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Salvia farinacea seed oil, a potential biomass for synthesis of biodiesel: A critical analysis of its fuel properties.

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Abstract: The non-renewable energy sources such as coal, petrol decreasing day by day and their price also increasing. In this fast depleting era of fossil fuels biodiesel produced from nonedible seed oils plays an important role. In the present work the biodiesel is produced from nonedible seed oil Salvia farinacea. In this work from *Salvia farinacea seeds* oil is extracted and fatty acid components are analysed by GC-FID. Physicochemical properties of the oil are determined by AOAC standard methods. The oil is transesterified in presence of KOH catalyst. Fuel parameters like iodine number, cetane number, heating values, kinematic viscosity, flash point, cold flow properties are determined and are compared with already existing biodiesels and petrodiesel. The emission components like CO, CO_2, NO_x, HC and Smoke opacity are analysed using four stroke one cylinder engine. This work reveals that *Salvia farinacea* seed oil is a potential renewable feedstock for the production of biodiesel.

Keywords: Salvia farinacea, Non-edible seed oil, Transesterification, Biodiesel properties, Fuel properties, Renewable energy.

1. Introduction

Fossil fuels such as coal and natural gas take centuries to form naturally and the crude oil takes millions of years to form. Worldwide burning up of these non-renewable energy sources is rising at its peak; meanwhile, the environmental pollution is escalating at an alarming rate. These non-renewable sources on combustion emit carbon monoxide (CO), nitrogen oxides (NO_x), sulphur dioxide (SO_2) and hydrocarbons (HCs). Even suspended particulate emissions are continuously increasing. The combination of NO_x and HC forms smog and can have harmful effect not only on human beings or animal kingdom but also on plant growth. These emissions can cause falling and bleaching of leaves thereby reducing photosynthesis. To preserve the fossil fuels and to reduce the environmental pollution, researchers focused on development of viable, sustainable, green and renewable energy sources (Sharma, Singh and Upadhyay 2008; Heywood 1998; Ramadhas, Jayaraj and Muraleedharan 2005; Rao P V 2011.).

Vegetable oil is basically triglyceride moiety and has become popular due to some inherent advantages of being sustainable, biodegradable, non-toxic, eco-friendly, renewable, etc. The vegetable oil not only has industrial importance such as production of cosmetics, medicines, food, polymers, drugs, etc., researchers found that it acts as an alternative and sustainable energy source for diesel (Sharma, Singh and Upadhyay 2008; Katagi, Munnolli and Hosamani 2011). However, vegetable oil cannot be used directly into compressed engine because of its high viscosity (Rao P V 2011; Demirbas A 2003). Methods like, blending, catalytic cracking, pyrolysis, micro-emulsion and transesterification are employed to reduce the viscosity of oil. Transesterification became popular and effective among all these methods. It is the process where oil is mixed with alcohol (methanol or ethanol) in suitable ratio in presence of catalyst (acid or base) at a temperature of 55°C to 60°C to produce fatty acid methyl esters (FAMEs) or fatty acid ethyl esters (FAEEs). The mixture of FAMEs or FAEEs synthesized from vegetable oils is termed as "Biodiesel" (Ramadhas, Jayaraj and Muraleedharan 2005; Rao P V 2011; Katagi, Munnolli and Hosamani 2011; Demirbas A 2003; Ma and Hanna 1999).

Biodiesel can be used as alternative to diesel or blended with diesel at appropriate ratios. Biodiesel has gained much more importance in depleting era of fossil fuels. Biodiesel contains C_{12}-C_{22} carbon chains, whereas, conventional diesel contains C_{10}-C_{21} carbon chains. Initially, biodiesel was prepared from edible oils like sunflower, soybean, palm, and rape seed oil. To avoid escalating prices of edible vegetable oils, non-edible vegetable oils are now being used for the synthesis of biodiesel (Azam, Waris and Nahar 2005; Marchetti, Miguel and Errazu 2007; Srinivas and Satyarthi 2012; Joshi and Pegg 2007).

Biodiesel is clean burning fuel with no sulphur emissions and is environment friendly. Although, its heat of combustion is slightly lower than that of the petrodiesel, there is no need for engine adjustment and there is no loss in efficiency. The production of biodiesel from vegetable oil provides numerous regional and national economic benefits (Zhang, Stanciulescu and Ikura 2009).

1.1. Salvia farinacea seed

a. Flower b. Seeds

Fig 1: *Salvia farinacea* flower and seeds.

Salvia farinacea, also known as Mealy cup Blue Sage, is herbaceous perennial. It is native to New Mexico and Texas; its native habitat includes prairies and the edges of woodlands. Its names "Mealy" and "*farinacea*" both refer to the way the sepals (the parts around the flower petals) look, which is as if they are dusted with flour or meal and is caused by tiny hairs on them. Mealy cup Blue Sage grows 18-36 inches tall and 18-36 inches wide. Its leaves are usually about 3 inches long, grey-green to green, and lance-shaped. Mealy cup Blue Sage blooms from April until frost with a bloom peak in April and one more time in late September or October. Flower spikes with many florets are held above the foliage. The flowers range from white to violet-blue and are 2/3–3/4 inches long, with two stamens and a pistil (Figure 1). Seeds (Figure 1) may be collected following flowering (Edward and Teresa 1999; Jayashree 1983).

2. Materials and methods

2.1. Salvia farinacea seeds

The fresh seeds are collected from Waynadu forest area, Kerala state, India. The seeds are selected avoiding damaged seeds. The seeds are deshelled and dried at a temperature range of 110-115^{o}C for 20 minutes in hot air oven.

2.2. Oil extraction

The dried *Salvia farinacea seeds* are ground, powdered and the oil content extracted with light petroleum ether (B.P. 40-60^{o}C) in a soxhlet extractor for 24 hrs. The organic extract is filtered and dried over anhydrous Na_2SO_4. Petroleum ether is removed using vacuum. The % oil for dry seeds is calculated using the following equation.

$$\% Oil = (\text{Weight of oil} \times 100)/Weight \text{ of sample seeds} \tag{1}$$

2.3. Fatty acid profile

The fatty acid composition of seed oil is determined using the Agilent Gas Chromatograph by converting oil into fatty acid methyl esters. Agilent 7890/A gas chromatograph fitted with flame ionization detector (FID) is used for the determination of fatty acid composition of oil. HP-INNOWax polyethylene glycol 30 m × 0.320 mm × 0.25 µm capillary column is used for chromatographic analysis. The oven temperature is set to 210ºC for 40 min. Total run time is 40 min. 1µL of solution (Methyl ester + internal standard) is injected in GC. Methyl heptadecanoate (C17:0, 99% purity) is used as internal standard. Helium gas is used as carrier and the other gases like H_2 for flame, air for supporting the flame and N_2 for carrying ions up to detector near flame. FID temperature is set at 250ºC. The fatty acid composition is reported as relative percentage of total peak area. The fatty acid profile obtained from GC-FID analysis (Figure 2) is compared with literature (Jayashree 1983) and is shown in Table 1.

