1	2.73
	Hikkeri-2	1.97
	Heggodu	2.03
Kodagu	Tanimani	2.22
	Sampaje	2.21
Bengaluru	GKVK	1.59
	Lalbagh	3.39
S.Em ±		0.03
CD @ 5%		0.10

Properties of *Mesua ferrea* L. biodiesel

The quality of *Mesua ferrea* L. biodiesel and mesua oil (Sringeri-2 sample), which is expressed in terms of biochemical properties are given in table 7. The properties of biodiesel compared with standard biodiesel and various non-edible oil biodiesels are presented in the table 8. The comparison of *Mesua ferrea* L. biodiesel with International standards *viz*., American Standards (ASTM D6751). Indian Standards (BIS/ISO 15607) are given in table 9 and properties of *M. ferrea* L. biodiesel with various biodiesels are given in Table 10. The transesterification process is used to convert the triglycerides to biodiesel using NaOH as catalyst. There was a significant improvement in the properties of oil by transesterification process *viz*., acid value, iodine value, viscosity, density and calorific value.

The acid value of *M. ferrea* L. biodiesel (0.45 mg KOH/g) was found to be lower than the acid value of *Mesua ferrea* L. oil (10.69 mg KOH/g). The variation in the acid value of oil was due to the transesterification process. Bora *et al*. (2018) [8] have reported that the acid value of mesua oil reduced from 12.34 mg KOH/g to 0.35 mg KOH/g after transesterification process. Similar findings are also reported by several workers in mesua (Chakraborthy *el al*., 2009; Bora *et al*., 2014 and Kushwah *et al*., 2008) [25, 9]. The acid value was within the specifications provided by ASTM and BIS (0.5 mg KOH/g).

Table 7: Properties of *Mesua ferrea* L. biodiesel and oil (Sringeri-2 sample)

Parameters	Biodiesel	Mesua oil
Acid value (mg KOH/g)	0.45	10.69
Iodine value (gI_2/100 g)	63.33	84.71
Saponification value	242.88	178.16
Viscosity (mm^2/s) @ 40 °C	4.32	39.28
Density (kg/m^3)	879.70	45.84
Calorific value (MJ/kg)	39.37	917.90
FAME (%)	96.70	-

The iodine value is the indication of the total number of double bonds (*i.e*, level of saturation) in a mixture of molecules. It helps to indicate the oxidation stability and provide information about the fuel's tendency to form sludge, affect the lubricant quality and may cause corrosion. Lower oxidation stability, presence of polyunsaturated fatty acids that may polymerize at higher temperatures and form sludge affect the performance of engine are the representation of higher iodine value.

There was a reduction in iodine value of *M. ferrea* L. oil to biodiesel from 84.71 gI_2/100 g to 63.33 gI_2/100 g by transesterification process. This was in comparison with the results, where there was a reduction in iodine values of rapeseed and soybean oils from 109 gI_2/100 g, 106 gI_2/100 g to 96 gI_2/100 g and 103 gI_2/100 g respectively by transesterification process (Jordanov *et al*., 2007). The reduction in the iodine number may be due to changes in the molecular structure from triglycerides to fatty acid methyl esters (Jordanov *et al*., 2007). The maximum iodine value specified by BIS is 120 gI_2/100 g of the sample. The results are in confirmation with the standards specification.

The kinematic viscosity of *M. ferrea* L. biodiesel was 4.32 mm^2/s, which falls in the range specified by ASTM (1.9-6.0 mm^2/s) and BIS (2.5-6.0 mm^2/s) standards indicating the suitability of oil for use as biodiesel. There was a significant reduction in the viscosity of *M. ferrea* L. oil from 45.84 to 4.32 mm^2/s at 40 ºC by transesterification process. The high viscosity of oil was due to the presence of higher molecular weight molecules such as triglycerides. The earlier studies on the viscosity of *M. ferrea* L. biodiesel revealed 4.76 mm^2/s at 40 ºC (Devi *et al*., 2018) [12], which was on par with the present study (4.32 mm^2/s at 40 ºC). Similar findings have also been reported by Chakraborthy *et al*. (2009) and Kushwah *et al*. (2008) [25] in Mesua. The variations in the viscosity could be due to the environmental factors. The results of the present study are also in confirmation with the results reported in previous studies suggesting that it can be safely used as biodiesel.

Table 8: Properties of *M. ferrea* L. biodiesel with various biodiesels

Parameters	Biodiesel[a]	Pongamia[b]	Jatropha[b]	Diesel[c]
Acid value (mg KOH/g)	0.45	0.36	0.32	0.02
Iodine value (gI_2/100 g)	63.33	71.30	76.70	-
Viscosity (mm^2/s) @ 40 °C	4.20	5.4-5.6	4.8-4.9	3.12
Density (kg/m^3)	879	884-886	878-880	840
FAME (%)	96.70	99.70	99.70	-
Calorific value (MJ/kg)	39.37	36.00	35.60	44.96

[a] Present study; [b] Kumar *et al*. (2013) [24], [c] Ikwuagwu *et al*. (2000).

