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Banat's Journal of Biotechnology
2016, VII(13)

BIODIESEL PRODUCTION AND FUEL PROPERTIES OF THREE MINOR TREE–BORNE SEED OILS

DOI: 10.7904/2068–4738–VII(13)–5

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Abstract. Nowadays non–edible minor oils have been considered as promising sustainable feedstock for future biodiesel production. Three tree–borne minor seed oils from *Annona squamosa* (AS), *Bombax ceiba* (BC) and *Ceiba pentandra* (CP) plants were studied to assess their potentiality as sources of biodiesel. The seed oils were analyzed for their physicochemical properties and fatty acid composition. The AC seed oil was converted into biodiesel by single step NaOH catalyzed transesterification process without any pretreatment as its FFA content was below the 2 % safe limit. The BC and CP seed oils had high FFA content for which they were converted into biodiesel employing acid esterification followed by alkaline transesterification. The biodiesel yields under the experimental conditions for AS, BC and CP seed oils were 89.4 %, 86.2 % and 85.6 % respectively. The important fuel properties of the seed oil biodiesels such as density, kinematic viscosity, flash point, cetane number, calorific value and oxidation stability were tested which revealed that most of them were close to that of diesel and also met the IS and ASTM standard specification for commercial biodiesel. The suitability of seed oil biodiesels blended with diesel was also evaluated. Oil content, biodiesel yield and fuel properties of these three tree–borne oilseeds were satisfactory, therefore, they can be considered as potential sources of biodiesel production.

Keyword*:* biodiesel, tree–borne seed oils*, Annona squamosa*, *Bombax ceiba*, *Ceiba pentandra*

Introduction

Energy that is a critical input for socio–economic development mainly comes from fossil fuels since their exploration.

Among the fossil fuels, nowadays diesel is largely used in the transport, agriculture, commercial, domestic and industrial sectors. However, fossil fuel resources are limited, non–renewable and polluting. This emphasizes the need for looking an alternative fuel. Biodiesel is considered as most promising alternative as it is a non–toxic, renewable and more environmentally friendly compared to conventional petrodiesel [DEMIRBAS, 2007].

Even the use of biodiesel does not require engine modification when blended with diesel. Though India has begun by introducing a five percent blend of biodiesel with conventional diesel, the Government of India announced its 'National Biofuel Policy' on 12 September, 2008 which aims to meet 20 % of India's diesel demand with biodiesel mainly derived from plants by 2020 [BISWAS and POHIT, 2013]. Biodiesel, referred to as a mixture of mono–alkyl ester of long chain fatty acids is made by treating the vegetable oils or fats with an alcohol using catalyst [ABBASZAADEH *et al.*, 2012].

Currently more than 95 % of biodiesel is prepared from edible vegetable oils like soybean, rapeseed, palm and sunflower oil [ATABANI *et. al.*, 2012].

The usage of such edible oils may cause shortage for their human consumption and the production cost of biodiesel will not be economically viable, as well leading to alleviate food versus fuel issue.

This problem might be solved by using non–edible or minor oils [KUMAR and SHARMA, 2011; CHHETRI *et. al.*, 2008] which are usually cheaper than edible oils [GASHAW and LAKACHEW, 2014] and do not even compete with food item for human consumption [BALAT, 2011].

Considering these promising prospects, a huge number of studies on the minor oils from plant resources like jatropha [SHARMA and JAIN, 2010; BISWAS et. al., 2010; PARAWIRA, 2010; BASIR et. al., 2011], karanja [DWIVEDI et. al., 2011; BOBADE and KHYADE, 2012; SAYYED et. al., 2013], mahua [ARUN et. al., 2014], neem [SATYA and MANIVANNAN, 2013], custard apple [OMKARESH et. al., 2015; SIDDALINGAPPA et. al., 2013], kapok [SILITONGA et. al., 2013; KATHIRVELU et. al., 2014–15; ASOKAN and VIJAYAN, 2014] and rubber [KUMAR and PURUSHOTHAMAN, 2012] have recently been reported in the literature.

In spite of the best effort made by several researchers, the progress in this field is not to the mark.

