

Exploring Sustainable Sources for Biodiesel Production: Utilizing Fish, Chicken Waste and Aquatic Weeds to Reduce Emissions"

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Abstract

Biodiesel is an alternative, sustainable, eco-friendly, clean, biodegradable fuel that helps to get rid of fossil fuels that are not only depleting but also causing health issues for humans and environment. In present study, waste animal fats (fish and chicken waste) and aquatic weeds (*Eichhornia crassipes*, *Pistia stratiotes* and *Lemna minor*) were utilized as oil source for biodiesel production. Highest lipid content shown by fish waste oil that was 36% then followed by 33% in chicken waste oil, 16.7% in *Eichhornia crassipes* oil, 12.6% in *Lemna minor* oil and 4.11% in *Pistia Stratiotes* oil. Fatty acids converted into fatty acid methyl esters (biodiesel) through transesterification method. Then characterized by GCMS that confirmed the presence of highest percentages like 51% of oleic acid in Chicken waste oil biodiesel, 35.7% of palmitic acid in Fish waste oil biodiesel, 14.6% of palmitoleic acid in *Eichhornia crassipes* oil biodiesel, 61.7% of phthalic acid in *Lemna minor* oil biodiesel and 10.9% of linoleic acid in *Pistia Stratiotes* oil biodiesel. Physicochemical analysis of each biodiesel confirmed within the ASTM standard. Emission performance of biodiesel and petro-diesel blends showed maximum decrement in CO (26%, 22%, 24% and 23%), NO (90%, 80%, 60% and 60%), SO₂ (70%, 87%, 87% and 83%) and smoke (25%, 50%, 25% and 62%) were observed in fish waste oil biodiesel, *Eichhornia crassipes* oil biodiesel, *Pistia Stratiotes* oil biodiesel and *Lemna minor* oil biodiesel respectively. Similarly increment in CO₂ (3.75%, 3.8%, 3.72% and 3.8%) and O₂ (11.62%, 11.32%, 11.57% and 11.68%) was observed respectively because biodiesel have more oxygen content that make the complete combustion of fuel. Thus, biodiesel can adopted as an alternative fuel having less environment impact.

1. Introduction

Energy has become vital necessity for survival of human globally (Amenaghawon et al. 2021). Different activities are totally energy dependent like domestic, transportation and industrial because of many reasons like modernization, raising population and increasing needs for better lifestyle (Khan et al. 2020). Mostly fossil fuels utilized as source of fuel energy for multi-purposes in the world (Buchori et al. 2022). Fuels are ineludible for economic growth of a country as the development is more dependent on how much energy demands are fulfilled (Maawa et al. 2020; Alsultan et al. 2021). Major portion of fossil fuel consuming sector is transportation with two-third usage approximately. According to estimation, the energy demand will be increase by 50% from present until 2030 (Chozhavendhan et al. 2020; Quah et al. 2019). In the same way, the fossil fuels resources like coal, oil, petroleum, natural gas and diesel are depleting due to their fast utilization (Nabgan et al. 2022; Teoh et al. 2022). These situations imposed serious threats to energy security as it is estimated that petroleum will be run out in next half century (Mujtaba et al. 2020). In order to make the survival of humans possible in future these must be synchronization (Ewunie et al. 2021).

Similarly, extensive use of non-renewable fuel are source of environmental pollution by releasing gaseous emissions like carbon monoxide, oxide of nitrogen, carbon dioxide, sulphur, hydrocarbons and particulate matter (Khanjani et al. 2021; Rajkumar et al. 2019) that result in harmful health impacts (Clauser et al. 2021; Erison et al. 2022). The major cause of air pollution are industries and transportation that are using fossil fuel based energy sources (Chen et al. 2022; Simsek 2020). In 2015, about 193 countries signed the agreement of SDGs in United Nations general assembly with purpose of working for well-being of humans and sustainable use of resources (Rozina et al., 2022). In that SDG goal 7 (affordable clean energy) and 12 (responsible consumption and production) are related to it.

Therefore, in such scenarios of raising issues of limited quantity, increasing demand and negative environmental impacts going for alternative is best practical way (Iqbal et al. 2021; Hoang et al. 2021; Almarashi et al. 2020) like biofuels including biodiesel, which is sustainable, biodegradable, low sulphur content and renewable fuel (Ingle et al. 2020; Shafiq et al. 2020). It is consist of mono-alkyl esters of long chain fatty acids mixture (Firemichael et al. 2020). It has low environmental impacts than conventional fuel with reduced emissions and free of aromatic compounds (Da Costa Cardoso et al. 2019; Saravanan et al. 2020) and increases energy security as well (Chandran 2020; Forsberg et al. 2021; Ge et al. 2021). It have almost same physicochemical properties with diesel (Sahar et al. 2022). It can directly use or with some blends in existing engines without technological modifications (Samuel et al. 2022).

It can easily produce by various physicochemical processes and method like pyrolysis, transesterification, supercritical methanol method, micro emulsions, and ultrasonic waves assisted method etc (Bashir et al. 2022). However, in literature mostly transesterification method is reported as simple and cost effective (Tamjidi et al. 2021) and can be performed by using catalyst or without catalyst (Fatima et al. 2021; Nayab et al. 2022). Variety of catalyst have been used and majorly classified into three groups depending upon nature. First type is homogeneous catalyst, second is heterogeneous catalyst and third is biocatalyst (Athar et al. 2022; De Oliveira et al. 2022).

Selection of economic and ecological friendly feedstock is the crucial step in production of biodiesel (Yasar, 2020) as 70–80% of production price is dependent on it (Amenaghawon et al. 2021; Sun et al. 2021). Different types of edible, non-edible oils and waste animal fats have been reported and classified into different generations (Singh et al. 2021; Da Costa Cardoso et al. 2019). Meanwhile non-edible oils and waste derived feedstock are cheaper and high yield oils (Sundar et al. 2022; Athar and Zaidi 2020).

Fish and chicken waste as oil source for biodiesel production is cost effective feedstock like in term of waste management and environmental issues (Odetoye et al. 2021). According to literature about more than 60 types of fatty acids in fish and chicken waste oil (Al- Azad et al. 2019) which can easily converted into esters by transesterification (Toldra-Reig et al. 2020). These are cheaper than other plants and vegetable oils (Mahyari et al. 2021). Therefore, it can be a source to minimize the wastes and associated impacts (Foroutan et al. 2021; Hossain et al. 2022).

Aquatic weeds (*Eichhornia crassipes*, *Pistia stratiotes* and *Lemna minor*) are exotic, floating plants with significant negative ecological and monetary effects (Bronzato et al. 2020). They showed good lipid content for biodiesel production with no compromise on fuel quality (Mubarak et al. 2021; Ullah et

al. 2021). They seriously harm aquatic habitat, prevent the use of water for drinking water sources, fish farming, recreational activities, and hydropower production (Miranda et al. 2020).

The aim of present study was to produce biodiesel by utilization of different types of waste as feedstocks like fish and chicken waste and aquatic weeds (water hyacinth (*Eichhornia crassipes*), water lettuce (*Pistia stratiotes*) and duckweed (*Lemna minor*)). Biomass characterization of each feedstock done in order to determine the proximate parameters. The extracted oil was converted into fatty acids methyl esters by transesterification method through utilization of different acid and basic homogeneous catalyst. Produced biodiesel was characterized by gas chromatography mass spectrometry (GCMS) and physicochemical parameters were analyzed. Then the biodiesel was blend in different quantities with petroleum diesel and emissions were monitored and compared with petroleum diesel.

2. Materials and methods

2.1. Materials

Fish and chicken waste samples were collected from market near Anarkali Lahore. It includes high fat containing discarded organs like skin, internal organs and head. Samples of aquatic weeds (Macrophytes) like *Eichhornia crassipes* and *Pistia stratiotes* were collected by hand sorting method from GCU botanical garden, Lahore while *Lemna minor* was collected by using plankton net from a lake near Mureedkey.

Other chemicals used like concentrated sulphuric acid, hydrochloric acid, sodium hydroxide, potassium hydroxide, anhydrous sodium sulphate, commercial ethanol, methanol, propanol, phenolphthalein all were of analytical reagent grade provided by Sigma Aldrich Company.

