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Influence of Soil Sulfur Content and Other Edaphic Factors on Sulfur Levels in *Calophyllum inophyllum* L. Biodiesel

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: This study investigates the sulfur content in biodiesel produced from *Calophyllum inophyllum* L. seeds collected from various regions in Southern Karnataka.

Place and Duration of Study: The study area selected was Southern Karnataka region viz., Bengaluru (Plateau), Hassan (Plain) and Udupi (Coast).

Methodology: Calophylum kernels collected at four different places in each district were subjected to the oil extraction process and an acid-base catalyzed transesterification process produced biodiesel due to the high acid value in oil. NaOH was used as a catalyst, and methanol served as the analytical solvent for transesterification reaction. During the process, a 1: 6 oil to methanol ratio was used at 60ºC reaction temperature. The sulfur content in soil, oil and biodiesel was analyzed using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) through the $CaCl_2$ extractant method(turbidimetry).

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Results: The study revealed better biodiesel quality was observed in the Udupi region, followed by Bengaluru and Hassan, as Udupi (coast) is native to this species and rainfall determines the growth performance. Also, biodiesel produced in these three regions met ASTM D6751 and BIS (ISO 15607) standards. The sulphur content in CIME was 7 ppm, 46 ppm and 46 ppm in Bengaluru, Hassan, and Udupi regions, respectively. The soil samples reveal that the total sulfur in the study area ranged from 10.31 ppm to 53.47 ppm. The samples collected from the Udupi region have shown higher sulfur content (42.49 to 53.47 ppm). The higher concentration of sulfur in biodiesel is due to the influence of edaphic factors.

Conclusion: Calophyllum is found to be a suitable feedstock for biodiesel production by developing methods for purifying the elements that hinder its quality. The study highlights regional differences in sulfur content, which could impact biodiesel quality standards. These predictions, however, need further work to validate reliability.

Keywords: Calophyllum inophyllum L.; transesterification; NaOH (catalyst); biodiesel; sulphur analysis.

1. INTRODUCTION

India will overtake the European Union as the world's third-largest energy consumer by 2030, the International Energy Agency (IEA) said as it forecast India account for the most significant share of energy demand growth over the next two decades. This might be due to the country's dynamic economic development, population growth, and modernization over the past several years. Fossil fuels play a pivotal in developing and managing the global economy and are integral to a country's economic development. A developing country like India's economy depends heavily on imports of fossil fuels from other countries.

The escalating petrol and diesel prices, declining reserves of fossil fuel, and growing environmental concerns are the primary impetus for many initiatives to search for alternative energy sources to, supplement or replace fossil fuels. Biodiesel is one of the promising alternative energy sources for transport and mechanised agriculture sectors. Biodiesel is a non-toxic, biodegradable fatty acid methyl ester produced from edible, non-edible, and animal fat.

Biodiesel can make a significant contribution in the future if it meets the few percent of petroleum and it can provide improved fuel properties, lower emission of unburned hydrocarbons and carbon monoxide and higher levels of nitrogen oxides [1].

Biodiesel, as defined by the World Customs Organization (WCO), is "a mixture of mono-alkyl esters of long-chain [C 16-18] fatty acids derived from vegetable oils or animal fats which is a domestic renewable fuel for diesel engines and meets the international specifications (ASTM D 6751)." The transesterification process produces esters from vegetable oil. It is a reaction process between triglycerides and alcohol in the presence of a catalyst to produce glycerol and ester (biodiesel).

The Government of India has formulated the National Policy on Biofuels which was introduced in 2008 and approved by the Union Cabinet in May 2018. The policy aimed to take forward the indicative target of achieving 20% blending of biofuels with fossil-based fuels by 2030. The government has set some ambitious goals for the energy sector which include electrification of all census villages by 2019, 24x7 electricity and 450 GW of renewable energy capacity by 2030, reduction in energy emissions intensity by 33%-35% by 2030, and production above 40% electricity from non-fossil fuels by 2030. These goals exhibit the Centre's push towards strengthening country's energy infrastructure while promoting sustainability. To achieve this target, more and more feedstocks are to be explored along with technology for handling these feedstocks for biodiesel production.