More and more investigations on newer minor oils as resources of biodiesel are needed to fulfil the target of 'Biofuel Policy'. With this enthusiasm, three tree–borne minor seed oils namely *Annona squamosa*, *Bombax ceiba* and *Ceiba pentandra* have been studied to assess their potentiality as sources of biodiesel.

The fuel properties of produced biodiesel have been evaluated and compared with the standard specifications to ascertain their feasibility to substitute the petrodiesel. *A. squamosa* (AS) Linn. (Annonaceae), popularly known as custard apple is cultivated for its fruit in Indian subcontinent, China, Philippines, Indonesia, Egypt, Mexico and some other tropical African countries like Cameroon, Nigeria and Sudan.

In India it is largely cultivated in several states like Maharashtra, Andhra Pradesh, Karnataka, Bihar, Orissa and Tamilnadu even though it is widely planted in home gardens all over India because of its high quality fruit and good adaptation to a wide variety of soils and climates. Indian Council of Agricultural Research (ICAR) estimated that it is grown nearly in 40000 hectares in India from which about 4 lakh tonnes seed could be available. This in turn can yield 1.12 lakh tonnes of oil [OMKARESH et. al., 2015].

Unfortunately these huge amounts of seeds are left unused and disposed as waste. The seeds contain 27.5 % oil.

The fatty acid composition of the seed oil and possibility of using it in nutrition have been evaluated earlier in my laboratory [MONDAL, 2015]. This time, investigation has been carried out to assess its potentiality as source of biodiesel.

B. ceiba (BC) Linn. (Bombaceae) is naturally grown or widely planted in India, Bangladesh, Indonesia and some parts of tropical and subtropical Asia, Australia and Africa for kapok of commerce.

Different parts of the plant are used in Ayurveda for their medicinal properties [VERMA et. al., 2014; JAIN and VERMA, 2014].

The trees bear fruit of woody five–valved capsule that opens when matured and produces white fibres or floss like cotton. Inside the floss, there are numerous black seeds, so during collection of floss, seeds are separated mechanically or manually by beating.

One mature tree on an average produces 1000 fruits that yield nearly 6 kg floss and 5 kg seeds.

The seeds as obtained by–product are mostly unused. Very little of the collected seeds are used for oil extraction and the non–edible seed oil is employed in illumination and massage locally in tribes. The fatty acid composition and nutritional properties of the seed oil are reported [MONDAL, 2015; ARAFAT et. al., 2011].

Considering the potential of seed production, its commercial exploitation as newer source for biodiesel production might be considered that has been attempted in the present study.

C. pentandra (CP) L. (Malvaceae), an elegant tree that can reach a height more than 50 m, grows naturally in humid–hotter regions of Southeast Asia including India, Sri Lanka, Malaysia, Indonesia and tropical America.

It resembles *B. Ceiba* and is considered most important as a source of kapok obtained from the floss derived from the pods. Generally each tree yields about 700–1000 pods per year.

Pods are ellipsoid capsule that split open into five valves when matured, having cotton–like woolly floss in which 120–175 brownish black seeds are embedded.

The seeds, available largely as waste by–products contain 25–28 % pale yellow non–edible oil that resembles cotton seed oil [MONDAL, 2015; KIRAN and RAO, 2014].

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CP seed has the potential to be used as raw material for biodiesel because it has advantages such as abundant availability as by–product, containing high percentage of oil, ease for oil extraction and relatively cheap. Hence, the study aims to produce biodiesel from the CP seed oil as well as evaluate the suitability of the produced biodiesel too.

Material and methods

Seed oils, equipment and reagents

The seeds of *Annona squamosa* (AS) were collected from ripened fruit in the month of September and the seeds of *Bombax ceiba* (BC) and *Ceiba pentandra* (CP) in the month of May when they are abundantly available locally.

All the collected seeds were dried in the sunlight for 4–5 days for removing moisture. The seeds were pulverized into powder and extracted individually with petroleum ether (40–60°C) in a Soxhlet apparatus for 72 hours.

The solvent was evaporated at low temperature under reduced pressure in a rotary evaporator to obtain the seed oil. The oil content was calculated as a percentage of the extracted oil to the seed weight (w/w).

The oil obtained so far was stored separately in dark bottle glasses in cold (4°C).

A three necked 2 litre round bottom flask was used as reactor to produce biodiesel in laboratory scale.