2.2. Sample drying and characterization (proximate analysis)

All samples were oven dried at 105 °C for 24 hours (Zhang et al. 2020). Then proximate analysis of each grinded sample was carried out as it provides blueprints of the biomass in order to estimate their utilization in energy processes. Percentage of moisture content, ash content, volatile content and fixed carbon were estimated according to methods described in (Kasthuri et al. 2021; Reza et al. 2022; Setyani et al. 2021).

2.3. Oil (Lipid) extraction and solvent recovery

The Soxhlet apparatus used to extract oil (lipids) for each type of feedstock. Commercial ethanol used as extracting solvent and extraction procedure was adopted from (Yasin et al. 2021). After completion of oil extraction, lipids and solvent was separated through rotatory evaporator. Lipid content of each type of sample was calculated by using formula given in (Bitire et al. 2021).

2.4. Acid value and free fatty acids determination

Acid value refers to the quantity of base required for neutralization of fatty acids present in oil. Before going for biodiesel production by transesterification method acid base titration was performed in order to check the acid value and free fatty acid content of oil samples because it has huge influence on conversion of fatty acids into fatty acids methyl esters (biodiesel). Procedure adopted given in (Hasan et al. 2022) used. Then Acid value and free fatty acid percentages calculated by using formula given (Al- Azad et al. 2019).

2.5. Biodiesel production and purification

The conversion of oil into biodiesel was carried out by transesterification through utilization of different catalyst. Single and two-step transesterification methods were adopted. The need of esterification before transesterification determined by free fatty acids content of oil. If the oil containing less than 2% of FFA then there is no need of esterification and transesterification will be performed directly (Bitire et al. 2021). For single step transesterification procedure given in (Kamran et al. 2020) was adopted and sodium hydroxide used as homogeneous catalyst. On other hand for two step transesterification different acid catalyst (H_2SO_4 and HCl) used during first step (esterification) and base catalyst potassium hydroxide kept same in all methods for second step (transesterification) for each type of oil sample and adopted procedure was of (Saravanan et al. 2020).

Biodiesel purification done by water washing described by (Khan et al. 2022). Biodiesel treated with anhydrous sodium sulphate to remove remaining water. Then biodiesel yield calculated by formula given in (Kumar et al. 2019).

2.6. Physicochemical properties of produced biodiesel

Different physicochemical parameters like density, kinematic viscosity, acid value and refractive index were determined by following the procedures of ASTM standards given in (Sahar et al. 2022).

2.7. GCMS Analysis of produced biodiesel

Fatty acid profile of biodiesel produced by transesterification reaction determined through gas chromatography -mass spectrometry model (GCMS - QP2010). It is considered as one of important qualitative parameter for biodiesel testing. GC separate the individual components (analyte) according to their molecular weight and then identified by MS according to their molecular weight (Ameer et al. 2022).

2.8. Emission monitoring of produced biodiesel

Biodiesel burned and emissions were monitored. When biodiesel burnt gaseous, emissions came out of upper chimney of gyzer and monitored by sensor of TESTO 350. The blends were prepared B0 (100% petro-diesel), B10 (10% biodiesel + 90% petro-diesel), B20 (20% biodiesel + 80% petro-diesel) and B30 (30%

biodiesel + 70% petro-diesel) by mixing biodiesel and petro-diesel. Oxides of nitrogen, sulphur dioxide, smoke, carbon monoxide, carbon dioxide and oxygen emissions were monitored.

3. Results and discussion

3.1. Proximate analysis (characterization) of feedstock

Percentage of moisture content, ash content, volatile content and fixed carbon content were determined for each type of feedstock and given in (Table 1). The quantity of water accessible in dry sample of a solid biomass is moisture content and its higher quantity in biofuel reduces quality (Sukarni et al. 2019; Maksimuk et al. 2021) therefor for effective quality, its value should be less than 10 (Fadhil et al. 2017). The moisture content of all feedstocks in present study were within range compared to other reported studies (Gusain et al. 2017; Maktoof et al. 2020; Setyani et al. 2021). Volatile matter is majorly comprises of hydrogen gas, hydrocarbons, carbon dioxide, and some tar (Zhuang et al. 2021). During thermochemical process, the reactivity of biomass is dependent on quantity of volatile matter present. Therefore, if volatile content will high the reactivity will also be high (Reza et al. 2022; Magalhães et al. 2022). Volatile percentages of all feedstocks were higher and greater value reported in fish waste in present study. Ash content determines the mineral content of biomass. The ash content in dry mass is affected by the presence of inorganic elements, which refers to the nonflammable content of biomass (Lam et al. 2019). According to standard it should not be more than 14% otherwise it will affect the quality. The ash content of present study are comparable with reported literature (Gusain et al. 2017; Kamarudin et al. 2013; Maktoof et al. 2020).

Table 1
Proximate analysis, lipid content, FFA (Free fatty acid) % and acid values of samples

Feedstock	Percentages %						Acid value (mg KOH/g)
	Moisture content	Volatile content	Ash content	Fixed carbon	Lipid	Free fatty acid	
Fish waste	9.1	87	12	8	36	17.5	33
Chicken waste	7.1	80	15	2.1	30	20	40
<i>Eichhornia crassipes</i>	4.5	45.1	25.1	25.3	16.7	0.33	0.67
<i>Pistia stratiotes</i>	5.3	45.0	21.7	28	4.11	0.6	1.2
<i>Lemna minor</i>	3.6	60.0	18.6	17.8	12.60	0.44	0.88

3.2. Extracted lipid content, acid value and FFA% of samples

Lipid extraction was done through the Soxhlet apparatus. Although it is a time-consuming process but it is cost-effective as compared to the conventional Bligh and Dyer method (Ulmer et al. 2018). Because chloroform is required in that method which is expensive as compared to commercial ethanol which was used in present study. Fish and chicken waste oil have shown higher lipid content than aquatic weeds as given in (Table 1). Because animal fats are lipid rich than aquatic weeds. Only the internal organs of fish and chicken were used because of their low market demand, higher fat content and considered as waste. Similarly, fish and chicken waste oil have more acid value because of presence of free fatty acids. Similar values reported in (Al-Azad et al. 2019; Gusain et al. 2017; Rahman et al. 2021).

3.3. Transesterification and biodiesel yield

Single step transesterification was not successful because of high acid values of oil. Huge quantity of soap formed with negligible amount of biodiesel. On other hand two-step, transesterification had successfully formed biodiesel with different catalyst as given in (Table 2). Acid value was reduced using acid catalyst, which leads to formation of fatty acid methyl esters using base catalyst. Reported literature of different countries on biodiesel production along with different catalyst and reaction conditions given in (Table 6).

Table 2
Biodiesel yield of each feedstock with different catalyst

Feedstock	H ₂ SO ₄ and KOH catalyst	HCl and KOH catalyst
Fish waste oil biodiesel	91%	82%
Chicken waste oil biodiesel	84%	ND
<i>Eichhornia crassipes</i> oil biodiesel	85%	89%
<i>Pistia stratiotes</i> oil biodiesel	83%	82%
<i>Lemna minor</i> oil biodiesel	91%	90%
*ND not detected		

3.4. Physicochemical Properties of produced biodiesel

Physicochemical properties of newly produced biodiesel are among the important criteria to be determined. It must be meeting the existing standards in order to be reliable. Results of present study are given in (Table 3). Density is important parameter as it have direct influence on injection and fluid movement of fuel. Generally, biofuels have higher densities than conventional diesel (Kamran et al. 2020). Higher density produces slow injection, less efficient atomization and combustion. Density have relation with composition of fatty acids as well. Greater the degree of unsaturation of fatty acids, higher will be the density. The densities of present study are comparable with reported in (Hundie et al. 2022; Nayak et al. 2021) and within ASTM standard that is 860–900 Kg/m³. Viscosity is another important parameter affecting the quality of fuel. It has influence on atomization and flow of fuel. Higher viscosity causes ring sticking, fuel pump failure, and carbon deposits and poor atomization as well (Karkal et al. 2020). Greater the length of fatty acids chain greater will be value but opposite in case of increase in amount of unsaturation. Results of present study are consistent with reported in (Angulo et al. 2020; Da Costa Cardoso et al. 2019; Ergan et al. 2022; Kumar et al. 2020) and within ASTM standards. The presence of free fatty acids in oil and fuel are evaluated by their acid number and is related to long-term performance of fuel against corrosiveness. Therefore, lower the value good will be the fuel stability (Zhang et al. 2020). So in order to avoid high acid value moisture should be avoided. Acid value of present study biodiesel are within ASTM standards and comparable with literature (Ching-Velasquez et al. 2020; Santya et al. 2019). The Refractive Index is a parameter that relates to molecular weight, fatty acid chain length, degree of unsaturation, and degree of conjugation. When the biodiesel temperature is close to cloud point, a cloudiness appears, and the refractive Index changes. Therefore, it's a significant parameter to evaluate the state of biodiesel. Results of present study are similar to reported in (Binhweel et al. 2021; Shafiq et al. 2020).