There are different potential feedstocks for biodiesel production. The use of edible vegetable oils or first-generation feedstock has been of great concern recently; because they raise many concerns about the issue of the food versus fuel debate. Therefore, non-edible vegetable oils or second-generation feedstocks have become more attractive for biodiesel production. A substantial number of non-edible oilseed plants were being identified which could be used as biodiesel feedstocks. Pongamia has been successfully proven as a potential tree-born oil for India's biodiesel production. A few more oils are to be explored to meet the massive demand for biodiesel. One such oil could be Calophyllum (surahonne oil), obtained from the kernels of *Calophyllum inophyllum* L. fruit. It is locally with familiar names– Alexandrian laurel (English), Punnai (Tamil), Surahonne (Kannada), and Undi (Marathi – Maharashtra).

Calophyllum inophyllum L., commonly known as Polanga, is an inedible oilseed, ornamental evergreen tree belonging to the Clusiaceae family in tropical regions of India, Malaysia, Indonesia, and the Philippines. Typically growing up to 25 m in height, the Polanga tree produces a slightly toxic fruit that contains a single, large seed. The oil obtained from polanga seeds is high in FFA content (up to 22 wt. %) and unsaturated species such as linoleic (38.3 wt. %) and oleic (34.1 wt. %) acids. The remaining fatty acids found in polanga oil are stearic (13.0 wt. %) and palmitic (12.0 wt. %) acids, with a trace amount of linoleic acid (0.3 wt. 0/0) [2].

1.1 Botanical Description of *Calophyllum inophyllum* L.

Calophyllum inophyllum L. belongs to the plant family Clusiaceae (Mangosteen family). The plant is named for its beautiful leathery leaves. Calophyllum grows in mixed cultures with minimal cultivation, and in previously cleared and degraded lands. The tree naturally grows in the sub-tropical and tropical atmosphere (between 18 and 33 °C) and free-draining soils close to shorelines. It is frequently found in clay soils within Australia, India, Sri Lanka, and central and southern Asia including Indonesia. In India, states like Maharashtra, Gujarat, Madhya Pradesh, Andhra Pradesh, Karnataka, and Tamil Nadu are blessed with many Calophyllum trees.

The tree is a low-branching and slow-growing tree with two distinct flowering periods of late spring and late autumn. The tree shows two flowering and fruiting seasons in most of the world. However, sometimes flowering may occur throughout the year. The tree supports a dense canopy of glossy, elliptical, shiny, tough leaves, fragrant white flowers, and large round drupes. Its size typically ranges between 8–20m (25–65ft) tall at maturity, sometimes reaching up to 35m (115ft). The tree's growth rate is 1m (3.3ft) in height per year on suitable sites. Its leaves are heavy and glossy, 10– 20cm (4–8in.) long and 6–9cm (2.4–3.6in.) wide, light green when young and dark green when older. Fruits are spherical drupes and arranged in clusters. The fruit is pinkish-green later turning bright green and when ripe, it turns dark grey-brown and wrinkled. The tree yields 100–200 fruits/kg. In each fruit, one large brown seed 2–4cm (0.8–1.6in.) in diameter is found. The single, large seed is surrounded by a shell (endocarp) and a thin, 3–5mm pulp layer. The oil is tinted green, thick, and has a woody or nutty smell. Oil yield per unit of land area has been reported at 2000kg/ha. The kernels have higher oil content in the 43% - 75% range [3,4]. Calophyllum was recognized as one of the most potential feedstock for biodiesel production as a result of the high oil productivity of the seeds. *C. inophyllum* is completely non-edible and trans-esterified oil shows similar engine performance and emission characteristics like other biofuels [5].

1.2 Advantages of *Calophyllum inophyllum* L.

There are many advantages of using *Calophyllum inophyllum* L. such as high survival potency in nature, up to 50 years of productivity, and higher oil yield. These trees serve as windbreakers at the seashore, where they can reduce abrasion, protect crops, provide ecotourism, and conserve coastal demarcation. Its biodiesel meets the US ASTM D 6751 and European Union EN 14214 biodiesel standards. Calophyllum biodiesel can be used as a potential substitute for diesel and possesses better lubrication capability.

1.3 Need of the Study

However, the potential of Calophyllum oil as a source of second-generation biodiesel is yet to be utilized commercially because of the absence of knowledge on the production process and biodiesel quality. Calophyllum biodiesel properties like viscosity (6.0 cSt at 40°C), density (0.88 kg/m^3), calorific value (34 MJ/kg), flash point (178°C), and fire point (196°C) all were within the specified limit [6].