One side neck of the reactor was plugged with air–tight rubber stopper that holds a thermometer used to measure the reaction temperature.

The middle neck was fitted with a water cooled condenser while the other side neck was used to pour the sample oil, catalyst and methanol.

The reactor was kept on a magnetic stirrer supported with 1.5 kW heating plate. In order to achieve uniform temperature as well as to ensure homogeneous mixing of the reactants stirring was controlled at constant rate of 750 rpm during production of biodiesel.

Pyrex made glass beakers, fuel measuring jar, separating funnel, pipette and burette were used. All the solvents and chemicals used in this study were of analytical grade, procured from M/S Merck India Ltd. and usually employed without further purification.

Degumming of the seed oils

The seed oils of BC and CP contain gum that usually composed of phosphates, proteins, carbohydrates and resin. Degumming of the seed oils is needed to improve the oxidization stability of produced biodiesel.

For degumming, 1 litre of crude oil was taken in a beaker and 5 mL of 10 % H_3PO_4 was added into it.

The content was stirred for 30 minutes at a temperature of 65–70°C.

After another half an hour, the mixture was poured in a separating funnel and left for 2 hours.

Gums were then separated from the oil and dropped down at the bottom of the funnel that was removed. The oil was washed once with 10 mL lukewarm water and finally the degummed oil was dried under reduced pressure at 45–50°C.

The weight of the degummed BC oil was 974 g (97.4 %) and for CP oil it was 971 g (97.1 %). AS seed oil does not contain gum.

Physicochemical analysis

The Physicochemical constants of AS and degummed BC and CP seed oils like iodine value, saponification value and unsaponifiable matter [AOCS, 2000], density [ASTM, 2011], kinematic viscisity [ASTM, 2012] and calorific value [ASTM, 2009] were determined.

Free fatty acid (FFA) of the seed oils was determined using titration method.

For this, 10 g of the oil sample was taken in a 250 mL conical flask and 40 mL of isopropyl alcohol was added into it. The mixture was heated to 50°C, allowed to cool and 5–6 drops of phenolphthalein indicator was added with well shaking.

Finally it was titrated with freshly prepared 0.1 N NaOH solutions taken in a 50 mL burette to the end point when the pink colour persisted permanently.

FFA was calculated using the formula:

FFA (%) = 28.2 x normality of NaOH solution x titration value/ weight of oil in g.

Fatty acid analysis

The fatty acid composition of the seed oils was determined by gas liquid chromatography (GLC) as described earlier [MONDAL, 2015]. The seed oils were converted to their corresponding methyl esters by refluxing with methanol containing 0.1 % sodium methoxide following the method used earlier [MONDAL et. al., 1984]. As CP seed oil contains cyclopropenoid fatty acids, its methyl esters were treated with anhydrous methanol saturated with $AgNO_3$ for 20 hours at ambient temperature to convert esters into stable ether and keto derivatives for GLC analysis.

Thin–layer chromatography (TLC) of methyl ester was carried out on Silica Gel G using n–hexane, diethyl ether and acetic acid (80:19:1 v/v/v). GLC analysis of the fatty acid methyl esters (FAME) was done by using a Perkin Elmer F 11 gas chromatograph (GLC) fitted with a flame ionization detector. Nitrogen was used as carrier gas with a flow rate of 30 mL per minute. The stationary phase was a glass column (1.8 m X 6 mm) containing 15 % DEGS coated on 100–120 mesh chromosorb 'W'. Column temperature was maintained at 200°C while the injection port at 250°C and detector at 300°C.

The chart speed of one centimeter per minute and attenuation (16 X 10^{-10}) were also suitably maintained. The peaks obtained for FAME of the oil samples were identified by running a mixture of standard FAMEs (Sigma Chemicals, Germany). The areas of the triangular Gaussian peaks were measured and they were summed up to calculate the percent distribution of individual fatty acids [BUTNARIU, 2014].

Biodiesel production

The FFA values of the seed oils allowed for biodiesel production by transesterification using alkali catalyst should be less than 2 %.

If the oil contains large amount of FFA, it will form soap with the alkali catalyst and the formed soap prevents the separation of biodiesel from glycerine. In the present investigation, the FFA content of the AS, BC and CP seed oils were recorded 1.6 %, 8.4 % and 7.2 % respectively. As the BC and CP seed oils contain FFA above the safe limit of 2%, a two-step transesterification process was used for their biodiesel production.