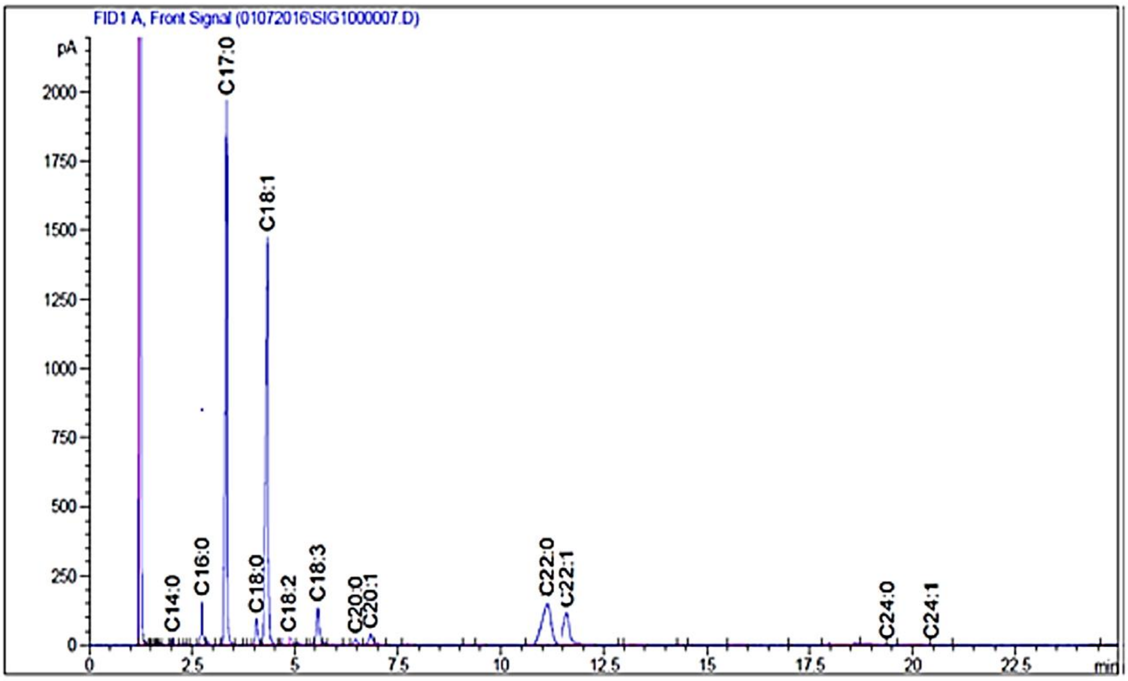


Fig 2: GC-FID of mixture of *Salvia farinacea* methyl ester

Table 1: Comparison of the fatty acid profile of *Salvia farinacea* seed oil (SFSO) obtained from GC-FID analysis with the literature.

Component fatty acids in the seed oil	% Fatty acid composition of *SFSO*	
	Present work	Literature (Jayashree 1983)
Lauric acid (12:0)	ND	2.3
Myristic acid (14:0)	2.28	2.3
Palmitic acid (16:0)	2.38	2.6
Stearic acid (18:0)	2.77	2.7
Oleic acid (18:1)	83.21	82.2
Linoleic acid (18:2)	2.08	1.9
Linolenic acid (18:3)	1.19	ND
Arachidic acid (20:0)	1.09	1.1
Gadoleic acid (20:1)	0.30	ND
Behenic acid (22:0)	4.66	4.9
Erucic acid (22:1)	0.01	ND
Lignoceric acid (24:0)	0.03	ND
Nervonic acid (24:1)	0.01	ND

Note: ND - Not detected

2.4. Analysis of seed oil

Physicochemical properties of the oil like density, refractive index, iodine value, saponification value, acid value, free fatty acid content and ester value of seed oil under investigation are determined according to AOAC official method of oil analysis (Washington D C 1990). The physicochemical properties of the oil are shown in Table 2.

Table 2: The physicochemical properties of the *Salvia farinacea* seed oil

Parameter	***Salvia farinacea* seed oil (SFSO)**
Solvent used for extraction	Petroleum ether (BP 40-60°C)
% Oil	26.9
Molecular weight (MW) of oil (g/mol)	889.32
Colour of the oil	Dark brown
Physical state of the oil (at room temp)	Liquid
Acid value (AV) in mg KOH/g	2.007
Free fatty acids (FFA) in %	1.01
Saponification value (SV) in mg KOH/g	202.43
Iodine value (IV) in mg I_2 /100 g oil	80.43
Kinematic viscosity (KV) in mm^2/s of oil	48.0
Density (d_{oil}) in g/mL	0.920
Refractive index (RI) at 30°C	1.480
Total saturated fatty acids (% TSFAs)	13.2
Total unsaturated fatty acids (% TUSFAs)	86.8
Degree of unsaturation (DU)	91.11

2.5. Transesterification

The seed oil of *Salvia farinacea* is subjected to base catalysed transesterification wherein 250 mL of seed oil is mixed with methanol in the molar ratio of 1:6. The free fatty acid content was 1.01%, so a strong homogeneous base catalyst, KOH (1%) is used to enhance the rate of reaction. The mixture is refluxed for one hour at 55°C to 60°C on a rota mantle. The mixture is transferred to separating funnel and allowed to stand for 6-7 hours. Two distinct liquid phases are formed; the crude ester phase is formed at the top and the glycerol phase at the bottom. The upper layer of mixture of *Salvia farinacea* methyl esters (SFME) layer is separated and washed with warm deionised water repeatedly to remove any soap content, entrapped methanol and unreacted fatty acids. Mixture of FAMEs obtained is heated on heating mantle at 110-115°C to remove water and dried over anhydrous sodium sulphate. Magnetic bead is used in the mixture of FAMEs container and the solution is kept agitated for proper removal of water. The yield of SFME obtained is 90.0 % by volume.

Temperature between 55°C and 60°C is observed to be the optimum temperature for the Tranesterification. One hour reaction time resulted in completion of the reaction with higher conversion efficiency to FAMEs.

2.6. Spectroscopic support

2.6.1. FTIR analysis of Salvia farinacea seed oil (SFSO) and Salvia farinacea methyl ester (SFME)

The Fourier Transform Infrared (FTIR) spectra of seed oil and SFME are obtained using FTIR spectrophotometer (measured within a range of 400–4000 cm^{-1}). Seed oil and its fatty acid methyl esters are examined by IR spectral studies. Comparison of FTIR spectra of SFSO and SFME is made in below in Figure 3.

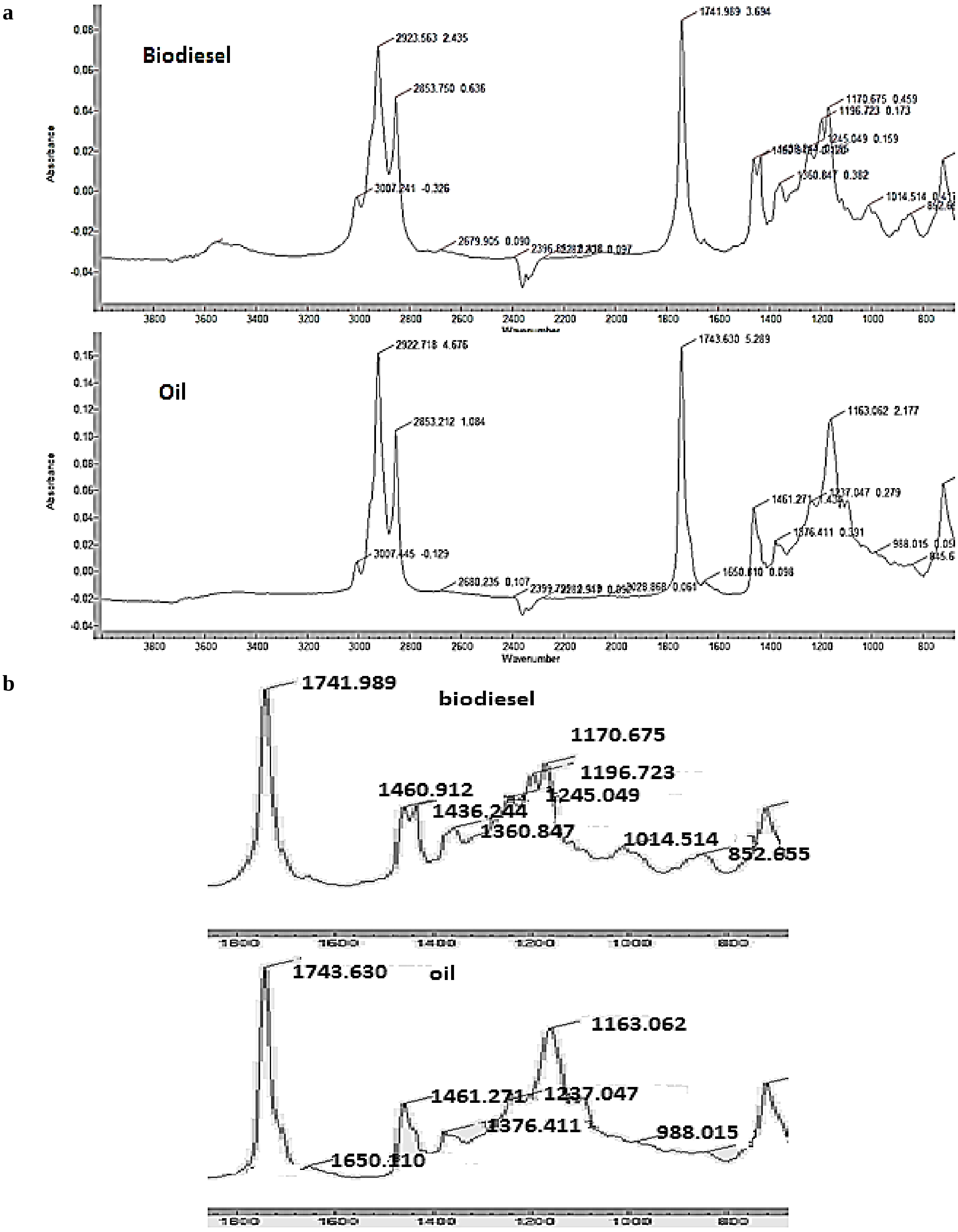


Fig 3: a) FTIR spectra of SFME and SFSO, b) Enlarged picture of region: 1800 cm^{-1} to 800 cm^{-1}.