Biodiesel quality control also involves the determination of sulfur content. Sulfur is invariably present in petroleum products, feedstock and crude oil. Several analytical methodologies are available to determine the Sulfur content from trace level to percentage level. Bajia et al. [7] studied the analytical techniques being employed for Sulfur determination in petroleum products, feedstock and crude oil. It plays a crucial role because it modifies the efficiency of biodiesel production and the stability of these products. Furthermore, they are toxic and generate environmental concerns, whereas others are used as additives. Biodiesel and bioethanol are typically mixed with conventional fossil fuels (diesel and gasoline). These elements come from the raw product employed for biofuel production (seeds), the production and storage process or even from the added fuels. The elements in raw materials may come from edaphic factors. Contaminated soils can be a source for crop plants of such elements like As, Cd, Cr, Cu, Ni, Pb, and Zn [8].

While biodiesel from *Calophyllum inophyllum* L. has been explored for its high oil content, the impact of regional soil sulfur content on the sulfur levels in biodiesel remains underexplored. With this background the present study is undertaken to analyse the suitability of Calophyllum oil for the production of biofuel and to evaluate the quality of the biodiesel produced.

2. MATERIALS AND METHODS

2.1 Study Area

The present study was conducted in the southern districts of Karnataka, viz. Bangalore, Hassan, and Udupi. Bangalore and Hassan are located in the southern interior region of Karnataka, while Udupi is in the south coastal region.

Bangalore (Bangalore Urban) is Karnataka's capital city, covering an area of 2,196 sq. km. It lies between 12.9716° North latitude and 77.5946° East longitude at a mean altitude of 920 m above mean sea level and receives an average annual rainfall of 920 mm.

Hassan district lies between13.0753° N latitude and 76.1784° E longitude, totalling 6826.15 Sq. km at 980 m (mean) above mean sea level and receives an average annual rainfall of 806 mm. The geography is mixed with the Malnad or mountainous region to the west and southwest, Bisle Ghat and the Maidan or Plains regions in the north, south, and east.

Udupi district covers an area of about 3,582 sq. km. It lies between 13.3409° North latitudes and 74.7421° East longitude at 9 m above mean sea level and receives an average rainfall of 4360 mm annually.

2.2 Determination of Kernel Oil Content

The estimation of kernel oil content was done by using the Soxtherm apparatus. This works on the principle of the solvent extraction process. Akintayo [9] extracted Pongamia seed oil using Soxhlet method; yield was found to be in the range of 26.0—33.0% by using different solvents.

2.2.1 Procedure

The dried seeds of *Calophyllum inophyllum* L. were powdered in a mixer grinder. Then 4 g of powdered samples were weighed. Then the samples were placed inside the cotton thimble and plugged with cotton. Then the weight of the Soxtherm jars containing boiling stones was taken and a cotton thimble was placed inside the jar with the help of a hanger. 100 ml of petroleum ether was added to each jar and placed into the Soxtherm apparatus. The oil extraction was performed by running the pre-programmed Soxtherm apparatus for 3 hours 27 minutes. To remove the remaining petroleum ether and moisture, the extracted oil was subjected to oven drying for 1 hour at 110 °C after the completion of the oil extraction process. The jars were then placed inside the desiccator containing $CaCO_3$ for one hour, and the final weight of the jar containing oil was noted[10]. The following formula was used to calculate the kernel oil content.

$$\text{Kernel oil content (\%)} = ((W2 - W1)/W)\times 100$$

Where,

W = Weight of powdered kernel sample
W1 = Weight of Soxtherm jar along with boiling stones
W2 = Weight of Soxtherm jar with boiling stones and extracted oil

2.3 Biodiesel Production from Calophyllum oil

2.3.1 Biodiesel production

Biodiesel was produced by pooling the oil samples collected from Bangalore, Hassan, and Udupi districts separately and analysed for its nature and properties, yield, quality and potentiality of biodiesel. The biodiesel quality obtained from the kernel was within the standards prescribed by ASTM. The biodiesel was produced from the kernel oil by transesterification using methanol and NaOH/KOH as a catalyst to yield fatty acid methyl ester (FAME or biodiesel) and glycerine as a by-product. Similar findings were also reported by Ma et al. [11].