In the first step acid catalyzed esterification was done to reduce the FFA level and in the second step alkali catalyzed transesterification was done to produce biodiesel. However, for AS seed oil with low FFA level, only alkali catalyzed transesterification process was conducted to produce biodiesel.

Acid catalyzed esterification

In this process, 1 litre of the seed oil was taken in the three necked reactor into which 150 mL of methanol was added.

Then 10 mL of concentrated H_2SO_4 was added into the oil mixture drop wise.

The mixture was heated at 60°C and stirred constantly using the magnetic stirrer at a speed of 750 rpm for 2 hours.

The mixture was then cooled for half an hour while stirring without heating.

The esterified oil mixture was then removed from the reactor, poured into a separating funnel and left for one hour.

The excess methanol and H_2SO_4 along with some impurities moved to the upper surface while lower phase contained esterified oil.

The esterified oil sample was taken in another separating funnel and washed once with 0.5 % $NaHCO_3$ solution and then with distilled water.

Finally the esterified oil sample was dried by rotary evaporation. The FFA of the esterified oil was determined.

Alkali catalyzed transesterification

The transesterification was carried out in a three necked reactor equipped with thermometer and condenser while heating and stirring were done with a hot plate magnetic stirrer system as indicated earlier. One litre of AS seed oil or acid catalyzed esterified BC and CP oil was taken in the reactor and heated at 60°C.

The NaOH–methanol solution was prepared freshly by stirring 7.5 g of NaOH in 250 mL methanol in a beaker and added to the oil sample in the reaction flask rapidly under stirred condition.

The transesterification was continued at 60°C with constant stirring at

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750 rpm for 2 hours. After the transesterification process, the entire reaction mixture was transferred into a separating funnel and allowed to settle under gravity for 5–6 hours resulting in the separation of two distinct phases.

The upper phase contained biodiesel while the lower one glycerin as byproduct.

The glycerin at the bottom layer was removed. The biodiesel obtained so far was washed with warm water to remove residual methanol, NaOH and glycerin remained in the biodiesel.

After the mixture had got settled down, the water was drained out.

The washing was repeated twice and finally biodiesel was dried by heating at 100°C for 10 minutes.

Then it was allowed to cool at room temperature and weighted to determine the biodiesel yield following the formula:

biodiesel yield (%) = g of biodiesel produced/g of oil used for reaction X 100.

Analysis of fuel quality

The fuel properties of the obtained biodiesels of AS seed oil (Annona oil methyl esters: AOME), BC seed oil (Bombax oil methyl esters: BOME) and CP seed oil (Ceiba oil methyl esters: COME) were evaluated. At present India's 'National Biofuel Policy' aimed to use 20% blended biosdisel, therefore, fuel properties of various blends (B10: 10 % biodiesel with 90 % petrodiesel; B20: 20 % biodiesel with 80 % petrodiesel; B30: 30 % biodiesel with 70 % petrodiesel; B50: 50 % biodiesel with 50 % petrodiesel) of AOME, BOME and COME were also evaluated.

For the assessment of fuel quality of biodiesels (AOME, BOME and COME) density [ASTM, 2011], kinematic viscosity [ASTM, 2012], flash point [ASTM, 2006], cetane number [SIVARAMKRISHNAN and RAVIKUMAR, 2012], calorific value [ASTM, 2006] and oxidation stability [DIN, 2011] were determined.

Three important parameters, density, kinematic viscosity and flash point were considered for comparative evaluation of fuel properties of various blends of AOME, BOME and COME.

Results and discussion

Physicochemical properties

The physicochemical properties of the three tree–borne minor seed oils are summarized in Table 1.

The economical conversion of plant seed oil to biodiesel needs 20–30 % of oil content in the seed. The results revealed that the percentage of oil content in AS and CP seeds were 27.1 and 28.2 respectively and it was 20.4 for BC.

Thus, all these plant seeds can be suitable feedstock for biodiesel production.

The iodine value of the seed oils is nearly 100 which is quite high and lies within the values of semidrying oil.

Table 1.