Table 3: Comparison of FTIR spectra of SFSO and SFME.

Absorption bands	SFSO (in cm^{-1})	SFME (in cm^{-1})
C=O (ester carbonyl)	1744.174	1741.989
$O-CH_2$	1376.678	-
C-CO-O-	1237.204	1245.048
$-(CO)-O-CH_3$	-	1436.244
-C-O- (in triglyceride)	1160.856	-
$-C-O-CH_3$	-	1170.675 and 1196.723
-C-O (in ester)	-	1196.723
$-CH_2$(wagging)	967.817	-

The peak analysis of both SFSO and SFME shows significant differences. A characteristic absorption peak, especially C=O ester carbonyl group at 1744.174 cm^{-1} in SFSO spectrum and 1741.989 cm^{-1} in SFME spectrum confirms the conversion of oil to FAMEs. The main spectral region that allows for chemical discrimination between SFSO and SFME is 1500-900 cm^{-1}, known as "finger print" region. The characteristic peak at 1436.244 cm^{-1} corresponds to the asymmetric stretching of $-(CO)-O-CH_3$ present in the spectrum of SFME which is absent in SFSO spectrum. The peak at 1376.678 cm^{-1} can be attributed to the glycerol group $O-CH_2$ (mono, di and triglycerides), which is present in the SFSO spectrum and is absent in the SFME spectrum. The strong, broad signal at 1160.856 cm^{-1} in SFSO will separate into two concrete signals at 1170.675 cm^{-1} and 1196.723 cm^{-1}. The stretching of C-O, represented by absorbance at 1196.723 cm^{-1}, is typical of biodiesel. The stretching of C-CO-O- is represented by absorption at 1237.204 cm^{-1} and 1245.048 cm^{-1} in the spectra of SFSO and SFME respectively. The signal at 967.817 cm^{-1}, which represents CH_2 wagging frequency, is observed in SFSO spectrum and is absent in the SFME spectrum. This spectral analysis confirms the conversion of SFSO into SFME.

2.6.2 ^{1}H NMR analysis of SFSO and SFME.

^{1}H NMR analysis of SFSO and SFME are performed using Avan CE 300 MHz spectrometer. Deuterated chloroform ($CDCl_3$) and tetramethylsilane (TMS) are used as solvent and internal standard respectively.

^{1}H NMR spectrum of SFSO shows glyceridic protons at 4.2-4.3 ppm. In the proton NMR spectrum of SFME, a strong singlet at 3.4 ppm shows methyl ester formation. The significant difference between ^{1}H NMR spectrum of SFSO and that of SFME is the disappearance of glyceridic protons at 4.2-4.3 ppm and appearance of methyl ester protons at 3.6 ppm (Figure 4).

2.7. The instruments used for analysing fuel properties of the SFME

Petroleum instruments India private limited (ASTM D2500, ASTM D97) apparatus which is used for cloud point and pour point measurement. Saybolt viscometer (ASTM D88) is used for the determination of viscosity of SFSO and SFME. Viscosity is measured at 40°C. Cleveland open cup flash point apparatus (ASTM D92) is used for flash point determination. Petroleum Instruments India private limited made (ASTM D204) Bomb calorimeter is used to determine the higher heating value (HHV).

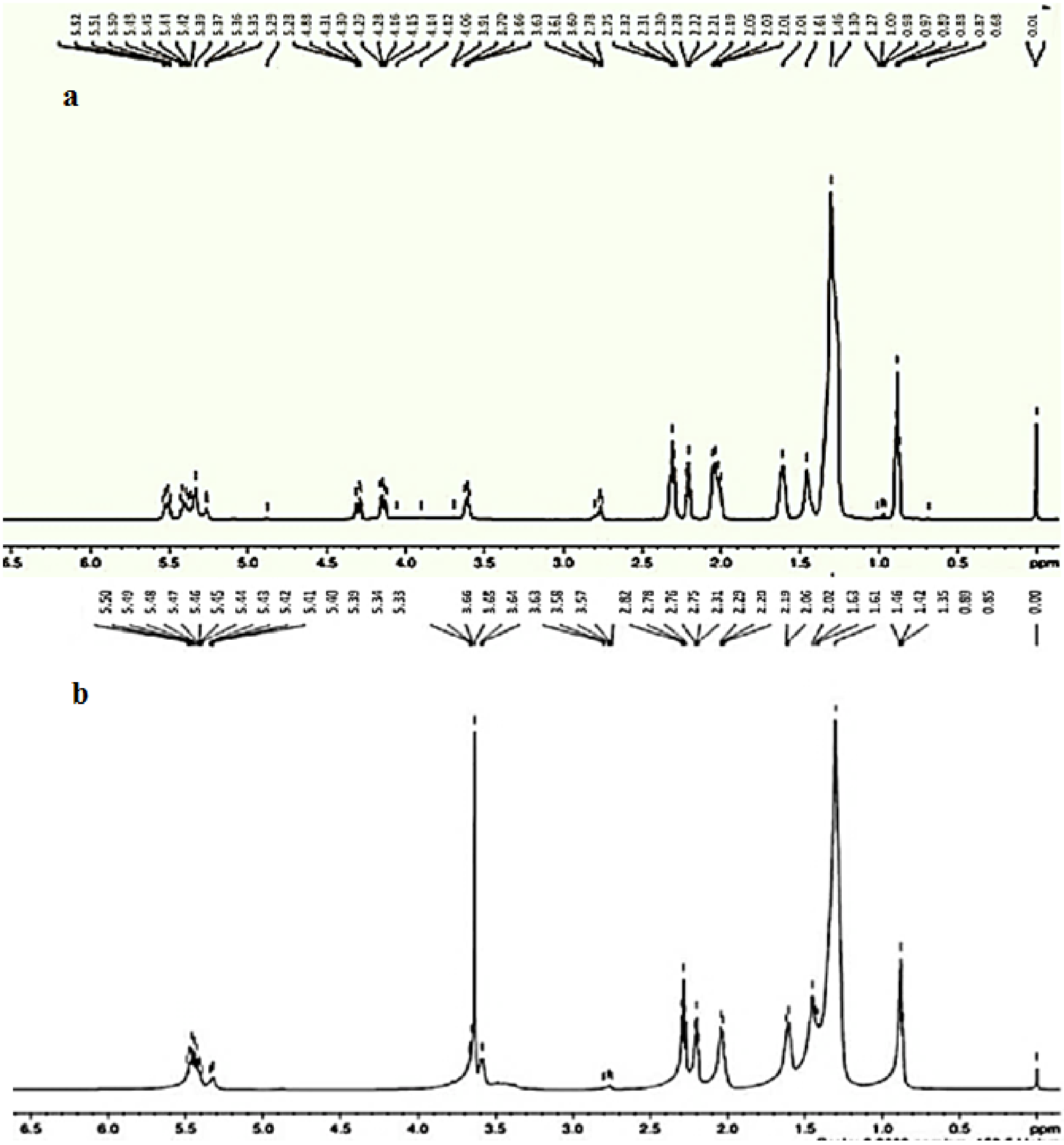


Fig 4: ^{1}H NMR of *SFSO* and SFME

2.8. Computational methods used to substantiate the biodiesel properties of SFME.

By deploying the mathematical models shown in Table 4, the biodiesel properties are assessed based on the component fatty acids in the *SFSO*.

Table 4. Mathematical models used to substantiate the fuel properties of SFSO.

