

Research Article

Waste to Energy: Response Surface Methodology for Optimization of Biodiesel Production from Leather Fleshing Waste

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Background. The demand for diesel fuel is constantly increasing, requiring its alternate that could be sustainable, technically feasible, price competitive, and ecologically acceptable. Biodiesel is one of ecologically acceptable substitute for the conventional fuels. **Methods.** Sufficient lime fleshing waste was collected from Addis Ababa tannery share company. The limed fleshing waste in the wet condition was delimed using boric acid, dried, chopped, and subjected to Soxhlet extraction using petroleum ether solvent. The oil was treated by orthophosphoric acid and distilled water to remove gums. The pretreated oil was subjected to homogeneous base catalyzed transesterification. Response surface was used to optimize the process variables. GC-MS was used to see composition of the biodiesel produced. **Result.** The oil yield of the goat, hide, and sheep delimed fleshing wastes were 23.08%, 12.05%, and 26.7%, respectively. The conversion to biodiesel by KOH-catalyzed transesterification was achieved above 96% under optimum conditions: a methanol-to-oil molar ratio of 6:1, catalyst amount of 1% w/w, and reaction temperature of 60°C for an hour reaction time. **Conclusion.** It was proven that fleshing wastes from tanneries whose storage and disposal are both troublesome and costly could be transformed to a fuel with low emission values and a performance close to diesel fuel.

1. Introduction

The human society, with its expansion and high technological development, is highly dependent on petroleum fuel for energy generation. However, fossil fuels are non-renewable resources, which take millions of years to form up and remained with limited reserves and high price. Around 60% of world's oil consumption and one-fifth of global CO₂ emissions are related to transportation sector [1]. The demand for diesel fuel is constantly increasing, requiring its alternate that could be sustainable, technically feasible, price competitive, and ecologically acceptable [2]. Politico-environmental situations, emission of huge amounts of greenhouse gases, health problems, economic concerns, cost-effectiveness, and predicted shortage of conventional fuels calls for the exploration

of alternative fuel to drive diesel engines [2]. Since biodiesel production from food-grade oils is not ethically acceptable and economically competitive with petroleum-based diesel fuel, therefore, it is necessary to look for novel and low cost oil feedstocks for its production. The use of cheap waste cooking oils (WCOs), waste oil by-products from edible-oil refinery, non-edible oils, and waste animal fats (WAFs) can be opted as low cost source in the production of sustainable and ecologically acceptable product.

One of these biomass sources would be the leather industry fleshing waste. The leather fleshing waste generated from the tanneries always triggers secondary and tertiary environmental impacts such as ground water contamination, greenhouse gas emission, and odor problem.

The capacity of world leather process is around 15 million tons of hides and skins per year. Solid waste generation from tannery process is estimated over 6 million tons/year. The disposal of large quantity of sludge which is about 4.5 million tons from effluent treatment plants is one of the major environmental pollution issues [1, 3, 4].

Ethiopia is relatively well-endowed in its livestock base with a share of 12, 15, and 22 percent of the global cattle, sheep, and goats population, respectively. This makes the country one of the most promising leather producing economic center in Africa. Ethiopia's livestock population is estimated at 52 million cattle ranking first in Africa, 27 million sheep population which is third in Africa and 23 million goat population which is third in Africa [5]. Currently, Ethiopia owns 28 tannery industries generating 86,567.22 tons of waste per annum [6]. Although the leather industry contributes to the national economic growth, it has also negative environmental impacts by generating organic and inorganic pollutants. Fleshing waste is among tannery wastes with considerable amounts of fatty acid composition as compared to the other vegetable oil fatty acid compositions. However, these wastes are not changed in to value added products. One way to recover the leather industry wastes is using them as feedstock in biodiesel production due to their rich fat content [7]. Consequently, the pollution coming from the leather industry wastes can be reduced dramatically and more value added products can be obtained by converting them to biodiesel. Essentially, biodiesel is nonaromatic and sulfur-free as compared with petrodiesel which contains 20 to 40 wt.% aromatic compounds and 500 ppm SO₂ [8].

Currently, the production of oil directly from the agricultural industry has the greatest potential for the production of biodiesel. However, producing biodiesel from virgin oil is not commercially feasible to satisfy the need of the transportation due to the cost and dilemma of food or energy. Different researchers have investigated the potential of animal fats and waste oils for biodiesel production [8–10]. The price of raw material consists of about 70–95% of the total biodiesel cost [3]. The major limitation in biodiesel production is cost of feedstock. The current alternative feedstock is cheap and disposed discriminately. Therefore, the purpose of the present study was to optimize parameters for biodiesel production from low cost fleshing oil feedstock through performing extensive experiments on the oil extraction, hydrolysis, and transesterification reactions throughout the production process. Goat, sheep, and cow skins are the three major raw materials utilized by the Ethiopian tanneries. Because of this reason, in our study we utilized the fleshing waste from these three sources.