Physicochemical properties of three tree–borne seed oils[a]

Physicochemical constants	AS seed oil	BC seed oil	CP seed oil
Oil yield (g/100 g seed)	27.1±0.4	20.4±0.4	28.2±0.3
Iodine value (mg I_2/g oil)	103.2±1.4	98.8±1.6	104.5±2.1
Saponification value	189.6±2.1	197.6±1.4	202.4±1.8
Unsaponifiable matter (%, w/w)	1.2±0.1	3.4±0.2	3.8±0.1
Density (kg/m^3)	898.2±2.6	911.3±2.3	914.6±2.4
Kinematic viscosity (mm^2/s at 40°C)	5.8±0.2	6.8±0.3	6.7±0.2
Calorific value (mJ/kg)	37.2±0.5	38.4±0.4	37.9±0.5
FFA (% as oleic acid)	1.6±0.1	8.4±0.3	7.2±0.3

[a]All determination were carried out in triplicate and values are expressed as mean ±standard deviation; AS: *Annona squamosa*, BC: *Bombax ceiba*, CP: *Ceiba pentandra*

The seed oils had a high saponification value in the range 189–202, that supports their semidrying nature too. The non–edible seed oils are usually characterized by deep colour and high content of non–lipid components as unsaponifiable matter which limit their edibility in the raw state. Both of the BC and CP seed oils had high unsaponifiable matter which is probably due to presence of gum therein. On the contrary, AS seed oil had low unsaponifiable matter which indicates that it does not contain gum or residual hydrocarbons, carbohydrates and proteins in significant amount.

The crude seed oils had higher density and viscosity, therefore, cannot be considered directly as fuel for engine.

Higher density and viscosity of the fuels adversely affect the flow properties of the fuel like spray atomization, subsequent vaporization and air–fuel mixing in the compression chamber.

However, conversion of seed oil into its methyl ester through transesterification results in reduction of molecular weight of triglycerides and thereby reduces its density as well as viscosity. It has been successfully attempted in the present study. FFA is one of the most significant parameters of the plant seed oils that should be considered for biodiesel production. The FFA contents of AS, BC and CP seed oils were 1.6 %, 8.4 % and 7.2 % respectively.

Thus, the FFA levels of BC and CP seed oils are too large and above the 2 % safe limit. Many researchers [PUTRI et. al., 2012; KATHIRVELU et. al., 2014] suggested a two-step transesterification process to convert the high FFA oils to their methyl esters. It was followed for BC and CP seed oils in the present investigation. It was found that the first pretreatment step of acid catalyzed esterification reduced the FFA content of the BC and CP oils well below the 2 % safe limit. The FFA levels of the acid catalyzed BC and CP seed oils were 1.01 % and 1.1 % respectively.

Fatty acid composition

Fatty acid composition of the three tree–borne seed oils obtained by GLC analysis is shown in Table 2.

Table 2.

Fatty acid (FA) composition (%)[a] of the three tree–borne seed oils

FA	AS	BC	CP
Myristic acid (C14:0)	1.2	2.2	0.5
Palmitic acid (C16:0)	12.4	24.8	22.4
Stearic acid (C18:0)	8.6	–	2.7
Oleic acid (C18:1)	52.4	62.0	25.6
Linoleic acid (C18:2)	19.6	8.2	37.2
Linolenic acid (C18:3)	1.5	–	1.0
Arachidic acid (C20:4)	4.3	2.8	–
Malvalic acid (C18:CPFA)[b]	–	–	7.5
Sterculic acid (C19:CPFA)[b]	–	–	3.1
SFA	22.2	27.0	25.6
MUFA	52.4	62.0	25.6
PUFA	25.4	11.0	38.2
CPFA	–	–	10.6

[a]Average of 3 samples; [b]Ether plus keto derivatives; AS: *Annona squamosa*, BC: *Bombax ceiba*, CP: *Ceiba pentandra;* SFA: Saturated fatty acids, MUFA: Monounsaturated fatty acids, PUFA: Polyunsaturated fatty acids, CPFA: Cyclopropenoid fatty acids

The major fatty acids in AS seed oil were oleic (52.4 %), linoleic (19.6), palmitic (12.4 %) and stearic (8.6).