Equation	**Denominations**	**Ref.**	**Eq No**
Molecular weight of oil: $MW_{oil} = 3MW_i + MW_{glycerol} - 3MW_{alcohol}$	where, MW_i = Molecular weight of ith fatty acid. $MW_{glycerol}$= Molecular weight of glycerol. $MW_{alcohol}$= Molecular weight of alcohol.	(Yebo and Samir Kumar 2016)	(2).
Saponification value: $SV = \sum (561.06 \times A_i)/MW_i$	where, A_i is the % of component ith component fatty acid, MW_i is the molecular mass of ith component	(Azam, Waris and Nahar 2005)	(3).
Iodine value: $IV = \sum (253.81 \times N_{db} \times A_i)/MW_i$	where, A_i is the % of component ith fatty acid, N_{db} is the number of double bonds, MW_i is the molecular mass of ith component	(Azam, Waris and Nahar 2005)	(4).
Density of SFME $\rho = 0.8463 + (4.9/M_i) + (0.0118 \times N_{db})$	where, M_i is the molecular weight of ith FAME, N_{db} is the number of double bonds.	(Luis Felipe, Javier Esteban and Alicia del 2012)	(5)
Cetane Number $CN = \sum CN_i W_i$	where, CN_i is the cetane number of ith FAME. W_i is the weight fraction of individual FAMEs.	(Su Y.C. 2011)	(6).
Higher heating value: $HHV = \sum HHV_i \times A_i/100$	where, HHV_i = HHV of individual pure fatty acid methyl ester and A_i is the % of ith component fatty acid methyl ester.	(Wanignon 2012)	(7).
***Lower heating value**:* $LHV = HHV - 221.199 \times H$ where, $H = \sum NH_i \times A_i/MW_i$	where, the second term is latent heat of steam condensation by burning 1 kg of fuel, H is % hydrogen. NH_i = number of hydrogen atoms in ith fatty acid methyl ester, MW_i is molecular weight of ith fatty acid methyl ester and A_i is the % of ith component fatty acid methyl ester.		(8).
Kinematic viscosity: $KV = (0.235 \times N_{wc}) - (0.468 \times N_{wdb})$	where, N_{wc} is the weighted average number of carbon atoms and N_{wdb} is the weighted average number of double bonds	(Su Y.C. 2011)	(9).
Flash point: $FP = 251.2 + (13.97 \times N_{wc}) - (0.1198 \times N_{wc}^2) - (19.9 \times N_{wdb})$	where, N_{wc} is the weighted average number of carbon atoms and N_{wdb} is the weighted average number of double bonds	(Carareto et.al, 2012)	(10).

Degree of unsaturation $DU = MUFA + (2 \times PUFA)$	where, MUFA is the percentage amount of monounsaturated fatty acids. PUFA is the percentge amount of polyunsaturated fatty acids	(Muhammad A.I. et. al 2013)	(11).
Cloud point $CP = -0.576 \times UFAME + 48.255$	UFAME: Percentage Content of total unsaturated FAMEs in biodiesel	(Su Y.C. 2011)	(12)
Pour point $PP = -0.626 \times UFAME + 45.594$	UFAME: Percentage content of total unsaturated FAMEs in biodiesel	(Su Y.C. 2011)	(13)

2.9 Emission performance of FAMEs of seed oil under investigation and its blends with petrodiesel

The experiments were conducted on direct injection, single cylinder four strokes Kirloskar diesel engine at different loads with different blend ratios of mixture of SFME and diesel. The load of the engine is varied from zero to rated load (0 to 18.3 kg). It is a water cooled engine with a rated power of 5.2 kW at 1500 rpm having bore 87.5mm and stroke 110mm,compression ratio of 17.5, injection pressure of 220 bar at 23˚Btdc injection timing. Diesel engine is connected to the eddy current dynamometer, a computer with the software called engine-soft, an AVL444 (5-gas analyzer) exhaust gas analyzer, AVL437 make smoke meter. Engine specifications are given in Table 5.

Table 5: Engine specifications

Make & model	Kirloskar Engine TV1
Bore & stroke	87.5 mm × 110 mm
Type of cooling	Water cooled
Speed	1500 rpm
Compression ratio	17.5:1
Number of cylinder	Single
Rated power	5.2 kW
Start of injection	23˚Btdc
Injection pressure	220 bar

3. Results and discussion

3.1 Fatty acid ester profile of Salvia farinacea seed oil (SFSO)

The percentage of seed oil obtained after extraction is found to be 26.9%. GC-FID analysis of SFME shows that, the seed oil contains higher amount of oleic acid (83.21%). Total saturated fatty acids (TSFAs) are lesser (13.2%) compared to total unsaturated fatty acids (TUSFAs) i.e., 86.8%. According to European standard EN14214, limitation for linolenic acid percentage in the seed oil is 12.0%. *Salvia farinacea* seed oil contains 1.19% of linolenic acid, which is within the range (Duarte and Maugeri 2014). The molecular weight (MW) of the seed oil is calculated based on % component fatty acids present in the seed oil and is found to be 889.32 g/mol (Yebo 2016).

3.2 Physicochemical properties of SFSO

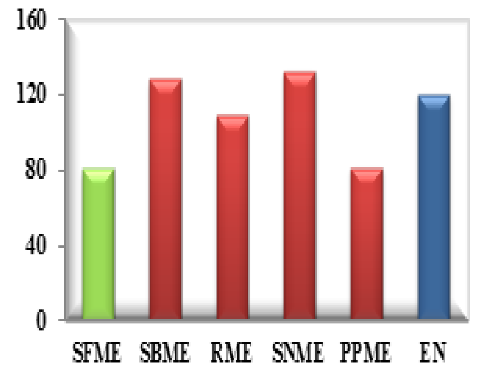
The SFSO is a dark brown coloured liquid at room temperature; with the possibility of chromophores present in the seed oil imparting the colour. Density of the seed oil is 0.920 g/mL at 30°C. The seed oil has high refractive index because it contains more of unsaturated fatty acids (Pandurangan, Murugesan and Gajivaradhan

2014; Ron Clavier 2007). Saponification value (SV) of the seed oil depends upon fatty acid composition and molecular weight of the seed oil. The experimentally determined SV of the seed oil is found to be 202.3 mg KOH/g of oil (Azam, Waris and Nahar 2005) and this is very close to the calculated value of 198.06 mg KOH/g equation mentioned in Table 4. Acid value is found to be 2.007 mg KOH/g of oil and free fatty acids is found to be 1.001%. Degree of unsaturation (Muhammad A.I. et al. 2013) is 91.11. The kinematic viscosity of SFSO is found to be 48 mm^2/s. The quality of biodiesel depends on many of the chemical and physical factors. Iodine value (IV) is one of the important parameter that determines the quality of the biodiesel produced and its storage stability. IV is direct measure of unsaturation in the seed oil. The experimentally determined IV of the seed oil is 80.43 mg I_2/ 100 g of oil (which is close to computed IV i.e., 81.98 mg I_2/ 100 g oil using equation mentioned in Table 4), which is within the range as per limitation laid by EN14214 i.e., 120 mg I_2/ 100 g oil. The IV of seed oil is compared with already existing biodiesel and EN 14214 and is shown in Fig. 5a. The seed oil contains higher amount of monounsaturated oleic acid (18:1) compared to polyunsaturated linoleic and linolenic acids (18:2, 18:3). As the number of double bonds within the ester increases, the storage stability decreases. This indicates that the SFME produced from *Salvia farinacea* seed oil is reasonably stable. It is confirmed by oxidation stability test according to ASTM D2440, IP 280. The oxidation stability is given by neutralisation value and sludge formation at ambient and elevated temperatures. The neutralisation value of SFME at ambient (25°C) and elevated temperature (110°C) is 0.25 mg KOH/g and 1.32 mg KOH/g respectively. The sludge formation at ambient and elevated temperature is 0.1 % and 8.90% respectively. The antioxidants like butylated hydroxyl anisole (BHA), tert-butylhydroquinone (TBHQ) in requisite quantities can be used to further improve the oxidation stability of the oil (Schober and Mittelbarch 2004).