2. Materials and Methods

2.1. Place of Experiment. The leather fleshing wastes were collected from Addis Ababa Tannery Share Company located in Addis Ababa, Ethiopia, as main raw materials. The fleshing waste was washed with distilled water to remove the impurities. All chemicals used in this study were analytical grade. The GC-MS analysis was carried out at Ethiopian Leather Industry Development Institute (LIDI), Addis Ababa. The

pH, viscosity, density, and ash content measurements were done in school of Chemical and Bioengineering Reaction Laboratory. All the other analysis was undertaken at Ethiopian Forest Product Utilization Research Center, Addis Ababa, Ethiopia. Triplicate was done for each of the measured variables.

2.2. Experimental Setup and Descriptions. Soxhlet extraction was used to extract the oil from the fleshing waste. A weighed amount of fleshing waste was charged into the Soxhlet. The heating mantle was heated to the desired temperature of boiling point of the solvent. Then, the extracted oil and solvent; i.e., petroleum ether 60–80°C was recovered by rotator vapor. The concentrated oil was subjected to degumming process to remove the phospholipids with centrifuge model TD₃, at 800 rpm to separate the oil from the mixture. Finally, the fleshing oil was washed several times with distilled water and dried to keep it in moisture-free container. All the pretreatment and transesterification experiments were performed in a laboratory scale glass reactor. Hot plate magnetic stirrer was used to heat and agitate the reaction mixture. When the crude oil temperature reached 70°C, a defined amount of orthophosphoric acid previously dissolved in distilled water was added to the heated oil. The mixture was stirred with magnetic stirrer at 200 rpm for 1 hour. After cooling, the reaction mixture was centrifuged with centrifuge model TD₃, 800 rpm for 20 minutes to separate the gum and oil mixture. The degummed fatty acid was further heated to 105°C to remove any remaining water. The acid and FFA values of the oil before and after degumming were determined and recorded. After obtaining the desired FFA level, the transesterification reaction experiment was performed in the same reactor. Vacuum filter was used for separation of the oils and the biodiesel from impurities.

2.3. Physicochemical Characterization of Waste, Oil, and Produced Biodiesel. The pH of the hide, goat, and sheep fleshing waste samples were determined by shaking five grams of sample of solid wastes in 100 mL of distilled water for 16–24 hours followed by direct measurement of the pH. To determine the moisture content of the fleshing waste, samples of the waste were first weighed and put in an oven at 105°C for 24 hours. It was kept in desiccators for about 30 minutes and then weighed and recorded. The wet-mass moisture content is expressed as follows.

$$\% \text{ moisture} = \frac{\text{Weight of dried sample (g)}}{\text{Weight of sample taken (g)}} \times 100\% \quad (1)$$

2.3.1. Ash Content of Limed Fleshing Waste (LFW) and Volatile Organic Content. About 1g of the oven dried LFW was taken in a silica crucible. The crucible containing the sample was ignited on the hot plate till the sample gets charred. Then the crucible along with the sample was kept in muffle furnace and heated at 550–600°C for 4 hours. Finally, it was allowed to cool and the ash formed was weighed. The percent of ash and volatile organic contents were calculated using the following formulae:

$$\% \text{ Ash} = \frac{\text{Weight of ash (g)}}{\text{Weight of sample taken (g)}} \times 100\% \quad (2)$$

% volatile organic content

$$= \frac{(\text{Weight of sample taken} - \text{Weight of ash}) (\text{g})}{\text{Weight of sample taken (g)}} \times 100\% \quad (3)$$

2.3.2. Total Fat Content of Delimed Fleshing Wastes. The total fat content was determined using AOAC method, 2005 [11]. About 1g of the sample was placed in the Soxhlet extraction apparatus and 150 mL of petroleum ether was added and the sample was extracted for 6 hours at the boiling point of the solvent. It was then allowed to cool and the ether evaporated. The weight of the extraction flask along with the dried extract minus the weight of the empty extraction flask gives the weight of the total fat being extracted. The % of total fat in delimed fleshing wastes was calculated using the following formula.

$$\text{Total fat\%} = \frac{\text{weight of the fat (g)}}{\text{weight of sample (g)}} \times 100\% \quad (4)$$

2.4. Physicochemical Characterization of Leather Fleshing Oil and Biodiesel. The physicochemical properties of the oil before and after pretreatment and after biodiesel production were conducted to identify the effects of the different pretreatments, i.e., degumming and acid catalyzed esterification. The physicochemical characterization of the biodiesel produced was performed to compare the results with the EN and ASTM standards. The physicochemical parameters that have been investigated include specific gravity, kinematic viscosity, acid value, ester value, FFA content, iodine number, high heat value, and saponification number.

2.4.1. Determination of Specific Gravity. The specific gravity of the oils extracted and biodiesel produced was determined by inserting hydrometer into a graduated cylinder containing 500 mL samples heated to 25°C.