2.3.2 Pre-treatment process

Oil (a known amount i.e. 500 ml) was taken in a one liter three-necked flask fitted with a reflux condenser, catalyst dozer, and temperature sensor. The oil was heated to the required temperature (55-60 ºC) on a magnetic stirrer with a temperature controller.

2.3.3 Acid esterification process

The esterification process is used when the refined oil's free fatty acid (FFA) content is greater than 2%. A two or three stage method has been applied to produce high quality biodiesel from the feedstock with high FFA [12]. The FFA content of Calophyllum oil was in the range of 4.4% - 9.9%. Therefore, a two-step acid– base- catalyzed trans-esterification was adopted to convert crude *Calophyllum inophyllum* oil (CCIO) into *Calophyllum inophyllum* methyl ester (CIME). 100 ml methanol was added to 500 ml oil and 2 ml Sulfuric acid was added and heated at 55ºC with a magnetic stirrer for 1 hr. On completion of this reaction, the products were poured into a separating funnel to separate the excess alcohol, sulfuric acid, and impurities present in the upper layer. The lower layer was separated. This process was repeated using the same methodology to reduce the FFA content to 2%.

2.3.4 Trans-esterification process

2.3.4.1 Preparation of sodium methoxide

Sodium methoxide was prepared by dissolving NaOH in anhydrous methyl alcohol (> 99%) in a conical flask.

2.3.4.2 Procedure

With constant stirring, sodium methoxide was added slowly to the esterified oil obtained from the previous step. The trans-esterification reaction was carried out for 2 hours at 60ºC. Then it was subjected to settling in a separating funnel to form an upper biodiesel layer and a lower glycerine layer. The bottom glycerine layer was drained out and the biodiesel obtained in the upper layer was collected.

2.3.5 Biodiesel washing

Biodiesel thus produced was washed three to four times with an equal quantity of water acidified with acetic acid (0.1%) to avoid emulsification. Further, the biodiesel was washed twice with water to remove the soluble contaminants. Biodiesel was then dried by heating at 110ºC till the moisture content was obliterated. It was cooled and filtered, then subjected to further analysis.

2.4 Digestion of Oil and Biodiesel

Approximately 0.4g of oil sample was weighed and transferred to the digestion tube and 8 ml of concentrated nitric acid was added. Then the tubes are placed in Gerhardt's digestion block for digestion until the appearance of white precipitate. The same procedure was repeated for biodiesel digestion. Then the digested samples were made to 25 ml using distilled water and utilized for further analysis.

2.5 Analysis of Sulfur Concentration in Soil, Oil and Biodiesel

The sulfur content of the samples was analyzed by Inductively Coupled Plasma - Optical Emission Spectroscopy (ICP-OES) through the $CaCl_2$ extractant method (Turbidimetry) (Black, 1965).

3. RESULTS AND DISCUSSION

3.1 Survey and Documentation of *Calophyllum inophyllum* L. along Southern Karnataka

Calophyllum inophyllum L. trees were distributed along the southern Karnataka region, especially in coastal areas and interior land. The survey was conducted in three districts of Southern Karnataka viz., Bangalore, Hassan, and Udupi. Bangalore and Hassan are located in the southern interior region of Karnataka, while Udupi is in the south coastal region. The different study sites and its GPS locations are given in Table 1.

3.2 Oil Content of Calophyllum Kernels

The oil content of Calophyllum seed kernels was determined by using Soxtherm extraction. The results obtained in this study are presented in Table 2. There is a significant variation in the oil content of the kernels collected from different locations. The content of oil ranged from 52.67% to 73.95%. The maximum oil content was noticed in the kernels from Dombi, Udupi (73.95%), and the lowest was in GKVK 2 (52.67%). The oil content of Calophyllum in Bangalore, Hassan, and Udupi varied from 52.67 to 68.36 percent, 56.96 to 59.94 percent, and 62.08 to 73.95 percent respectively. Udupi district samples recorded more oil content than other districts. This might be due to higher nitrogen content in Udupi soil, which influenced the oil content. Similar results were reported by Shilpi et al*.,* [13] in sesame oil content. It is indicated in Fig. 1.