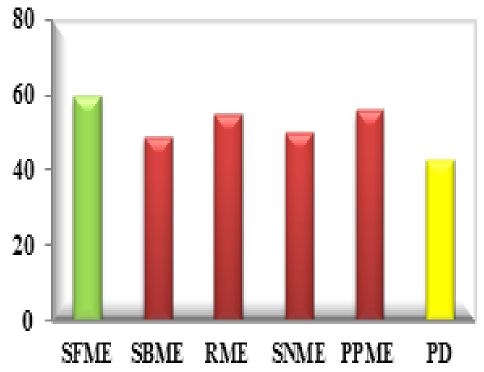
Table 6: Comparison of fuel properties of SFME with those of existing biodiesels and with petrodiesel

Fuel properties	**SFME**		**SBME**	**RME**	**SNME**	**PPME**	**PD**
	Obs.	**Cal.**					
Iodine value (IV) in mg I_2 /100g	80.43	81.98	128.00[a]	109.00[a]	132.00[a]	81.00[i]	NA
Saponification value (SV) in mg KOH/g	202.3	198.06	189.00[b]	168.00[b]	188.00[b]	182.00[f]	NA
Density (d) in g/mL	0.871	0.870	0.885[c]	0.882[c]	0.878[c]	0.875[i]	0.835[c]
Cetane number (CN)	-	59.69	49.00[a]	55.00[a]	50.00[a]	55.84[i]	42.60[j]
Higher heating value (HHV) in MJ/kg	39.88	39.88	39.84[d]	39.90[d]	39.95[d]	40.21[f]	46.00[j]
Lower heating value (LHV) in MJ/kg	37.15	37.15	37.44[e]	37.55[e]	37.48[e]	38.30 [i]	43.00[j]
Flash point (FP) in °C	175.00	173.2	171.00[a]	170.00[a]	177.00[a]	174.00[i]	60 to 80[g]
Cloud point (CP) in °C	2.00	-1.7	0.00[h]	-3.50[h]	1.33[h]	13.30[h]	-15 to 5[g]
Pour point (PP) in °C	-1.50	-8.7	-3.20[h]	-11.00[h]	-2.00[h]	6.40[h]	-35 to 15[g]
Kinematic viscosity (KV) in mm^2/s	3.80	3.81	4.20[a]	4.40[a]	4.20[a]	4.20[i]	3.10[j]

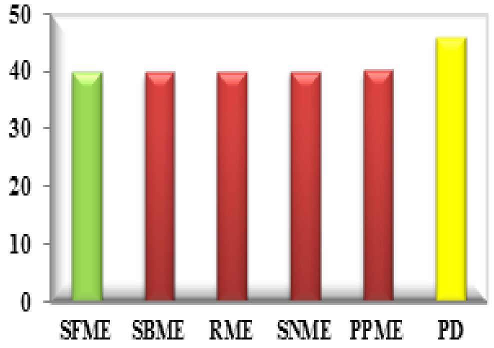
Note: Designations 'a, 'b', 'c', 'd', 'e', 'f', 'g', 'h', 'i'` and 'j' refer to references (Ramos et al. 2009,), (Knothe G 2002,), (Ramadhas, Muraleedharan and Jayaraj 2005), (Freedman and Bagbay 1989), (Mehta and Anand 2009), (Rengasamy et. al 2014) (Joshi and Pegg 2007), (Sajjadi, Abdul Raman and Arandiyan 2016), (Rao P. V. 2011) and (Katagi, 2015) respectively. Obs. = Observed value. Cal. = Calculated value, SFME = *Salvia farinacea* methyl ester, SBME = Soybean methyl ester, RME = Rape seed methyl ester, SNME = Sunflower methyl ester, PPME = *Pongamia pinnata* methyl ester and PD = Petrodiesel.



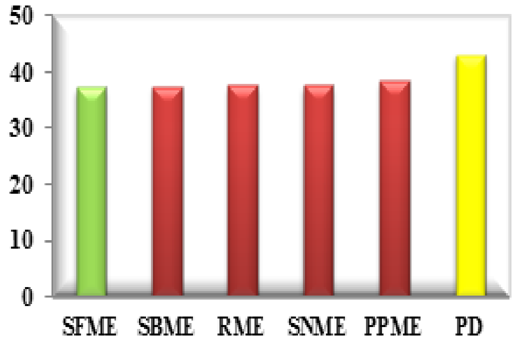
5a. Iodine value



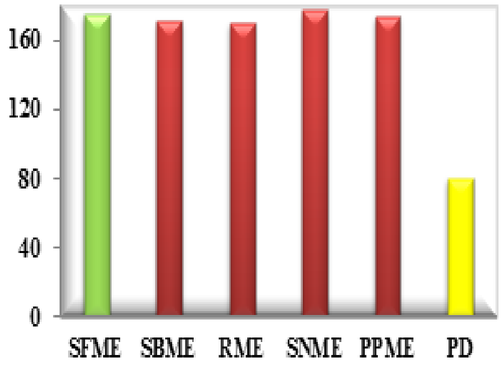
5b. Cetane number



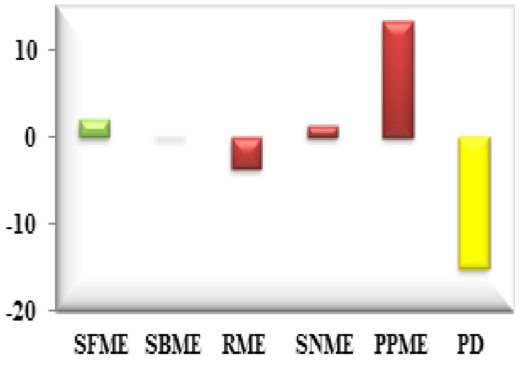
5c. Higher heating value



5d. Lower heating value



5e. Flash point



5f. Cloud point

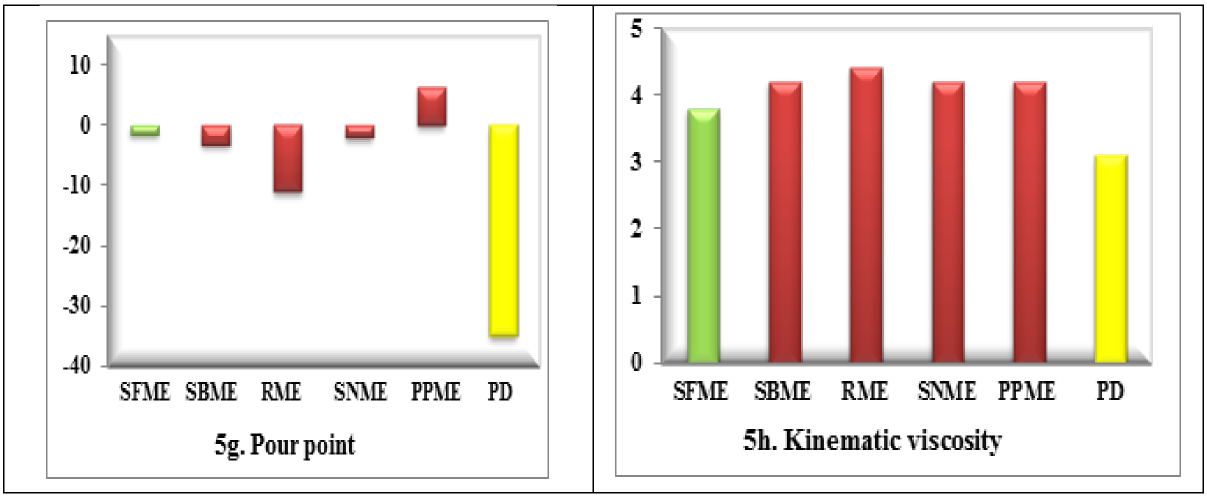


Fig 5: Comparison of fuel properties of SFME with already existing biodiesels and petrodiesel or EN14214.

3.3 Fuel properties of the SFME

Density of SFME oil is 0.871 g/mL which matches very well with the empirically determined density 0.870 g/mL. As per EN14214, the specified range for biodiesel is 0.860-0.90 g/mL and density of diesel specified by ASTM D975 is 0.848 g/mL [Joshi and Pegg 2007]. Density of SFME is slightly more than diesel because of presence of higher unsaturation (oleic acid 83.21%) and is lesser compared to already existing biodiesels (values are depicted in Table 6).