The BC seed oil was rich in oleic acid (62.0 %) followed by palmitic acid (24.8 %). On the contrary the major fatty acids in CP seed oil was linoleic (37.2 %) followed by oleic (25.6) and palmitic (22.4 %). The CP seed oil contained a pair of unique cyclopropenoid fatty acids (10.6 %) in which malvalic acid (7.5 %) was more predominant than sterculic acid (3.1 %). Fatty acid composition of the vegetable oil either edible or non–edible is one of the important criteria that influence the quality of biodiesel.

The high content of saturated fatty acids (SFA) in the seed oil increases the viscosity of the produced biodiesel and therefore not desirable. On the other hand, presence of high percentage of polyunsaturated fatty acids (PUFA) in the oil is also not good as biodiesel prepared from this oil is less stable during oxidative process but may have better performance in cold weather conditions [BHALE et. al., 2009].

The most suitable seed oil for the production of biodiesel is that which contains low SFA and PUFA but high MUFA. The present results revealed that AS seed oil contained 22.2 % of SFA, 52.4 of MUFA and 25.4 of PUFA while the BC seed oil 27.0 of SFA, 62.0 % of MUFA and 11.0 % of PUFA.

Thus, both the AS and BC seed oils contained high amount of MUFA which indicates that they are most suitable feedstock for biodiesel production.

The levels of SFA, MUFA and PUFA in the CP seed oil were 25.6 %, 25.6 % and 28 % respectively. As it contained high percentage of PUFA and cyclopropenoid fatty acids (CPFA), therefore, biodiesel obtained from this oil may have low oxidation stability.

However, earlier studies [SILITONGA *et. al.*, 2013; KATHIRVELU *et. al.*, 2014–15] did not support it and demonstrated that CP seed oil could be exploited as a potential resource of biodiesel.

Biodiesel yield

The data on biodiesel yield of three tree–borne seed oils are presented in Table 3.

Table 3.

Biodiesel yield of three tree–borne seed oils

Name of the seed oils	Name of the biodiesel	Yield (%, w/w)
AS	AOME	89.4
BC	BOME	86.2
CP	COME	85.6

AS: *Annona squamosa* BC: *Bombax ceiba* CP: *Ceiba pentandra*

The biodiesel yield from AS, BC and CP seed oils were 89.4 %, 86.2 % and 85.6 % respectively.

The biodiesel yield for AS seed oil was comparable with that reported earlier (85–90 %) [DODDABASAWA and RAVIKUMAR, 2014]. The BC seed oil gave a yield of 86.2 % biodiesel which is comparatively satisfactory.

According to best of my knowledge, BC biodiesel has been reported for the first time hence no research data on its potentiality as source of biodiesel are available in the literature.

The CP biodiesel yield in the present study was found to be 85.6 %.

Some of the earlier studies [PUTRI *et. al.*, 2012; KATHIRVELU *et. al.*, 2014] reported a higher biodiesel yield in the range of 88–90 % for CP seed oil.

It was found that the variation of biodiesel conversion efficiency depends upon the nature and amount of catalyst, amount of methanol, time and temperature used in the transesterification process for CP oil [HANDAYANI *et. al.*, 2013].

Fuel properties of seed oil biodiesels

The fuel properties of AS oil methyl esters (AOME), BC oil methyl esters (BOME) and CP oil methyl esters (COME) in comparison with those of petrodiesel as well as IS and ASTM standard specifications for commercial biodiesel are shown in Table 4.

Table 4.

Fuel properties three tree–borne seed oil biodiesels

Properties	AOME	BOME	COME	Petrodiesel	IS 15607[a]	Biodiesel ASTM D 6751[b]
Density (kg/m^3)	868	879	884	820–845	860–900	870–900
Kinematic viscosity (mm^2/s)	4.8	5.1	5.4	1.9–4.1	2.5–6.0	1.9–6.0
Flash point (°C)	159	148	145	60–80	≥120	≥93
Cetane number	48.6	56.5	59.3	44–55	≥51	≥47
Calorific value (MJ/kg)	38.4	39.4	39.1	44	–	37–42.5
Oxidation Stability (hour)	3.8	3.6	2.1	–	≥6	≥3

[a]Indian standard for testing 100% biodiesel: 15607 (2007), [b]American Society for Testing and Materials, standard for testing 100% biodiesel: 6751 (2009), AOME: *Annona squamosa* seed oil biodiesel, BOME: *Bombax ceiba* seed oil biodiesel, COME: *Ceiba pentandra* seed oil biodiesel, –Not mentioned

The results revealed that most of the fuel properties of the seed oil biodiesels were found to be close to that of diesel and also met the IS and ASTM standard specification for commercial biodiesel.