Oil formation is a complex biochemical pathway in which the enzymes play a significant role. Environmental conditions such as humidity, temperature, and soil characteristics are important parameters that influence the oil content in seeds. The percentage of oil in the kernels of Calophyllum was found to be higher compared to the other oil-yielding species. The oil percentage ranged from 47% to 75% as Atabani and Silva [3] reported. It is higher than Simaruba, Mahua, Jatropha, Pongamia, and Neem. Similar findings were reported by Pant et al*.,* [14], where they found that Jatropha oil content varied depending on the type of species and climatic conditions, but mainly on the altitude where it is grown. Manian and Gopalakrishnan., [15], also reported similar findings that photo assimilation was utilised more for plant growth than oil production at higher altitudes.

Table 1. Different study sites of *Calophyllum inophyllum*L. in Bangalore, Hassan, and Udupi districts with latitude, longitude, and altitude

S.No.	Districts	Locations	GPS points		
			Latitude	Longitude	Altitude(m)
1	**Bangalore**	Lalbagh 1	12° 57' 2.41" N	77° 35' 1.14" E	906.60
2		Lalbagh 2	12° 57' 1.8" N	77° 35' 0.96" E	887.40
3		GKVK - 1	13° 5' 27.85" N	77° 33' 56.48" E	1036.28
4		GKVK - 2	13° 4' 44.54" N	77° 34' 52.5" E	944.00
5	**Hassan**	Hassan 1	12° 58' 32.63" N	76° 16' 6.24" E	917.00
6	**(Biofuel Park,**	Hassan 2	12° 58' 33.6" N	76° 16' 6.89" E	906.20
7	**Madenur)**	Hassan 3	12° 58' 33.06" N	76° 16' 6.85" E	945.30
8		Hassan 4	12° 58' 33.06" N	76° 16' 6.42" E	924.90
9		Hassan 5	12° 58' 33.71" N	76° 16' 7.07" E	930.10
10	**Udupi (UD)**	UD - Kapsi, Kalthodu	13° 49' 39.94" N	74° 40' 28.99" E	90.76
11		UD- Gantihole	13° 49' 39.54" N	74° 40' 28.2" E	5.20
12		UD- Poduvari	13° 49' 51.21" N	74° 39' 37.3" E	5.60
13		UD- Dombi, Shiroor	13° 49' 51.21" N	74° 39' 37.3" E	5.60

Table 2. Oil content in Calophyllum kernels

S. No.	Location	Oil content (%)
1	Lalbagh 1	62.28^{i}
2	Lalbagh 2	68.36^{j}
3	GKVK – 1	59.34^{e}
4	GKVK – 2	52.67^{a}
5	Hassan 1	59.94^{g}
6	Hassan 2	56.96^{b}
7	Hassan 3	58.37^{d}
8	Hassan 4	59.60^{f}
9	Hassan 5	57.03^{c}
10	UD - Kapsi, Kalthodu	62.08^{h}
11	UD – Gantihole	72.58^{l}
12	UD – Poduvari	70.85^{k}
13	UD – Dombi, Shiroor	73.95^{m}
	Mean	0.05
	SE(m)	0.02
	C.D (5%)	0.02
	CV (%)	0.04