Table 3
Physicochemical properties of produced biodiesel

Parameters	ASTM standard	Fish waste oil biodiesel		Chicken waste oil biodiesel		<i>Eichhornia crassipes</i> oil biodiesel		<i>Pistia stratiotes</i> oil biodiesel		<i>Lemna minor</i> oil biodiesel		Conventional diesel
		H ₂ SO ₄ + KOH	HCl + KOH	H ₂ SO ₄ + KOH	HCl + KOH	H ₂ SO ₄ + KOH	HCl + KOH	H ₂ SO ₄ + KOH	HCl + KOH	H ₂ SO ₄ + KOH	HCl + KOH	
Kinematic viscosity (mm ² /s)	1.9-6	4.2	4.9	5.2	-	4.0	4.5	5.1	5.4	5.3	5.6	2.71
Density (Kg/m ³)	860–900	856	888	847	-	823	855	863	892	874	895	821
Refractive Index (RIU)	-	1.33	1.32	1.49	-	1.44	1.45	1.43	1.46	1.42	1.48	1.44
Color	-	Bright yellow	Golden brown	Yellow golden	-	Golden brown	Dark golden color	Yellow Golden	Greenish color	Light golden	yellow	Cloudy yellow
Acid value (mg KOH/g)	≤ 0.8	0.62	0.85	0.59	-	0.81	0.92	0.62	0.76	0.45	0.5s3	0.15

3.5. GCMS analysis of produced biodiesel

Triglycerides generally comprises of three types of fatty acids, which are responsible for quality of biodiesel includes saturated, monounsaturated, and polyunsaturated fatty acids. Presence of more saturated fatty acids are responsible for low-temperature fluidity on other hand unsaturated are responsible for more oxidation and cold fluidity (Khan and Haleem 2022). In present study there were 17, 6, 13, 17 and 11 peaks obtained by GCMS analysis of Fish waste oil biodiesel (FWOB), chicken waste oil biodiesel (CWOB), Eichhornia crassipes oil biodiesel (ECOB), Pistia stratiotes oil biodiesel (PSOB) and Lemna minor oil biodiesel (LMOB) as shown in (Fig. 1, Fig. 2, Fig. 3, Fig. 4 and Fig. 5) respectively. Complete profile of detected fatty acids with percentage composition given in following (Table 4). Majorly present fatty acids includes oleic acid (51.7% in CWOB then followed by 42.9% in ECOB, 34.2% in FWOB, 29% in PSOB and 18.1 in LMOB), palmitic acid (35.7% in FWOB, then followed by 25.6% in PSOB, 25.5% in CWOB, 15.7% in LMOB and 3.5% in ECOB) and stearic acid (7.9% in FWOB, 7.3% in CWOB, 4.7% in PSOB, 4.07% in ECOB and 3.5% in LMOB). Similar compositions reported in (De Medeiros et al. 2019; Espootin et al. 2021; Farooq et al. 2022; Nayak et al. 2021; Premadasa et al. 2022; Sundar et al. 2022) by using different feedstock for biodiesel production.

Table 4

Fatty acid profile obtained by GCMS analysis of Fish waste oil biodiesel (FWOB), chicken waste oil biodiesel (CWOB), *Eichhornia crassipes* oil biodiesel (ECOB), *Pistia stratiotes* oil biodiesel (PSOB) and *Lemna minor* oil biodiesel (LMOB).

Fatty acids	Molecular weight		Composition wt%				
			FWOB	CWOB	ECOB	PSOB	LMOB
Valeric acid	C6:0	130	0.88	-	-	-	-
Azelaic acid	C11:0	216	2.22	-	-	3.5	-
Myristic acid	C14:0	242	3.33	-	-	2.4	-
Pentadecanoic acid	C15:0	256	0.70	-	-	1.4	-
Palmitic acid	C16:0	270	35.7	25.5	3.5	25.6	15.7
Palmitoleic acid	C16:1	268	6.61	-	16.4	4.8	-
Margaric acid	C17:0	284	1.25	-	-	1.6	-
Cyclopropaneoctanoic acid	C17:1	282	0.95	-	-	0.92	-
Stearic acid	C18:0	298	7.9	7.3	4.07	4.7	3.52
Oleic acid	C18:1	296	34.2	51.7	42.93	29	18.1
Linoleic acid	C18:2	294	5.73	12.3	10.9	3.04	-
Phthalic acid	C24:0	390	-	3.14	20.9	22.5	61.7

3.6. Emission monitoring of produced biodiesel

Fuel emissions are among major challenges now a days because they are directly impacting the human and environmental health. Present study had monitored the CO, NO, SO₂, CO₂, O₂ and smoke reduction percentages of biodiesel produced from fish waste oil, Chicken waste oil, *Eichhornia crassipes* oil, *Pistia stratiotes* oil, *Lemna minor* oil with help of TESTO 350 flu gas analyzer. Different blends were prepared and percentage reduction of these emissions were compared with petro-diesel and reported literature as given in (Table 5).

Table 5
Comparison of reported and present study emissions with different feedstocks

Feedstock for biodiesel production	Percentage reduction in emissions							References
	CO%	NO _x %	HC%	SO ₂ %	Smoke %	CO ₂ %	O ₂ %	
Fish waste oil	26↓	80↓	-	70↓	25↓	3.75↑	11.62↑	Present study
<i>Eichhornia crassipes</i> oil	22↓	80↓	-	87↓	50↓	3.8↑	11.32↑	Present study
<i>Pistia stratiotes</i> oil	24↓	60↓	-	87↓	25↓	3.72↑	11.57↑	Present study
<i>Lemna minor</i> oil	23↓	60↓	-	83↓	62↓	3.8↑	11.68↑	Present study
Parsley oil	29.4↓	21.1↓	4.7↓	-	-	23.8↓	-	Bitire et al., 2023
<i>Salvinia molesta</i>	14↓	12.8↓	20.8↓	-	10.9↓	3.38↓	12.8↓	Mubarak et al., 2021
<i>Elaeocarpus Ganitrus</i> oil	50↓	19.1↓	49.1↓	-	11.6↓	15↓	-	Viswanathan et al., 2021
Waste palm and fish oil	18.2↓	10.6↑	23.4↓	-	15.4↓	-	-	Nayak et al., 2021
Chicken waste	3.8↓	4↓	-	-	-	5.4↑	-	Ge et al., 2021
Plastic oil	-	15↓	45↓	-	-	60↓	-	Sekar et al., 2021
Corn oil	33↓	2↑	16↓	-	-	9.5↑	-	Sathyamurthy et al., 2021
Jatropha oil	24↓	2.1↑	16.7↓	-	-	13.3↑	-	Singh et al., 2021
Palm-sesame oil	29.9↓	3.92↓	21.4↓	-	-	-	-	Mujtaba et al., 2020
Mahua oil	53↓	7↓	35↓	-	55↓	-	-	Raman et al., 2020
Palm oil	-	26↓	3.48↓	-	-	36.8↑	-	Maawa et al., 2020
Waste cooking oil	50↓	30↑	40↓	-	80↓	-	-	Zhang et al., 2020
Fish oil	14.3↓	5.1↑	26.2↓	-	17.5↓	-	-	Nguyen et al., 2020
Rapeseed and Mahua oil	20.6↓	3.7↑	8.5↓	-	6.9↓	-	-	Saravanan et al., 2020