The density of *Mesua* L. biodiesel was found to be 879. 70 kg/m^3. There was a reduction in the density of *M. ferrea*. oil from 917.90 to 879.70 kg/m^3 by transesterification process. The higher densities of *M. ferrea* oil as compared to the standard diesel could be attributed to higher molecular weights of triglyceride molecules present in them. Usually, higher density of biodiesel is observed than that of fossil diesel fuel, with specific values depending on the composition of fatty acids and purity of biodiesel. The biodiesel density can be significantly affected by adulteration or contamination. Slightly higher density of the oil is the indication of contamination by some unwanted compounds. The density of *M. ferrea* biodiesel was found to be on par with the previous studies which showed a density of 898.0 kg/m^3 (Chakraborthy *et al*., 2009). The slight variation may be due to changes in the environmental factors. The standard specification for biodiesel as per BIS is 860-900 Kg/m^3. The density of *M. ferrea* biodiesel was found to be within the BIS specification for density.

The calorific value of *M. ferrea* biodiesel (39.37 MJ/kg) was observed to be higher than the calorific value of *M. ferrea* oil (39.28 MJ/kg) due to transesterification process. Chakraborthy *et al*. (2009) reported 42.23 MJ/kg calorific value for *M. ferrea* L. biodiesel, which was comparable with that of the present study. Alnuami *et al*. (2014) reported calorific value for jatropha, soya bean and waste cooking oil biodiesel as 39.20 MJ/kg, 33.50 MJ/kg and 32.90 MJ/kg respectively. The results are comparable to that of the previous studies. The calorific value of biodiesel was slightly less than that of diesel (Ikwuagwu *et al*., 2000). The small variations in the calorific value could be due to the different sources of raw materials that were used for biodiesel production.

Table 9: Properties of *Mesua ferrea* L. biodiesel with standards

Parameters	***M. ferrea* L.**[a]	ASTM D6751	BIS (ISO 15607)
Acid value (mg KOH/g)	0.45	0.5 Max	0.5 Max
Iodine value (gI_2/100 g)	63.33	-	120 Max
Viscosity (mm^2/s)	4.32	1.9-6.0	2.5-6.0
Density (Kg/m^3)	878	-	860-900
FAME (%)	96.70	-	96.5 Min
Calorific value (MJ/Kg)	39.56	-	-

[a] Present study.

Table 10: Properties of *M. ferrea* L. biodiesel with various biodiesels

Parameters	Biodiesel[a]	Pongamia[b]	Jatropha[b]	Diesel[c]	ASTM D6751	BIS (ISO 15607)
Acid value (mg KOH/g)	0.45	0.36	0.32	0.02	0.5 Max	0.5 Max
Iodine value (gI_2/100 g)	63.33	71.30	76.70	-	-	120 Max
Viscosity (mm^2/s) @ 40 °C	4.20	5.4-5.6	4.8-4.9	3.12	1.9-6.0	2.5-6.0
Density (kg/m^3)	879.70	884-886	878-880	840	-	860-900
FAME (%)	96.70	99.70	99.70	-	-	96.5 Min
Calorific value (MJ/kg)	39.37	36.00	35.60	44.96	-	-

[a] Present study; [b] Kumar *et al*. (2013) [24], [c] Ikwuagwu *et al*. (2000).

FAME (Ester content)

FAME is an indicator of fuel quality. The amount of FAME in the fuel is indicated by the fuel ester content. A low amount of esters in biodiesel sample may indicate the unreacted compounds remained in the fuel. Low levels of esters may also indicate contamination with non-FAME compounds. The FAME content of *M. ferrea* biodiesel was observed to be 96.70 percent. The FAME content reported for pongamia, jatropha and waste cooking biodiesel was 99.70 percent, 99.70 percent and 99.63 percent respectively (Kumar *et al*., 2013) [24].

Conclusion

In the present study, *Mesua ferrea* under different provenances were evaluated for various parameters such as oil yield, oil quality, biodiesel quality. The oil percentage of *Mesua ferrea* was significantly influenced by different locations. The highest acid value was observed in Tanimani of Kodagu, iodine value in Megaravalli-1 of Shivamogga, Sampaje of Kodagu recorded the highest saponification value. The physical parameters of *Mesua ferrea* oil viscosity in Megaravalli-1, density in Tanimani of Kodagu and calorific value found highest in Sringeri of Chikkamagalur district. The fatty acid profile was found highest in Shivamogga and Kodagu districts. Domination of unsaturated fatty acids were observed in the fatty acid profile of *Mesua ferrea* oil and the presence of oleic acid indicated the good sign for proceeding oil for biodiesel from *Mesua ferrea*. The oil and biodiesel properties of *Mesua ferrea* within the international standards such as ASTM and BIS.

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