Note: Superscript alphabets (a to m) indicate significance at the 0.05 level

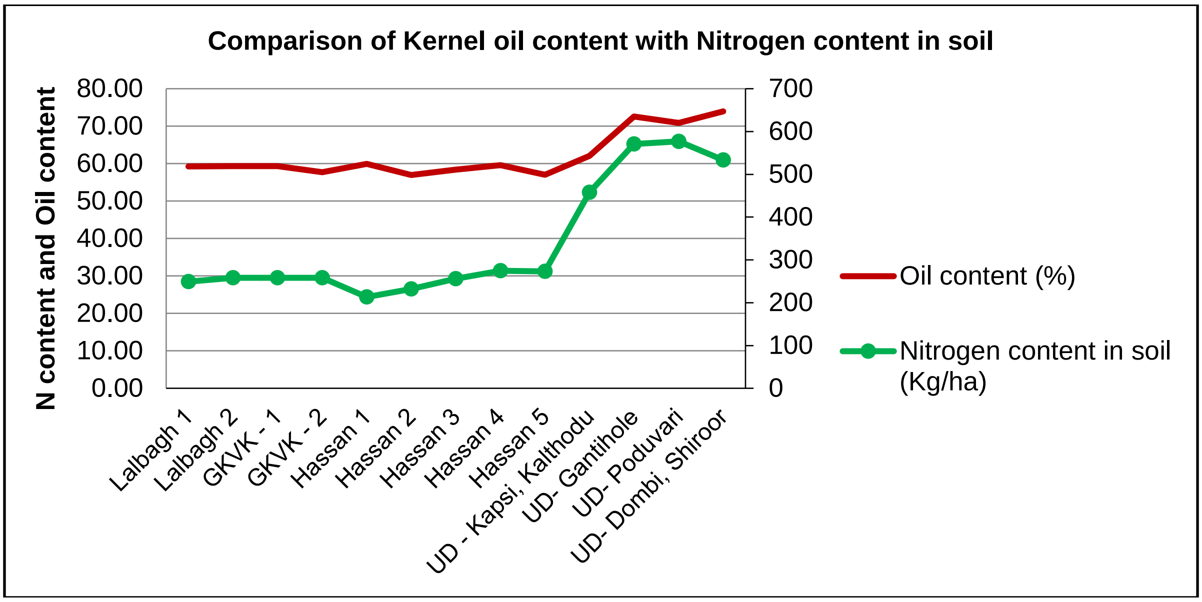

Fig. 1. Comparison of Kernel oil content with Nitrogen content in soil

3.3 Determination of Sulfur Content in Soil and Oil

The soil samples collected under each tree in 13 different locations at 0-15 cm and 15-30 cm depth were subjected to the analysis of sulfur content. Total sulfur in the study area ranged from 10.31 ppm to 53.47 ppm. The samples collected from the Udupi region have shown higher sulfur content (42.49 to 53.47 ppm). The sulfur content is on par with pH of the soil, which is in the acidic range. This might be due to the sulfur which is converted to sulfuric acid and gives an acidic pH range in that region. Similar results were obtained by Motowicka and Terelak [16]. Sulphur is available to plants in the form of sulphates. Sulphates dissolved in the water column are assimilated mainly by plants and incorporated into amino acids, i.e. cysteine and methionine [17,18]. However, some are also bound to sulphated polysaccharides in the oxidized form.

The S content is found to be higher in the Udupi region (72 to 88 ppm) compared to Hassan (42 to 67 ppm) and Bangalore (52 to 59 ppm). This might be due to its occurrence in the soil at a higher rate.

3.4 Biochemical Characteristics of Biodiesel

The quality of biodiesel is expressed in terms of the Calophyllum biodiesel's fuel properties, such as acid, iodine, saponification, density, viscosity, calorific, and sulfur content. All are well within the ASTM and BIS standards. Similar results were reported by Madhusudana [6]. The data obtained from the study are given in the Table 4.

3.5 Sulphur Content in Calophyllum Biodiesel

Sulphur emissions, both gaseous and particles, are harmful to human health. Acute exposure can cause trouble in breathing and long-time exposure to those emissions can cause heart disease, pulmonary illness, or even untimely death. In the environment, sulfur oxides are reactive and form H_2SO_4 which comes down with the rain and the acid rain again depletes nature in many ways. Moreover, buildings disintegrate because of acid rain [19]. Sulfur compounds in biodiesel are present in different forms such as hydrogen sulfide, sulfides, sulfur dioxide, mercaptans, and thiophenes.

The sulfur content in biodiesel should be within 500 ppm (ASTM D6751). Sulphur content in Calophyllum biodiesel varied from 7 ppm to 46 ppm. The concentration is within the prescribed limits.

Amongst these, the highest concentration is in Hassan and Udupi, and the lowest is in Bangalore. This might be due to higher concentration of sulfur in the soils of Hassan and Udupi. The simple relationship of sulfur content in each district's sample was taken as average in the case of soil (irrespective of depth) and oil, then compared with sulfur content in biodiesel. The relationship between the sulfur content in soil, oil and biodiesel is presented in Fig. 2. This shows that edaphic factors might have influenced the sulfur content in biodiesel.