Table 6

International studies on biodiesel production by using different feedstocks and catalyst

Country	Feedstock	Reaction/ catalyst type	Catalyst	Catalyst amount	Oil to Alcohol molar ratio	Reaction time and temperature	Yield	Reference
Thailand	Wet yeast	Direct 2step transesterification by lipase and acid catalyst	Yeast cell bound lipase H ₂ SO ₄	Wet cell conc. 17.97 mg-DCW 0.18 µL of 0.4M H ₂ SO ₄	Methanol 8.21 µL hexane 10.26 µL	1day at 30 C 2000 rpm 0.5 hr at 50 C 2000 rpm.	92%	Louhasakul et al., 2022.
Turkey	Canola oil	Heterogeneous catalyst	Dolomite	5%	1:9	120 min at 65 C	99%	Ergan et al., 2022
China	Soyabean oil	Solid based alkalized derived from spent bleaching clay	Na ₂ SiO ₃ /NaAlSiO ₄	0.32g	1:11	3 hr at 65 C	95%	Cong et al., 2022
Pakistan	Olive oil	Heterogeneous acid catalyst	TPA decorated Cr-Al	4 wt %	1:21	5 hr at 80 C with 600 rpm	93%	Islam et al., 2022.
Korea	<i>Chlorella vulgaris</i> oil	Nano catalyst	CaO nanocatalyst	4%	0.6:9	4 hr at 80 C	67%	Davoodbasha et al., 2021
UK	<i>Albizia Julibrissin</i> oil	Single step homogeneous catalyst	KOH	0.3 g	1:6	1 hr 65 C	98%	Khan et al., 2022
India	<i>Cassia auriculata</i> oil	Biocatalyst Enzymatic transesterification	Commercial lipase (<i>Aspergillus oryzae</i>)	2 wt%	1:6	2 hr at 35 C	92%	Sundar et al., 2022
Brazil	Waste cooking oil	Heterogeneous basic catalyst	Sodium potassium silicate	3.5 wt%	1:9	2 hr at 70 C	93%	De Oliveira et al., 2022.
Ethiopia	Jatropha curcus oil	Heterogeneous catalyst	Waste OX bones	5 wt%	1:12	4 hrs at 65 C	96%	Jayakumar et al., 2022
Finland	Microalga <i>Scenedesmus quadricauda</i>	One step in-situ transesterification	5 ml of CH ₃ OH:CHCl ₃ : H ₂ SO ₄	10:1:0.3 v/v/v	-	2 hrs at 90 C	-	Kafil et al., 2022
South Africa	Parsley seed oil	single step Basic catalyst	KOH	1 wt%	1:6	0.5 hr 60 C	98%	Bitire et al., 2021
Nigeria	Shea butter oil	Acid and biocatalyzed transesterification	H ₂ SO ₄ Calcine unripe plantain peels(CUPP) Calcine watermelon pod(CWMP)	1.5% v/v 2.5 g 2.5 g	4:1 5:1 3:1	55 min 50 min 55 min	92% 91%	Olatunji et al., 2021
Pakistan	Waste cooking oil	Heterogeneous catalyst	Hydroxyapatite (HAp) derived from Ostrich bones	5 wt%	1:15	4 hr at 60 C	90%	Khan et al., 2020
Egypt	Waste cooking oil	Homogeneous catalyst Heterogeneous catalyst	H ₂ SO ₄ Cement kiln dust	3.5% 2%	1:52 1:18	1 hr at 65 C 6 hr at 65 C	96% 98%	Al-Sakkari et al., 2020
Iran	<i>Elaeagnus angustifolia</i> .L	Single step homogeneous catalyst	KOH	1% oil molar wt	1:9	1 hr at 60 C	95%	Kamran et al. 2020
Lebanon	Waste cooking oil	Heterogeneous catalyst	CaO/Al ₂ O ₃ Aerogel.	1 wt% 3:1	1:11	4 hr at 65 C	89%	Kesserwan et al., 2020.
Indonesia	<i>Reutealis Trisperma</i> oil	Heterogeneous catalyst	KOH impregnated eggshell	5 wt%	1:12	1 hr at 60 C	94%	Kusmiyati et al., 2019.
Pakistan	Fish waste oil	Homogeneous acid and base catalyst	H ₂ SO ₄ KOH HCl KOH	10 ml/L for acid 7 g/L for base	1:0.35 for acid 1:0.25 for base	0.5 hr 60 C	91% 82%	Present study

Pakistan	Chicken waste oil	Homogeneous acid and base catalyst	H ₂ SO ₄	10 ml/L for acid	1:0.35 for acid	0.5 hr 60 C	84%	Present study
			KOH	7 g/L for base	1:0.25 for base			
			HCl					
			KOH					
Pakistan	<i>Eichhornia crassipes</i> oil	Homogeneous acid and base catalyst	H ₂ SO ₄	10 ml/L for acid	1:0.35 for acid	0.5 hr 60 C	85%	Present study
			KOH	7 g/L for base	1:0.25 for base		89%	
			HCl					
			KOH					
Pakistan	<i>Pistia stratiotes</i> oil	Homogeneous acid and base catalyst	H ₂ SO ₄	10 ml/L for acid	1:0.35 for acid	0.5 hr 60 C	83%	Present study
			KOH	7 g/L for base	1:0.25 for base		82%	
			HCl					
			KOH					
Pakistan	<i>Lemna minor</i> oil	Homogeneous acid and base catalyst	H ₂ SO ₄	10 ml/L for acid	1:0.35 for acid	0.5 hr 60 C	91%	Present study
			KOH	7 g/L for base	1:0.25 for base		90%	
			HCl					
			KOH					

3.6.1. Carbon monoxide emissions

CO is among the toxic gases formed because of partial combustion and oxidation of fuel. In present study all blend had shown low CO emissions than petro-diesel. These are because of presence of higher oxygen content in biodiesel than petro-diesel and result in complete combustion of fuel. The percentage reduction in present study blends were about 15–26% in FWOB, 19–22% in ECOB, 20–24% in PSOB, and 19–23% in LMOB and shown in (Fig. 6). Similar decrement in carbon monoxide emission of biodiesel than petro-diesel have been reported in (Khanjani et al. 2021; Pugazhendhi et al. 2020; Qureshi et al. 2019; Sharma et al. 2020; Shrivastava et al. 2020) by using different feedstocks.

3.6.2. Oxide of nitrogen emissions

Oxides of nitrogen are toxic, undesirable and hazardous gases emits during combustion of fuel. NO_x are formed by combination of nitric oxide and nitrogen dioxide (Rajak et al. 2020). Temperature, oxygen content, time duration and fuel properties are major causes of increased NO_x emissions (Teoh et al. 2022). In present study, only nitric oxides were observed in all types of samples. Percentage reduction in nitric oxide were about 40–80% in FWOB, 40–80% in ECOB, 20–60% in PSOB and 30–60% in LMOB and shown by graph in (Fig. 7). Similar studies also reported reduced emission of nitrogen oxide than present study (Khanjani et al. 2021) but some reported increased emissions than petro-diesel like (Ge et al. 2021; Nguyen et al. 2020; Rajesh et al. 2021) because of higher oxygen content in biodiesel. This higher oxygen content result in complete combustion and higher combustion temperature, thereby increasing the NO_x emission (Cavalheiro et al. 2020; Mujtaba et al. 2020).

3.6.3. Sulphur dioxide emissions

The petroleum diesel produces greater levels of SO₂ emissions compared to that of biodiesels. Sulphur dioxide is other harmful gas with many health impacts and is one of the main substances blamed for acid rain (Sharma et al. 2020). In present study decrement in Sulphur dioxide were about 60–70% in FWOB, 80–87% in ECOB, 83–87% in PSOB and 76–83% in LMOB as shown by graph in (Fig. 8).