Cetane number (CN) is one of the important parameter and is a measure the combustion quality of diesel / biodiesel. IV and CN are correlated to each other. As IV increases, CN decreases and vice versa. If CN is high, smooth and silent combustion is observed and it also helps easy cold starting. According to ASTM D6751 and EN14214, the CN specified for biodiesel are 47 and 51 respectively (Katagi et al 2015) and CN of the diesel is 42.6 (Katagi et al 2015). The upper limit of CN specified by US biodiesel standard is 65. The CN of SFME is computed using equation 5 mentioned in Table 4 and is based on CN of pure FAMEs and composition of the FAMEs. The data of CN of pure FAMEs is collected from Knothe G (2014), W. E. Klopfenstein (1985), B. Freedman and Bagbay (1990), Freedman et al (1990), Knothe, G et al (2003), Knothe, G et al (1997) and D. Tong et.al (2011) research papers. The computed CN of SFME is found to be 59.69 and is compared with already existing biodiesels and petrodiesel (Figure 5b). It is observed that CN of SFME is less than the upper limit of CN specified by US biodiesel standard and is more than CN of SBME, RME, SNME and PPME.

Higher heating value (HHV) and lower heating value (LHV) measure the total energy content and depend on the oxygen, carbon and hydrogen content of the biodiesel. The HHV of the SFME is determined using bomb calorimeter and is found to be 39.88 MJ/kg. The calculated HHV (using equation mentioned in Table 4) of the SFME is also found to be same (39.88 MJ/kg) as that of the experimental value. But when it is used in engine, lesser energy is released. It is because, 100% combustion of fuel will not take place in IC engine. HHV of the SFME is close to HHV of SBME, SNME, RME and PPME but is slightly less than petrodiesel (46.00 MJ/kg). It is because of inbuilt oxygen present in the FAMEs. And it is more than the heating value of coal (32-37 MJ/kg).The calculated LHV is found to be 37.15 MJ/kg. The European Biofuel Technology Platform 2011 reported the LHV of the biodiesel as 37.1 MJ/kg. LHV specified for biodiesel and diesel are 36.6 MJ/kg (ASTM D875) and 32.6 MJ/kg (ASTM PS121) respectively (Joshi and Pegg 2007). HHV and LHV of SFME are compared with already existing biodiesels such as SBME, RME, SNME, PPME and with petrodiesel and are shown in Figure 5c and 5d. It is observed that, LHV of the SFME is very close to those of existing biodiesels but is lesser than petrodiesel.

The flash point (FP) is the temperature at which fuel ignites when exposed to flame. According to ASTM PS121 and ASTM D975, the flash point (FP) range for biodiesel and petrodiesel are 100-170^{o}C and 60-80^{o}C respectively (Joshi and Pegg 2007). The computed and experimentally determined FP values of SFME are found to be 173.2^{o}C and 175^{o}C. Comparison of flashpoint of SFME with already existing biodiesels is shown in

Figure 5e. It is observed that the FP of SFME is more than SBME, SNME, RME, PPME and with petrodiesel. Evidently, SFME is safer to store when compared to petrodiesel.

Cloud point (CP) is the temperature at which a cloud of wax crystals first appear in the oil when it is cooled. The pour point (PP) is the lowest temperature at which the oil sample is a fluid and can be poured. These properties are related to the use of biodiesel in colder regions (Sarin et al 2011). The CP and PP values for biodiesel as specified by ASTM PS 121 are -3ºC to 12ºC and -35ºC to 10ºC respectively (Joshi and Pegg 2007). The CP of the SFME is 2.0ºC and PP is -1.5ºC and both are within the range specified by ASTM PS 121. The CP and PP are also calculated using equations mentioned in Table 4. The computed CP (-1.7ºC) and PP (-8.7ºC) values are not consistent with the experimental values. The probable reason for deviation is the higher percentage of unsaturation (86.8%) as stated to be the limitation by Sarin et al. The equations used for computing the CP and PP values have an upper limit of unsaturation at 84%. The CP and PP depend upon the quality of the feedstock. As SFSO contains higher amount of unsaturated fatty acids than saturated fatty acids, its FAMEs have better cold flow properties. Comparison of CP and PP of SFME with already existing biodiesels is shown in Figure 5f and 5g respectively. It is observed that, CP and PP values of SFME are close to already existing biodiesels. It is evident that SFME can be used as a fuel in cold temperature regions.

The kinematic viscosity (KV) increases with fatty acid chain length and with increasing degree of saturation of either fatty acid or alcohol moiety in the FAMEs (Knothe G 2005). ASTM specified KV range for biodiesel is 3.3-5.2 mm^2/s (Demirbas 2009). The computed and experimentally determined KV values of SFME are same i.e., 3.8 mm^2/s (Table 6), which is within the range suggested by ASTM but slightly more than KV of petrodiesel (3.1 mm^2/s). Comparison of KV of SFME with already existing biodiesels and petrodiesel is shown in Figure 5h. Obviously, KV of SFME is less than SBME, SNME, RME and PPME. It is possible that KV increase as the percentage of SFME in the blend with diesel increases, making atomization to be difficult at higher blends of SFME.

3.4 Emission characteristics of SFME and its blends

The FAMEs produced from the seed oils are an alternative to successfully complete the EPA's meticulous emissions. Biodiesel provides significantly reduced emissions of carbon monoxide (CO), smoke (particulate matters), unburned hydrocarbons (HC) compared to petrodiesel. In addition to this, biodiesel reduces emissions of carcinogenic compounds compared to petrodiesel. When biodiesel is blended with petrodiesel, these emission reductions are generally directly proportional to the amount of biodiesel in the blend.

FAMEs of SFSO blends with petrodiesel (B0, B20 and B40) are investigated for emission characteristics. A test is conducted on a single cylinder four stroke diesel engine. Experiments are conducted on the engine at different loads from 0 kg to 18.3 kg (rated load) with constant speed, varying the load up to the rated load keeping cooling water flow and calorimeter water flow constant. Observations are made to evaluate emission components and their comparison with rated load as shown below.

3.4.1. CO (% Volume)

CO in the internal combustion engine is formed during the intermediate combustion stages. However, diesel engines which operate on the lean side of stoichiometric ratios, emit lower CO. Carbon monoxide emission at lower loads will be lower and increase for full load as shown in the Figure 6a due to incomplete combustion (Rao P.V. 1999; Sara et. al 2013).

In the present study, CO emissions have decreased with increased amounts of SFME in the blend. Structurally, biodiesel contains carbon, hydrogen and oxygen. But petrodiesel is made up of only hydrocarbons. Biodiesel molecules as oxygenates, account for the better combustion and reduced CO emissions. It is to be noted that CN value of the SFME is higher than that of the petrodiesel which ensures smooth and near complete combustion when there is increase in percentage of SFME in the blend. Evidently, CO emission for B0 is higher compared to B20 and B40 which is shown in Figure 6a.

3.4.2. CO_2 emission (% Volume)

From Figure 6b it is observed that CO_2 emissions increase as the load increases because CO is converted to CO_2. As the percentage of SFME increases in the blend, the CO_2 emitted will also increase. The SFME helps reduce the risk of global warming by reducing net carbon emissions to the atmosphere. SFME is a carbon neutral fuel. CO_2 emitted by burning, does not add to atmospheric CO_2, instead, it is consumed by plants for photosynthesis.

3.4.3. HC (ppm) emission

During compression and combustion, increasing cylinder pressure forces some of the gas in the cylinder into crevice, or narrow volumes, connected to the combustion chamber. Most of this gas is un-burnt fuel-air mixture which escapes the primary combustion process because the entrance to these crevices is too narrow for the flame to enter. This gas leaves these crevices later in the expansion and is one of the reasons for HC emission. Another reason is combustion chamber wall. A quench layer containing un-burnt and partially burnt fuel-air mixture is left at the wall surface where the flame is extinguished as it approaches the wall. The un-burnt HCs in these thin (0.1mm) layers; burn up rapidly when the combustion chambers are clean. The porous deposits on the walls of engine, in actual engine operation, will increase HC emissions. The third reason of un-burnt HC emission is the engine oil left as a thin film on the cylinder wall, piston and on the cylinder head. This can absorb and desorb HC components of fuel before and after combustion, thus permitting the fuel to escape the primary combustion process (Rao P.V. 2011; Jain and Asthana 2002).

HC emissions are lower for blends of SFME. HC emissions in the exhaust are lowered with increasing amount of SFME in the fuel blend. The inbuilt oxygen content in its molecular structure is the reason for near complete combustion and thus reduced HC levels. Sometimes, the HC emission may depend on the combustion in different cycles and different loads.