Table 3. Sulphur(S) content in soil at different depths and oil at various locations

Location	Sulphur (ppm) in Soil			S(ppm) in Oil
	Soil Depth			
	0-15 cm	15-30 cm	Mean	
Lalbagh 1	10.8	9.83	10.31[a]	58
Lalbagh 2	18.24	16.89	17.56[i]	59
GKVK – 1	12.84	12.17	12.51[f]	56
GKVK – 2	12.51	12.14	12.32[e]	52
Hassan 1	16.16	11.77	13.97[g]	57
Hassan 2	16.16	13.25	14.70[h]	42
Hassan 3	12.49	11.26	11.88[d]	48
Hassan 4	11.73	9.63	10.68[c]	67
Hassan 5	11.28	9.58	10.43[b]	67
UD – Kapsi, Kalthodu	42.02	42.97	42.49[j]	72
UD – Gantihole	44.88	43.97	44.42[k]	87
UD – Poduvari	49.66	51.55	50.60[l]	82
UD – Dombie, Shirur	52.51	54.42	53.47[m]	88
Mean	23.94[b]	23.03[a]		
	Location	Depth	Interaction	
SE(m)	0.012	0.005	0.016	6
C.D (5%)	0.034	0.013	0.048	13
CV (%)	0.135			6.88