3.6.4. Carbon dioxide emissions

Carbon dioxide produced because of complete combustion of fuel. It is not as hazardous gas like other gases but have role in environmental issues, as it is GHG. In present study more amount of carbon dioxide, emit than petro-diesel because of more amount of oxygen in biodiesel resulting in more conversion of CO into CO₂. Maximum percentage detected in B20 (3.75%) of FWOB, B30 (3.8%) of ECOB, B30 (3.72%) of PSOB and B30 (3.8%) of LMOB than that of petro-diesel that was 3.54% as shown in (Fig. 10). Similar increment reported other studies (Gundoshmian et al. 2021; Maawa et al. 2020; Singh et al. 2021).

3.6.5. Oxygen emissions

Oxygen have major role in complete combustion of fuel. As we know that oxygen is required for conversion of carbon monoxide into carbon dioxide as well as it is required for formation of other oxides. Biodiesel have shown high oxygen content than petro-diesel which favoring the smooth and complete combustion of fuel. Higher oxygen content was observed in biodiesel blends than in petro-diesel in present study as shown in (Fig. 11) and were inconsistent with reported in (Callegari et al. 2020; Mubarak et al. 2021).

3.6.6. Smoke percentage

Smoke produce due to less oxygen content and incomplete combustion of fuel. In present study about 25% in FWOB, 50% in ECOB, 25% in PSOB and 62% in LMOB percentage of smoke reduced (Fig. 9) than petro-diesel because biodiesel have more oxygen and lower Sulphur content resulting in complete and smooth combustion. Observed reduction in smoke percentages were similar to reported by others (Devarajan et al. 2021; Hemanandh et al. 2021; Teoh et al. 2022).

4. Conclusion

It is concluded from present study that both animal fats (fish and chicken waste) and aquatic weeds (*Eichhomia crassipes*, *Pistia stratiotes* and *Lemna minor*) contains good potential to be used as feedstock for biodiesel production especially in the current energy crises and resource depletion globally. These are cheap and non-valuable material with good quantity of lipids. It can resolve the issues cause by improper handling and dumping of animal fat waste. Similarly use of invasive aquatic weeds that threat to other aquatic plant but having good lipid content for biodiesel potential and so it's will be useful. Biodiesel is good emerging renewable energy source with less emission and can be use directly without modification in present engine technologies. Similarly different other oil sources can be used but non-edible oil are sustainable options for biodiesel production. Different alcohols and catalyst should be investigated as huge quantity of catalyst have already shown potential like catalyst can also be derived from waste materials and reaction parameters can be varied in order to produce cheapest and feasible energy source. Thus by utilizing feedstocks used in present study and also exploring new oil sources could be used to produce biodiesel and provide alternative energy source for developing countries like Pakistan where energy crises are high.

Declarations

Author's Contribution

Dr. Amtul Bari Tabinda: Supervision, Conceptualization, methodology design, final review and editing. **Javairia Ansar:** Conceptualization, methodology design, writing original draft, experimentation, writing review and editing. **Mahnoor Nadeem:** Manuscript review and editing. **Dr. Abdullah Yasar:** Supervision, conceptualization, final review and editing. **Maria Abdullah:** conceptualization, methodology design and experimentation. **Sana Rehman:** conceptualization, methodology design and experimentation. **Dr. Rizwan Rasheed:** conceptualization, final review and editing.

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Consent to participate

"It is declared that there is no involvement of individuals so no consent to participate is required"