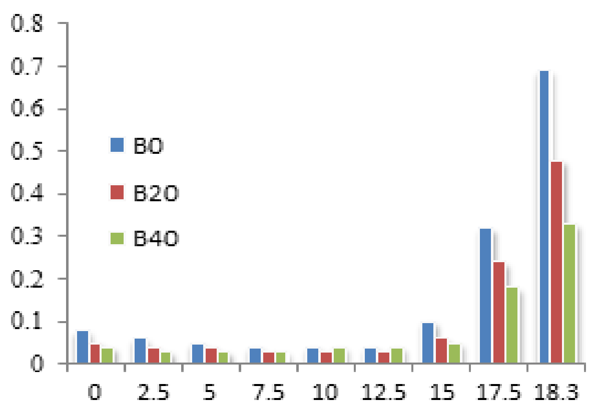
HC emissions are more in B0 due to incomplete combustion and oxygen availability is lesser at rated loads. HC emissions from B20 and B40 blends is lesser compared to B0 because of oxygen availability and consequently better combustion efficiency (Rao P.V. 2011; Ramadhas, Muraleedharan and Jayaraj 2005; Sara et.al 2013, Azad, Ameeruddin and Alam 2012). Comparison of HC emissions from B0, B20 and B40 is as shown in Figure 6c.

3.4.4. NO_x (ppm) emission

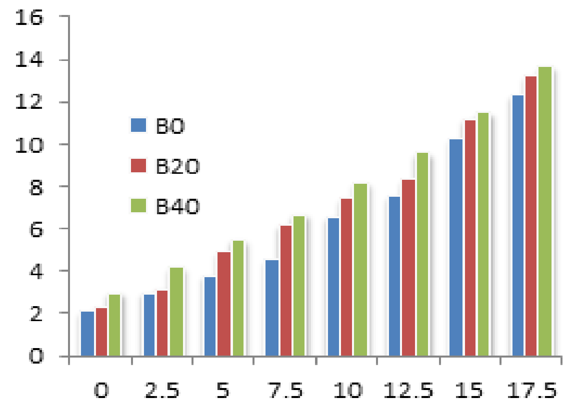
Formation of NO_x is dependent on the operating temperature of the cylinder wall and the availability of oxygen (Rao P.V. 2011; Ramadhas, Muraleedharan and Jayaraj 2005; Sara et.al 2013, Azad, Ameeruddin and Alam 2012; Krishnaswamy and Shenbaga 2012). From the Figure 6d, it is observed that NO_x emissions increase as the load increases. It is observed from the figure that NO_x emission for blends of SFME (B20, B40) are higher than that of petrodiesel (B0). It is because the SFME contain inbuilt oxygen in their molecules which help in better combustion that increases the cylinder wall temperature and consequently, formation of NO_x. However, there is not much of consistency in the results obtained at varying loads. Comparison of NO_x emissions from B0, B20 and B40 at different loads is shown in Figure 6d.

3.4.5. Smoke opacity (%)

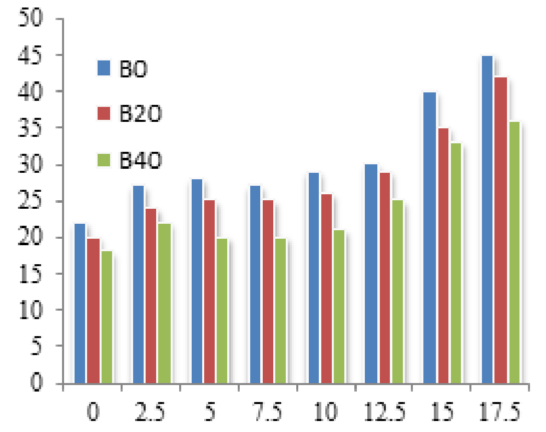
Smoke opacity is an indication of incomplete combustion and it limits the efficiency of the engine. Smoke formation occurs at the extreme air deficiency. Air or oxygen deficiency is a possibility in the near vicinity of fuel molecules within the diesel engine. It increases as the air to fuel ratio (A/F) decreases. Experimental observations indicate that smoke emissions are increased with increase in the load. Comparison of smoke emissions from B0, B20 and B40 are shown in Figure 6e. For operation of SFME, the smoke emitted is reduced because of the bounded oxygen which helps in better combustion (Krishnaswamy and Shenbaga 2012).



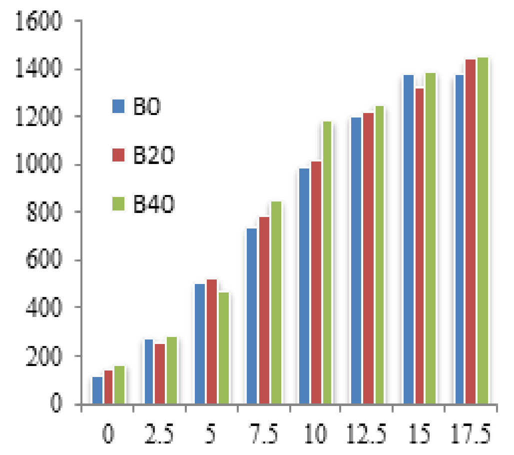
6a. CO vs Load



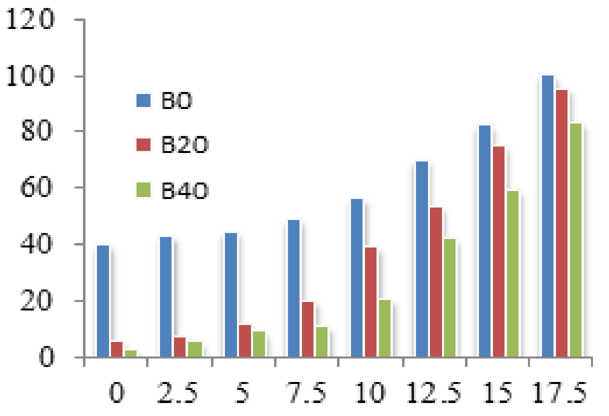
6b. CO_2 vs Load



6c. HC vs Load



6d. NO_x vs Load



6e. Smoke vs Load

Figure 6:

4. Conclusions:

FAMEs produced from *Salvia farinacea* seed oil by transesterification process in presence of methanol and 1% KOH catalyst give 90.0% yield. Spectral studies (FTIR and ^{1}H NMR) reveal the conversion of *Salvia farinacea* seed oil to FAMEs of *Salvia farinacea*. The fuel parameters like iodine value, cetane number, higher heating value, lower heating value, cloud point, pour point, flash point, viscosity, etc. meet major specifications of American (ASTM) and European (EN) standards of biodiesel. Further, emission performance reveals that blend of SFME with diesel at different ratios (B20, B40) reduces the green-house gas emissions compared to diesel (B0). NO_X emissions are higher at higher biodiesel blends. This work reveals that SFME is a splendid and potential candidate as biodiesel and *Salvia farinacea* is a promising renewable biomass for the biodiesel synthesis.

References

[1] Azad, A. K., S. M. Ameeruddin., and M. M. Alam. 2012. A comprehensive study of DI engine performance with vegetable oil: an alternative biofuel source of energy. *International Journal of Automotive and Mechanical Engineering* 5:576-586.

[2] Azam, M. M., A. Waris, and N. M. Nahar. 2005. Prospects and potential of fatty acid methyl esters of some non-traditional seed oils for use as biodiesel in India. *Biomass and Bioenergy* 29:293-302. doi:10.1016/j.biombioe.2005.05.001.

[3] Carareto, N. D. D., Y. C. S. Cecilia., E. C. O. Kimura., C. C. Mariana., and J. A. M. Antonio. 2012. Flash point of mixtures containing ethyl esters or ethylic biodiesel and ethanol. *Fuel* 96: 319-326. doi:10.1016/j.fuel.2012.01.025.

[4] Demirbas, A. 2003. Biodiesel fuels from vegetable oils via catalytic and non-catalytic supercritical alcohol transesterifications and other methods: A survey. *Energy Conversion and Management* 44:2093-3009. doi:10.1016/S0196-8904(02)00234-0.

[5] Demirbas, A. 2009. Progress and recent trends in biodiesel fuels. *Energy* 50:14-34.

[6] Duarte, H. S., and F. Maugeri. 2014. Prediction of quality properties for biodiesel production by oleaginous yeast cultivated in pure and raw glycerol. *Chemical Engineering Transactions* 37:463-468. DOI: 10.3303/CET1437078.