Note: Superscript alphabets (a to m) indicate significance at the 0.05 level

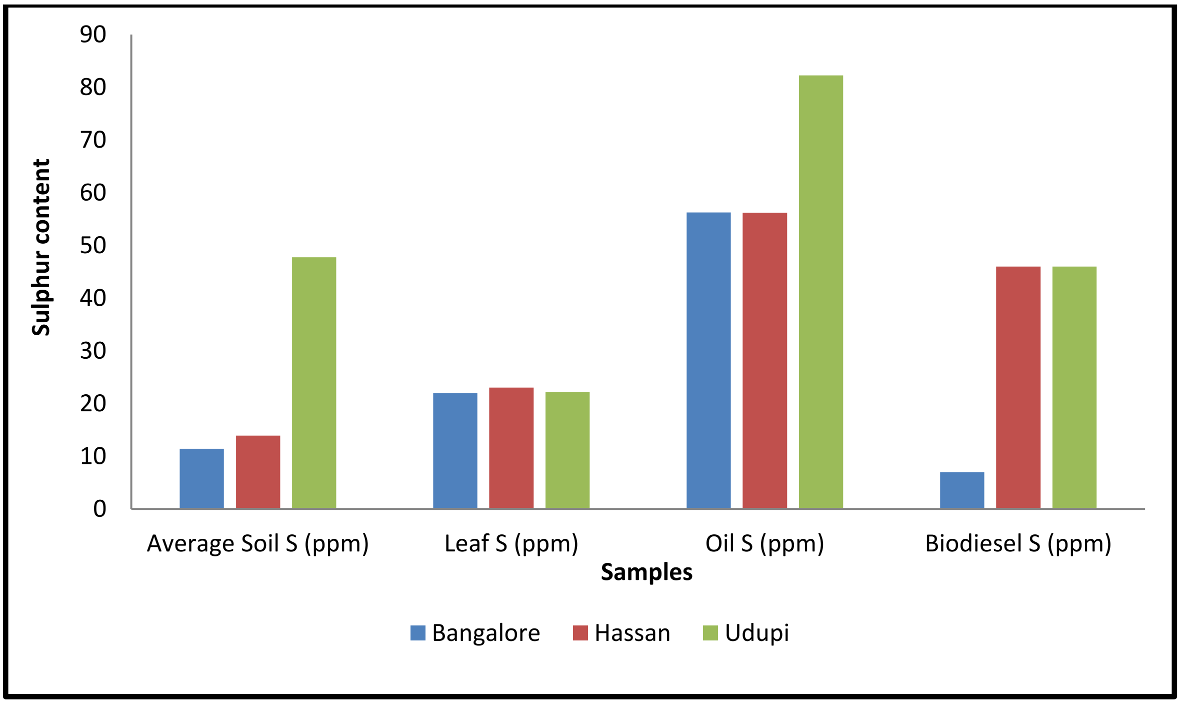

Fig. 2. Sulphur content in Soil, oil and biodiesel relationship

Table 4. Bio-chemical characterization of biodiesel

Biodiesel Parameters	ASTM D6751	BIS (ISO 15607)	Diesel	Biodiesel			C.D (At 5%)	SE(m)	C.V. (%)
				Bangalore	Hassan	Udupi			
Acid value (mgKOH/g)	Max 0.80	0.5 Max	0.02	0.232[b]	0.4[c]	0.072[a]	0.07	0.02	5.23
Iodine value (gI$_2$/100g)	-	120 Max	-	66.48[c]	47.19[a]	57.49[b]	1.18	0.38	1.48
saponification value (mgKOH/g)	-	-	-	185.49[a]	202.97[b]	184.90[a]	13.00	4.17	4.40
Calorific value (MJ/kg)	-	-	44.96	39.86[c]	39.13[b]	38.15[a]	0.03	0.01	0.05
Density (kg/m^3) at 40°C	860-900	860-900	840	874.18[c]	891.14[b]	873.82[a]	1.96	0.629	0.16
Viscosity (cSt)	1.9 - 6.0	2.5-6.0	3.12	5.56[a]	5.98[c]	5.78[b]	0.06	0.02	0.67
Cloud point Temp.(°C)	Max 18	-	-	9.8[a]	15.0[c]	11.4[b]	0.08	0.03	0.46
Pour point Temp.(°C)	-	-	-	6.0[a]	9.0[b]	6.0[a]	0.08	0.02	0.78
Flashpoint (°C)	Min 130	-	55	168.0[c]	158.0[a]	166.0[b]	0.76	0.25	0.33
Sulphur (ppm)	Max 500	-	-	7[a]	46[b]	46[b]	1	0	1.489
FAME content (%)	-	96.5 Min	-	90.6[b]	73.5[a]	99.7[c]	0.096	0.031	0.078

Note: Superscript alphabets (a to c) indicate significance at the 0.05 level

Gantihole – Udupi

Dombi – Udupi

Kapsi – Udupi

Lalbagh 2 - Bangalore

Plate 1. *Calophyllum inophyllum L.* trees selected for study in different locations

GKVK 1 – Bangalore

Hassan 1

Plate 2. *Calophyllum inophyllum* L. trees selected for study in different locations

Fibrous leaves

Fragrant White Flowers

Fresh fruits in tree

Dried fruits

Dried kernels

Oil and Biodiesel

Plate 3. *Calophyllum inophyllum* L. leaves, flowers, fresh and dried fruits, dried kernels, kernel oil and biodiesel

Plate 4. Apparatus used for transesterification process

Biodiesel settling **Biodiesel washing**

Plate 5. Apparatus used in biodiesel production process for Biodiesel settling and washing

4. CONCLUSION

The present study entitled "Influence of Soil Sulfur Content and Other Edaphic Factors on Sulfur Levels in *Calophyllum inophyllum* L. Biodiesel" was conducted with an objective to study the potentiality of Calophyllum biodiesel.

The study conducted on Calophyllum kernel oil content recorded that Udupi samples contain more oil content compared to other districts. This might be due to higher nitrogen content in Udupi soil which influenced the oil content. The oil available sulfur content has shown on par relationship with soil. This indicates that most of the elements present in oil might be due to its presence in soil.

Due to the high acid value (FFA>4%) of Calophyllum oil in all the locations, it has to pass through a two-stage process during biodiesel production. The transesterification process was carried out using NaOH as a catalyst and methanol. During the process, 1:6 oil to methanol ratio was used at 60ºC reaction temperature. The maximum conversion of biodiesel under optimum condition was observed in Udupi samples (99.7%) and least conversion in Hassan samples (73.5%). The properties like acid value, iodine value, saponification value, calorific value, viscosity and density, and FAME content of biodiesel were also studied. There was a drastic decrease in acid value, density, and viscosity of biodiesel compared to oil. This might be due to the transesterification process. Calorific value increased.

The higher concentration of sulfur was found in Hassan and Udupi and the least in Bangalore. This might due to the presence of a higher concentration of sulfur in the soils of Hassan and Udupi. This shows that edaphic factors might have influenced the sulfur content in biodiesel. All the three biodiesels produced one from each district were well within the prescribed ASTM standards.

However, the regional variability in sulfur content suggests the need for localised quality control measures in biodiesel production. These elements should be removed for usage as biodiesel. The purification process with conventional methods such as wet washing with water or acidified water had not found to remove these impurities. The other methods likely Vaccum distillation had to be performed.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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