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Figures

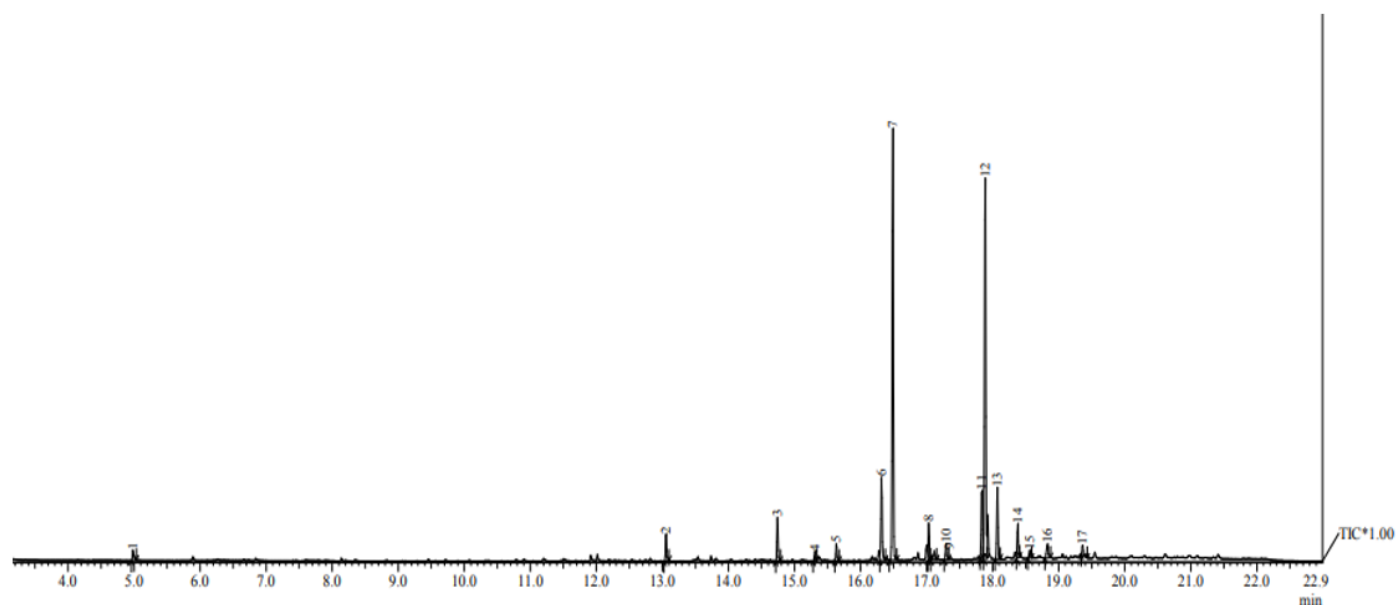


Figure 1

GCMS analysis of fish waste oil biodiesel

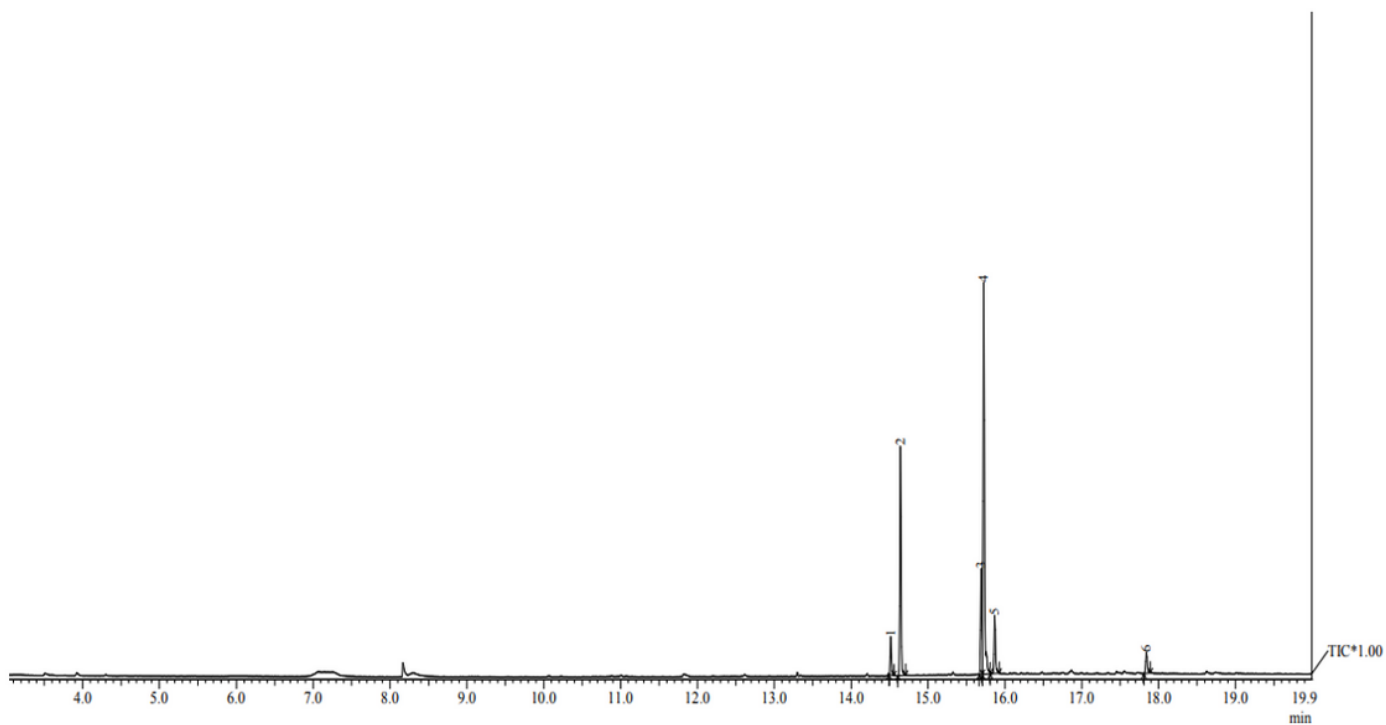


Figure 2

GCMS analysis of chicken waste oil biodiesel

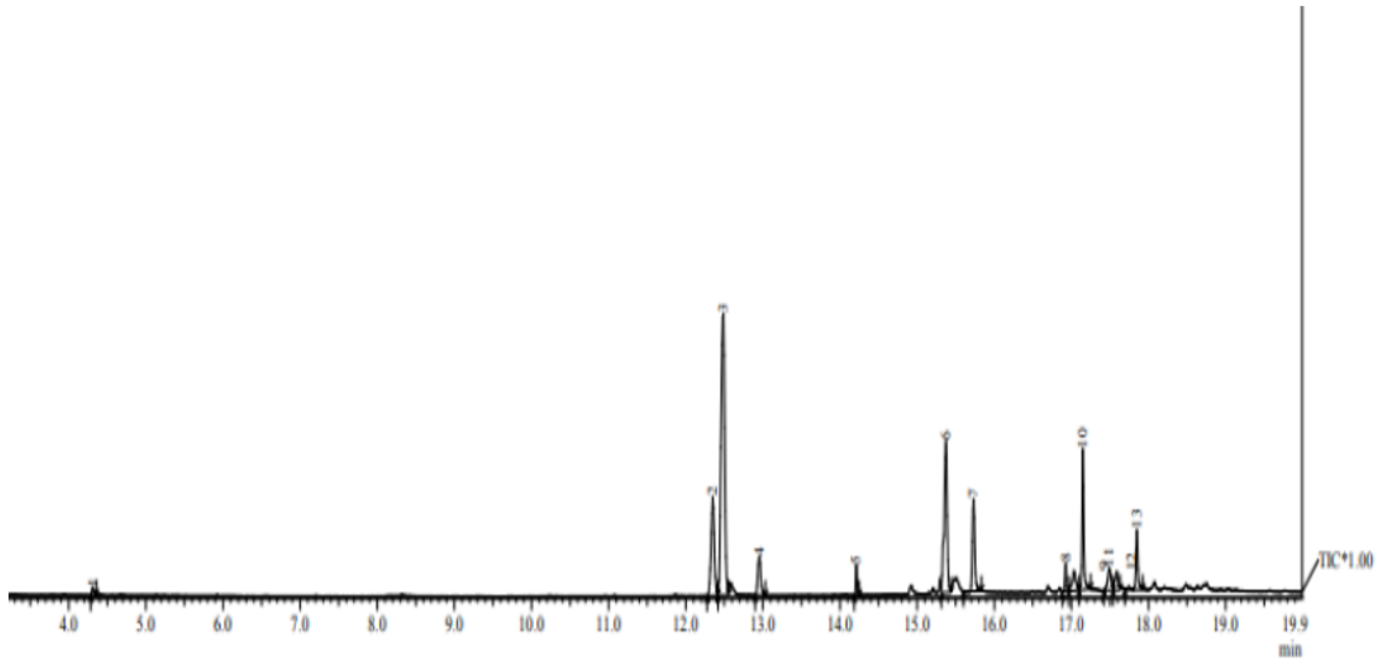


Figure 3

GCMS analysis of Eichhornia crassipes oil biodiesel