The densities of the seed oil biodiesels (AOME, BOME and COME) were higher than that of diesel which may be due to presence of high molecular weight fatty acid methyl esters therein.

High density means higher inject of fuel, high carbon, more heat and more power that compensate the lower energy content of the plant oil biodiesels [TAMILARASAN *et. al.*, 2015].

On the contrary, very high density of biodiesel is not also good as it will increase emissions and cause damage to the compression ignition engine.

The densities of the produced biodiesels were in the specified range of IS and ASTM standards.

Again to achieve the required density very close to that of diesel, the seed oil biodiesels were blended with diesel in various proportions and the results are shown in Figure 1.

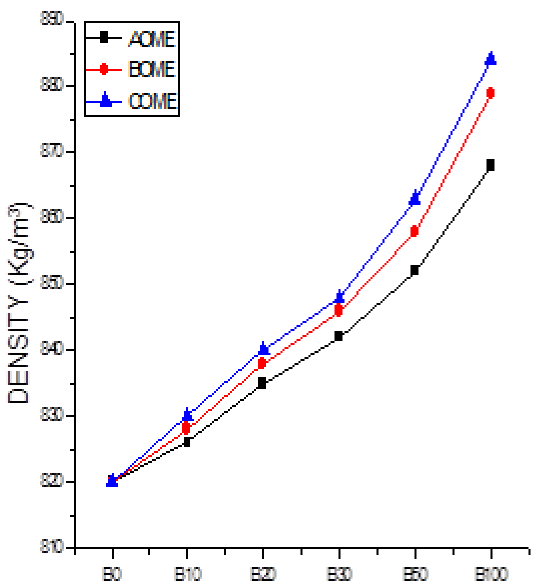

Figure 1. Density of various seed oil biodiesel blends

The conversion of seed oils into biodiesels through transesterification usually reduced the viscosity as evidenced from the results of the present study. It is attributed to the fact that high molecular weight triglycerides of the seed oils convert to comparatively low molecular weight fatty acid methyl esters in the course of biodiesel production.

The values for kinematic viscosity of the seed oil biodiesels were within the IS and ASTM specification range but somewhat higher than that of diesel.

The high viscosity of fuel reduces the flow of fuel to the engine and causes low fuel automization by making automized fuel into larger droplets with high momentum.

This in turn leads to an increase in deposits, exhaust smoke and fuel emissions along with poor combustion of the fuel.

The viscosity of the seed oil biodiesels can be further reduced by mixing them with the conventional diesel.

It was done and kinematic viscosity of various blends of AOME, BOME and COME are shown in Figure 2.

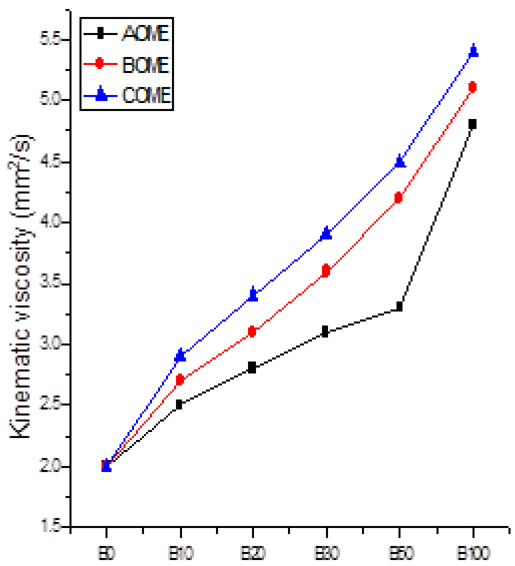

Figure 2. Kinematic viscicity of various seed oil biodiesel blends

It was found that the viscosity was gradually increased in the blends with higher proportion of biodiesels.

The results show that B10 and B20 blends of all the seed oil biodiesels had viscosity nearer to petrodiesel.

The flash points of the seed oil

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biodiesels were determined as 159°C, 148°C and 145°C for AOME, BOME and COME respectively.