[7] Edward, F. G. and H. Teresa. 1999. *Salvia farinacea 'Victoria Blue'***.** Comparative Extension Service, Institution of Food and Agricultural Sciences. University of Florida.

[8] Freedman, B., and M. O. Bagby. 1989. Heats of combustion of fatty esters and triglycerides. *Journal of American Oil Chemists's. Society* 66:1601-1605.

[9] Freedman, B., and M.O.Bagby. 1990. Predicting cetane numbers of n-alcohols and methylesters from their physical properties. *Journal of American Oil Chemists's. Society* 67:565–571.

[10] Freedman, B., M. O. Bagby., T. J. Callahan., and T. W. Ryan III. 1990. Cetane numbers of fatty esters, fatty alcohols and triglycerides determined in a constant volume combustion bomb. SAE Techn. Paper Series No. 900343.

[11] Heywood, J. B. 1998. *International combustion engine fundamentals*. New York, McGraw Hill.

[12] Jain, K. K., and R. B. Asthana. 2002. *Automobile Engineering by Ttti*. Tata McGraw Hill publishing company limited, New Delhi.

[13] Jayashree, K. T. 1983. Studies on chemistry of fatty acids. Ph. D. thesis. Sri S S Basavanal library, Dharwad, India.

[14] Joshi, R. M., and Pegg, M. J. 2007. Flow properties of biodiesel fuel blends at low temperature.*Fuel* 86:143-151.

[15] Katagi, K. S., R. S. Munnolli, and K. M. Hosamani. 2011. Unique occurrence of unusual fatty acid in the seed oil of *Aeglemarmelos Corre*: Screening the rich source of seed oil for bio-energy production. *Applied Energy* 88:1797–1802. doi:10.1016/j.apenergy.2010.12.010.

[16] Katagi, K. S., S. S. Kulkarni., R. S. Munnolli., S. D. Benni., and M.C. Akki. 2015. Assessment of Chemical and biodiesel properties of seed oils of *Holoptelea integrifolia* and *Ichnocarpus frutescens*: Based on component fatty acids. *Chemical Science Reviews and Letters* 4:1275-1286.

[17] Klopfenstein, W. E. 1985. Effect of molecular weights of fatty acid esters on cetane numbers as diesel fuels. *Journal of American Oil Chemist's. Society* 62:1029–1031.

[18] Knothe, G., M. O. Bagby., and T.W. Ryan III. 1997. Cetane numbers of fatty compounds: influence of compound structure and of various potential cetane improvers. SAE Technol. Pap. Ser. 9716811997.

[19] Knothe G. 2005. Dependence of biodiesel fuel properties on the structure of fatty acid alkyl esters. *Fuel Processing Technology* 86:1059-1070.

[20] Knothe, G. 2002. Structure Indices in FA Chemistry. How Relevant Is the Iodine Value?, *Journal of American Oil Chemist's. Society* 79: 847-853.

[21] Knothe, G., A. C. Matheaus., and T. W. Ryan III. 2003. Cetane numbers of branched and straight-chain fatty esters determined in an ignition quality tester. *Fuel.*, 82:971–975.

[22] Knothe, G. 2014. A comprehensive evaluation of the cetane numbers of fatty acid methyl esters. *Fuel*. 119:6-13.

[23] Krishnaswamy, T., and V.M. Shenbaga. 2012. Performance evaluation of diesel engine with oxygenated biofuel blends. *ARPN Journal of Engineering and Applied Sciences***.** 7:10-14.

[24] Luis Felipe, R. V., R. R. Javier Esteban., and R. Alicia del. 2012 Predicting cetane number, kinematic viscosity, density and higher heating value of biodiesel from its fatty acid methylester composition. *Fuel***.** 91:102-111. doi:10.1016/j.fuel.2011.06.070.

[25] Marchetti, J. M., V. U. Miguel., and A. F. Errazu. 2007. Possible methods for biodiesel production. *Renewable and Sustainable Energy Reviews.* 11:1300-1311. doi:10.1016/j.rser.2005.08.006.

[26] Mehta, P. S., and K. Anand. 2009. Estimation of a Lower Heating Value of Vegetable Oil and Biodiesel Fuel. *Energy & Fuels*. 23:3893–3898.

[27] Mehta, P. S., and K. Anand. 2009. Estimation of a Lower Heating Value of Vegetable Oil and Biodiesel Fuel. *Energy & Fuels*. 23:3893–3898.

[28] Pandurangan, M. K., S. Murugesan., and P. Gajivardhan. 2014. Physicochemical properties of groundnut oil and their blends with other vegetable oils. *Journal of Chemical and Pharmaceutical Research*. 6:60-66.

[29] Ramadhas, A. S., S. Jayaraj, and C. Muraleedhara. 2005. Biodiesel production from high FFA rubber seed oil. *Fuel*. 84:335-340. doi:10.1016/j.fuel.2004.09.016.

[30] Ramadhas, A. S., C. Muraleedharan, and S. Jayaraj. 2005. Performance and emission evaluation of diesel fuelled with methyl esters of rubber seed oil. *Renewable Energy*. 30:1789-1800. doi:10.1016/j.renene.2005.01.009.

[31] Ramos, M. J., C. M. Fernández., A. Casas., L. Rodríguez., and Á. Pérez, Influence of fatty acid composition of raw materials on biodiesel properties. *Bioresource Technology*. 100:261– 268. doi:10.1016/j.biortech.2008.06.0.

[32] Rao, P.V. 2011. Experimental investigations on influence of properties of Jatropha biodiesel on performance, combustion and emission characteristics of a DI-CI engine. *World Academy of Science, Engineering and Technology*. V5, Scholar.waset.org/1999.0/7939.

[33] Rengasamy, M., K. Anbalagan., S. Mohanraj., and V. Pugalenthi. 2014. Biodiesel production from *Pongamia pinnata* oil using synthesized iron nanocatalyst. *International Journal of ChemTech Research*. 6:4511-4516.

[34] Ron Clavier and Kirk-Othmer. 2007. V2 of *Food and Feed Technology*. Wiley's 5th ed.

[35] Sajjadi, B., A. A. Abdul Raman., and H. Arandiyan. 2016. A comprehensive review on properties of edible and non-edible vegetable oil-based biodiesel: Composition, specifications and prediction models. *Renewable and Sustainable Energy Reviews.* 63:62–92.

[36] Sara, P., R. Paul., M.H. Jose., T. Athanasios., and D.M. Pilar. 2013. The effect of biodiesel fatty acid composition on combustion and diesel engine exhaust emissions. *Fuel.* 104;170- 182.

[37] Sarin, A., R. Arora., N. P. Singh., R. Sarin., R. K. Malhotra., K. Kundu. 2009. Effect of blends of Palm-Jatropha-Pongamia biodiesels on cloud point and pour point. *Energy* 34:2016-2021.

[38] Schober, S., and Mittelbarch, M. 2004. The impact of antioxidants on biodiesel oxidation stability. *European Journal of Lipid Science and Technology* 106:382-389.

[39] Sharma, Y. C., Singh, B., and Upadhyay, S. N. 2008. Advancements in development and characterization of biodiesel: A review. *Fuel* 87:2355-73. doi:10.1016/j.fuel.2008.01.014.

[40] Srinivas, D., and J. K. Satyarthi. 2012. Challenges and opportunities in biofuels production. *Indian Journal of Chemistry* Vol. 51A:174-185.

[41] Su, Y. C. 2011. Selection of prediction methods for thermophysical properties for process modelling and product design of biodiesel manufacturing. In Proceedings of Chemical Engineering. Virginia Polytechnic Institute and State University, Virginia.

[42] Tong, D., C. Hu., K. Jiang., and Y. Li. 2011. Cetane number Prediction of Biodiesel from the Composition of the Fatty Acid Methyl Esters. *Journal of American Oil Chemist's. Society* 88:415–423.

[43] Wanignon, F. F. 2012. Higher heating value (HHV) of vegetable oils, fats and biodiesels evaluation based on their pure fatty acids' HHV. *Energy* 45:798-805.

[44] Washington, D. C. 1990. *Association of official analytical chemists. Official methods of analysis,* 15th ed. AOAC.

[45] Yebo, Li., and K. K. Samir. 2016. *Bioenergy: Principles and Applications.* John Wiley & Sons.