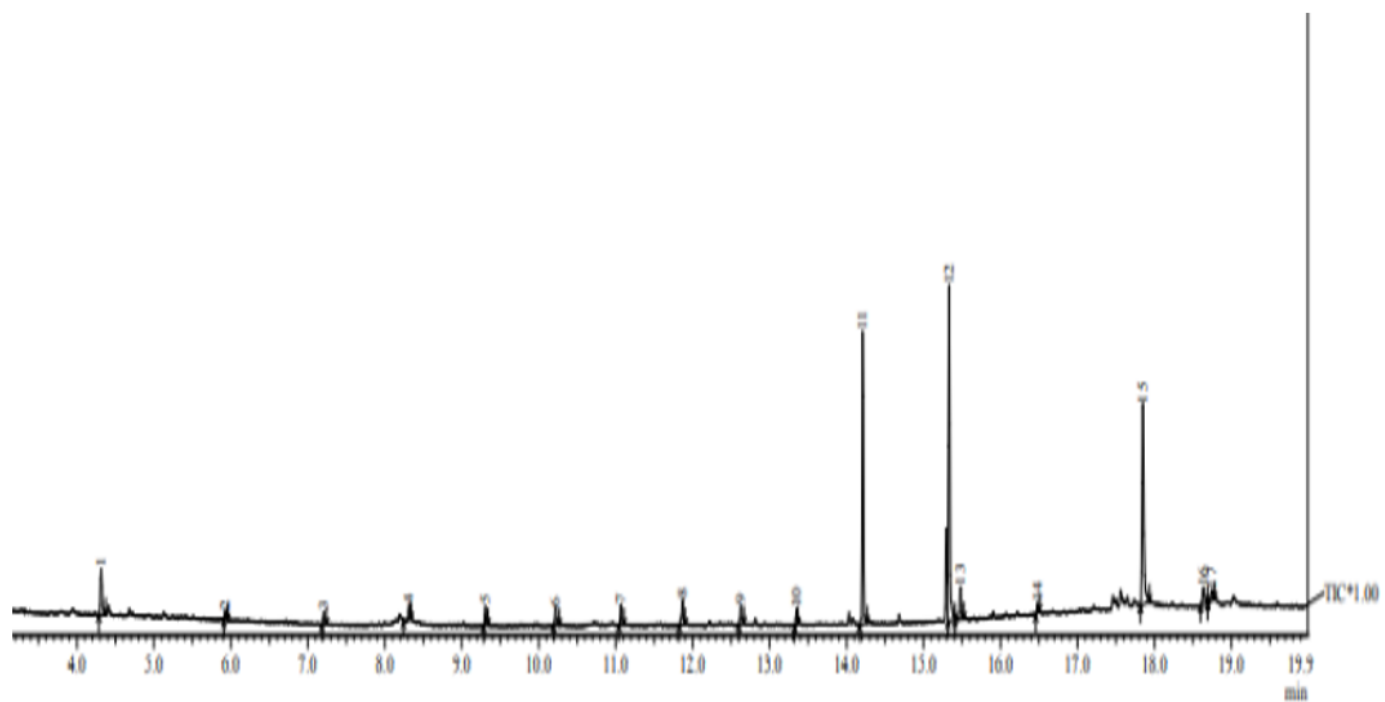


Figure 4

GCMS analysis of Pistia stratiotes oil biodiesel

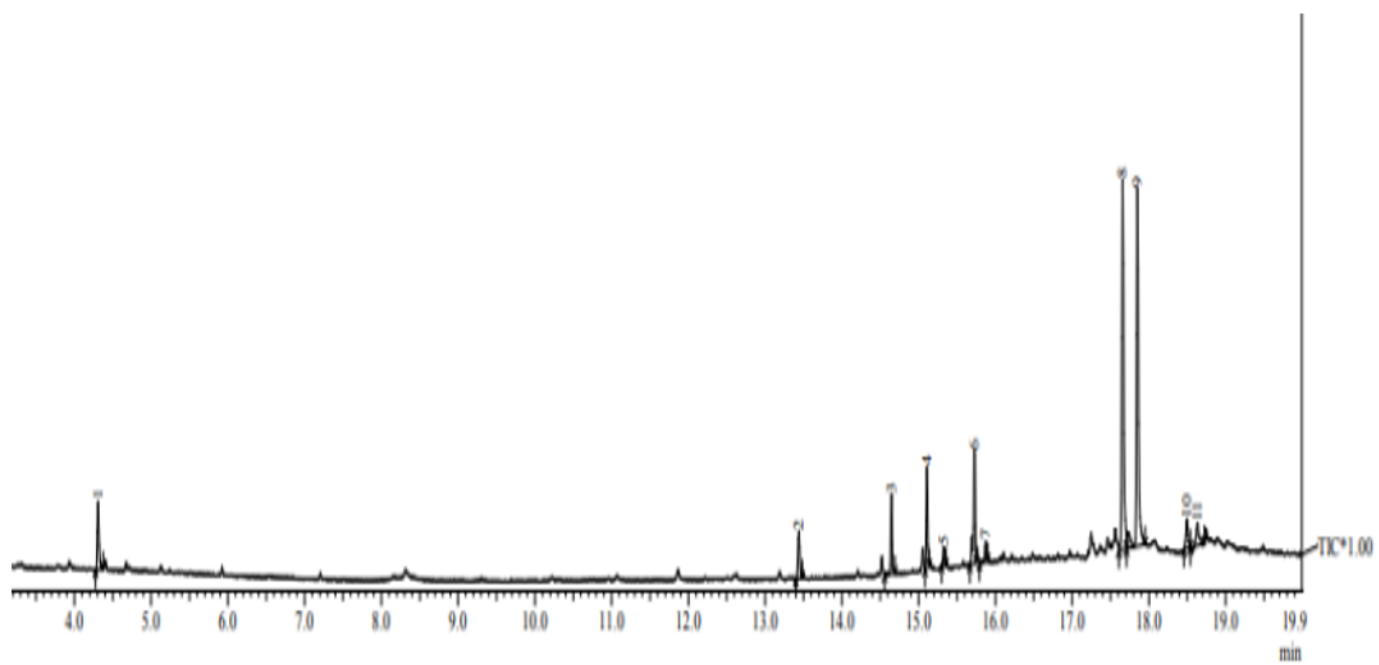


Figure 5

GCMS analysis of Lemna minor oil biodiesel

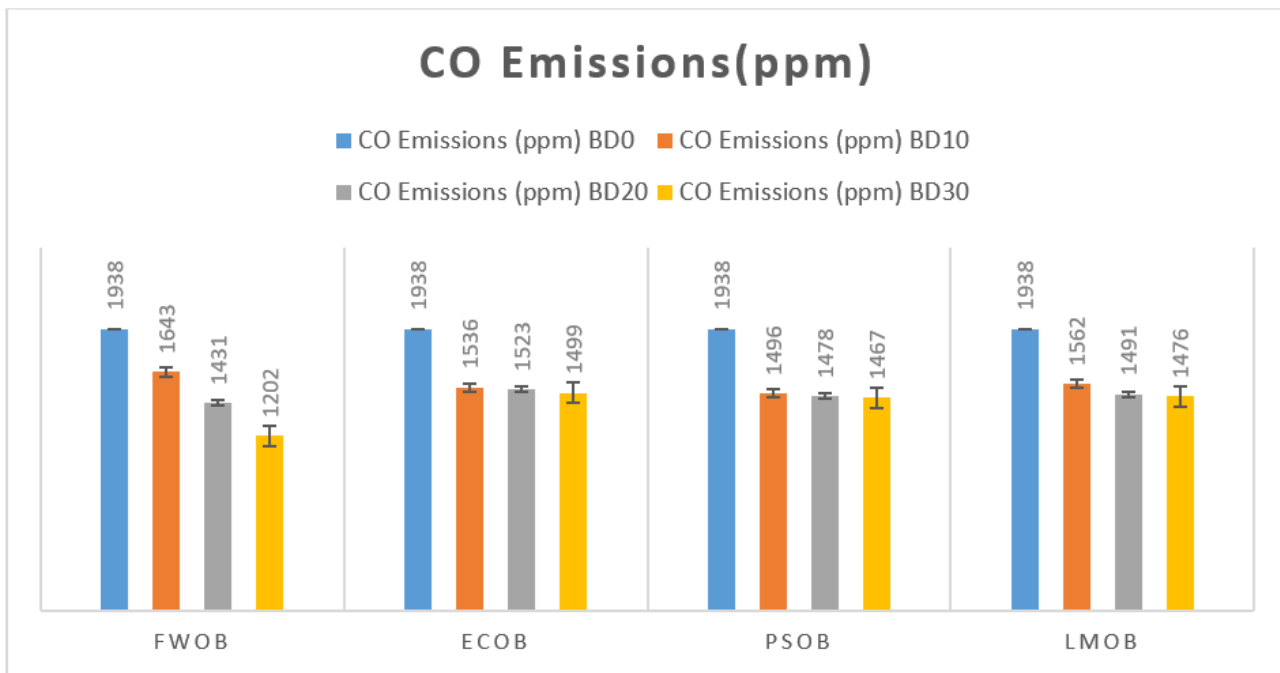


Figure 6

CO emissions of biodiesel blends

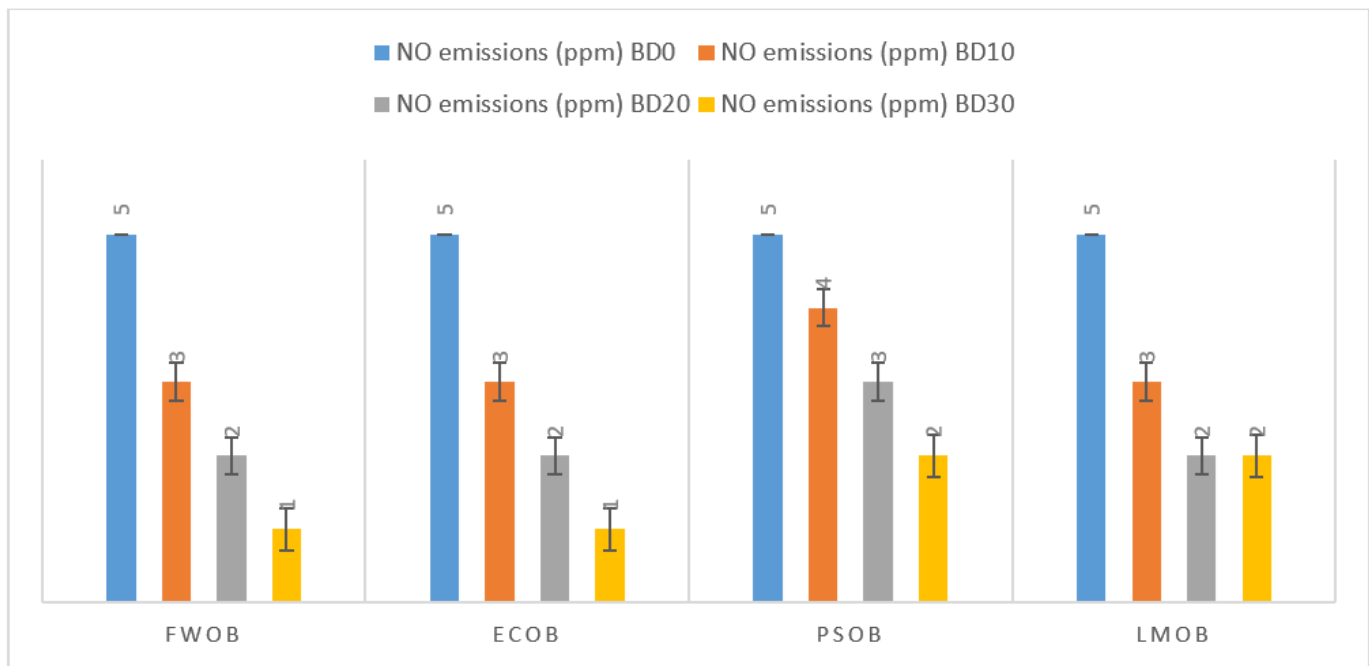


Figure 7