Thus, the flash points of seed oil biodiesels were found to be much higher than that of diesel.

Flash point of a fuel measures the flammability of the fuel.

Higher flash points of the seed oil biodiesels indicate that they are safer for storage and transportation.

However, addition of biodiesels with diesel increases the flash point of diesel fuel. And obviously use of biodiesel blended diesel is advantageous in that sense.

The flash points of various blends of AOME, BOME and COME are shown in Figure 3.

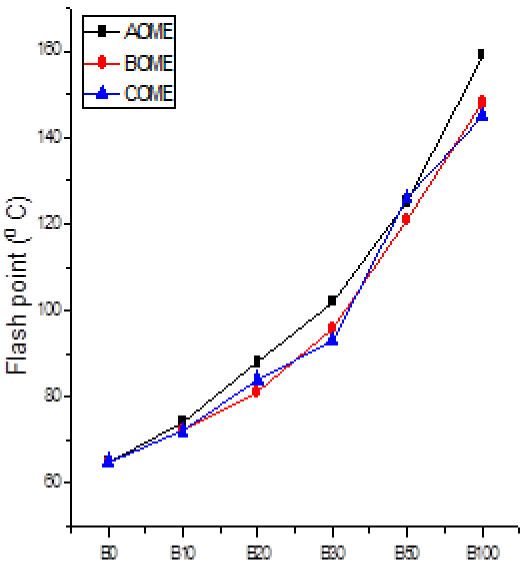

Figure 3. Flash point of various seed oil biodiesel blends

It clearly indicates that the flash points were gradually increased with blends and all the blends were found to be satisfactory.

The results show that cetane numbers of the seed oil biodiesels were somewhat higher than that of diesel.

Cetane number is an important parameter in evaluating the quality of biodiesel that influences the combustion process and engine performance.

It measures the readiness of the fuel to auto–ignite when injected into engine.

The higher cetane numbers of seed oil biodiesels indicate that they have the good ignition qualities [SIVARAMKRISHNAN and RAVIKUMAR, 2012; PETRACHE *et al.*, 2014].

In the present study COME showed highest cetane number (59.3) that may be attributed to the chemical nature of the fatty acid methyl esters which contain a higher degree of unsaturation (double bonds) and CPFA [BAMGHOYE and HANSEN, 2008].

The calorific value of the seed oil biodiesels were 38.4, 39.4 and 39.1 MJ/kg for AOME, BOME and COME respectively.

The calorific values of the studied biodiesels were slightly lower than that of diesel which may be due to the presence of oxygen in the molecular structures of the fatty acid methyl esters.

On the other hand, oxygen present in the seed oil biodiesels helps in the complete combustion of the fuel.

Oxidative stability is an important factor that affects the biodiesel quality during extended storage [PULLEN and SAEED, 2012, SAMFIRA *et al.*, 2014].

Oxidation stability of the seed oil biodiesels was determined using rancimat and the values were 3.8, 3.6 and 2.1 hours for AOME, BOME and COME respectively.

Though the values for AOME and BOME were found lower compared to IS standard but met the ASTM specification. COME showed lower oxidative stability probably due to presence of high degree of unsaturation and cyclopropenoid ring in its fatty acid methyl esters.

Conclusions

The demand for diesel is gradually increasing day–by–day for industrialization, urbanization and other developments of the world.

On the contrary, fossil fuel resources are limited, non–renewable and polluting. Biodiesel from minor seed oils of tree origin might be an effective alternative as it is a liquid solar energy.

The present study evaluates the possibility of using three tree–borne seed oils as sources of biodiesel.

It is found that the seed oils can be converted successfully by acid–alkali catalyzed transesterification process to biodiesels with satisfactory yield.

The fuel properties of the produced seed oil biodiesels and their blends meet the IS and ASTM standard specification for commercial biodiesel.

Thus, the present experimental study concludes that the biodiesels produced from tree–borne seed oils are quite suitable and can be exploited.

However, the only difficulty is in collection of these plant seeds.

Acknowledgements

The author would like to acknowledge the financial support from the University Grants Commission, New Delhi, India for the present study.

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Received: November 24, 2015
Article in Press: April 23, 2016
Accepted: Last modified on: May 20, 2016