NO Emissions of biodiesel blends

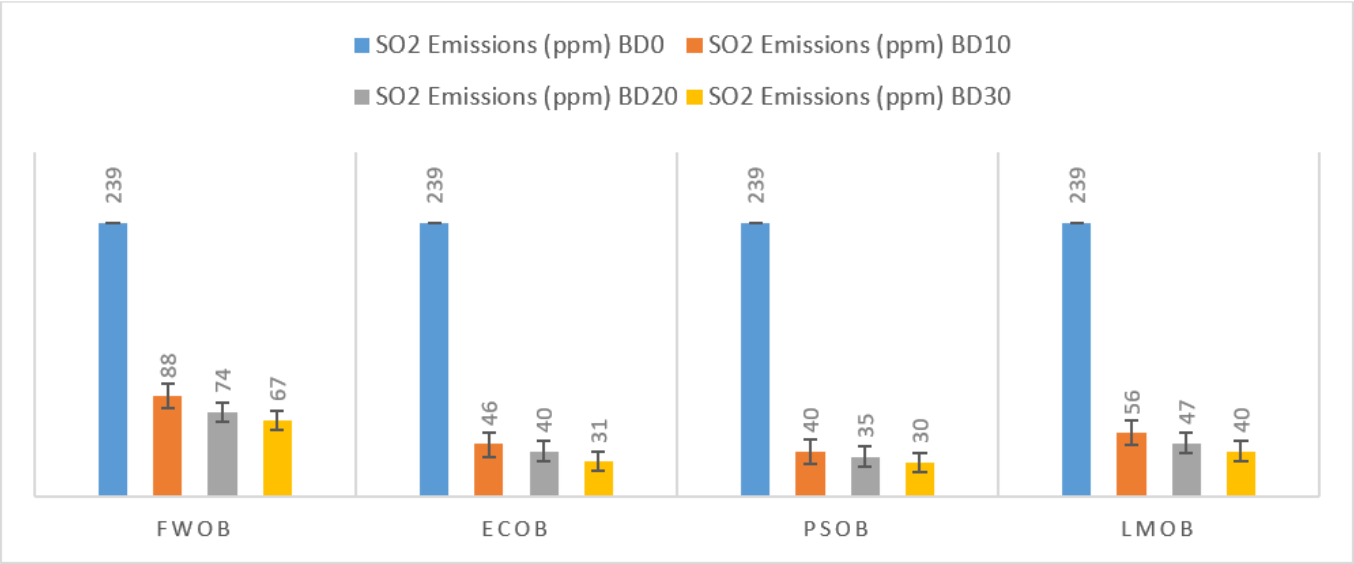


Figure 8

SO₂ Emissions of biodiesel blends

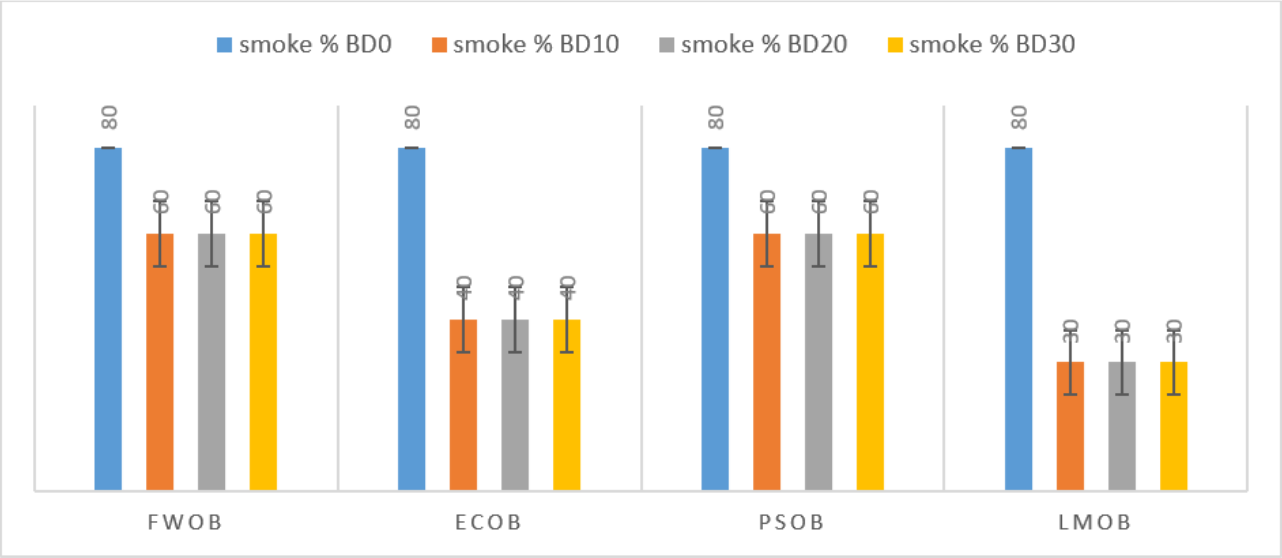


Figure 9

Smoke emissions of biodiesel blends

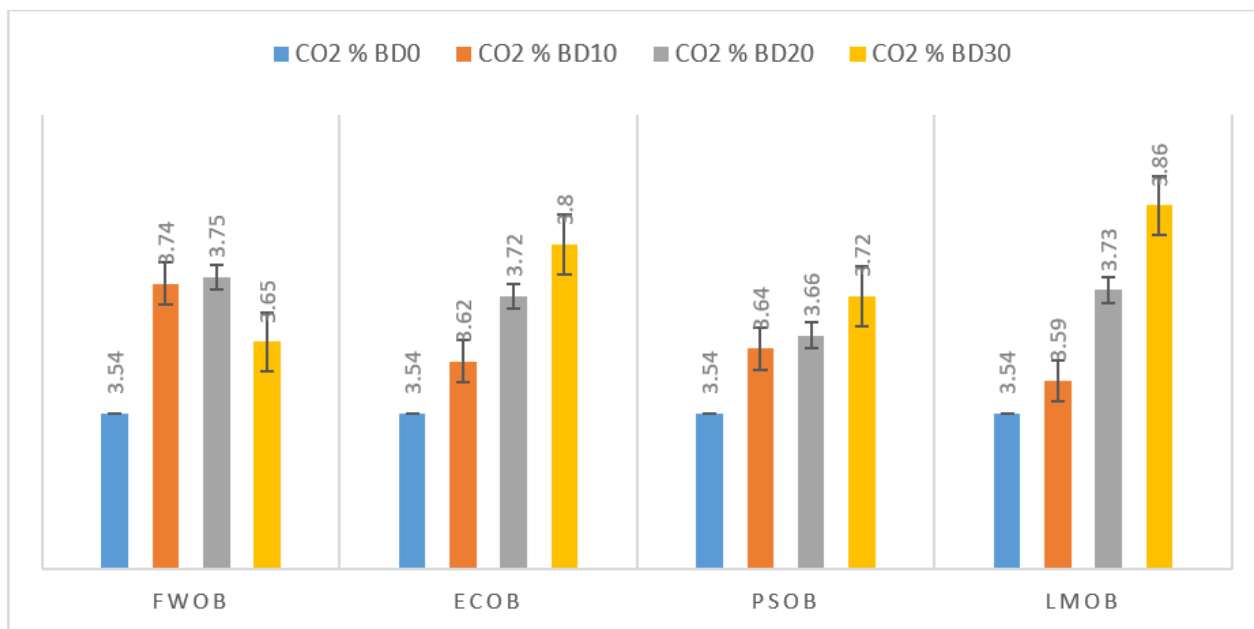


Figure 10

CO₂ Emissions of biodiesel blends

Supplementary Files

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