2.4.2. Determination of Kinematic Viscosity. Digital sine-wave (SV-10, 2011, Australia) vibrio viscometer was used to determine the viscosity of the oil and the biodiesel. The viscosity was determined at different temperatures. The reading of the vibrio viscometer is dynamic viscosity. Therefore, the kinematic viscosity was determined using the following empirical formula.

$$\text{kinematic viscosity} = \frac{\text{dynamic viscosity}}{\text{density of oil}} \quad (5)$$

2.4.3. Acid Value (Acid Number) Determination. The acid value (AV) is the number that expresses, in milligrams, the quantity of potassium hydroxide required to neutralize the free acids present in 1 g of the substance. The acid value may be over-estimated if other acid components are present in the system, e.g., amino acids or acid phosphates. The acid value is

often a good measure of the breakdown of the triacylglycerol into free fatty acids, which has an adverse effect on the quality of many lipids. For acid value determination of oil, a titration solution of 0.1N KOH was prepared and stored in brown bottle for five days. Two grams of oil was added to a beaker and heated at 70°C for three minutes. Next 20 mL of anhydrous ethanol (99.5% W/W), 20 mL of diethyl ether, and 5 drops of phenolphthalein were added to the titration beaker containing the 2 gram oil sample. The solution was mixed thoroughly and titrated with 0.1 N KOH by adding a drop at a time until pink color appeared. The acid value was determined by using the following correlation [12].

$$\text{AV} = \frac{M \times N \times V}{W} \quad (6)$$

where N is normality of KOH, V is volume of titrant, i.e., KOH used for titration (mL), M is molecular weight of KOH, and W is weight of the oil sample.

2.4.4. Free Fatty Acid (FFA) Determination. The free fatty acid of the oil was determined using acid value previously determined using the following equation.

$$\% \text{ FFA} = \frac{\text{AV}}{2} \quad (7)$$

where % FFA is percentage of free fatty acid and AV is acid value of the oil.

2.4.5. Saponification Value Determination. The saponification value is the amount of mg of potassium hydroxide required to neutralize the free acids and to saponify the esters in 1 g of the substance. The saponification number is a measure of the average molecular weight of the triacylglycerol in a sample. Saponification is the process of breaking down a neutral fat into glycerol and fatty acids by treatment with alkali. The smaller the saponification number, the larger the average molecular weight of the triacylglycerol present; i.e., saponification value is inversely proportional to the mean molecular weight of fatty acids (or chain length). Twenty-five milliliter of 0.5 mL ethanoic solution of KOH was added to 2 g of previously extracted oil of LFW. The mixture was heated to 70°C for 30 minutes in reflex condenser. Then the heated mixture was cooled immediately and 5 drops of phenolphthalein was added for indicator; subsequently the sample was titrated with 0.5 mol/l HCl solution. Titration was stopped when color change was observed. The same procedure was also performed using blank level test; i.e., without the presence of oil sample in parallel to the above activity. The saponification was then determined by using the following equation [8, 9, 13, 14].

$$\text{SV} = \frac{M \times N \times (V_b - V_s)}{W} \quad (8)$$

where SV is saponification value, mg KOH/g oil, M is molecular weight of KOH, N is normality of HCl solution, V_b is volume of HCl solution used in blank, V_s is volume of HCl solution used in the sample, and W is weight of the oil used.

2.4.6. Determination of Iodine Value. The iodine value determination was done by measuring one gram of biodiesel/oil and dissolving it in 10 mL of chloroform. 25 mL of Hanus solution (which was prepared by dissolving 13.6 g of iodine in 400 mL glacial acetic acid by adding 6 mL of bromine liquid) was allowed to stand in dark place for 30 minutes. Ten milliliter of 15% KI (15g of KI dissolved in 100 mL) was added to the oil sample and titrated against 0.1N sodium thiosulfate until yellow solution turns into almost colorless [8, 9, 14].

$$IV = \frac{MI \times (V_b - V_t) \times N}{Ma} \quad (9)$$

where IV is iodine value (g I₂ / 100 g sample), V_t is volume of sodium thiosulfate solution for the sample (mL), V_b is volume of sodium thiosulfate solution for the blank (mL), N is standard sodium thiosulfate solution concentration (N), Ma is mass of the biodiesel sample (g), and MI is molar mass of iodine.

2.4.7. Determination of High Heat Value. Determination of high heat value (HHV) was conducted using empirical equation available. Therefore, for calculation of the HHVs (MJ/kg) of oils, the following equation was suggested [15].

$$HHV = 49.43 - \frac{(0.041 \times SV) + 0.015 \times IV}{Ma} \quad (10)$$

2.4.8. Determination of Cetane Number (CN). Cetane number was determined using empirical formula suggested elsewhere [8, 9]. The calculation was based on the results from saponification number (SN) and iodine value (IV) of oils. The CN was calculated as below:

$$CN = 46.3 + \frac{5458}{SV} - 0.225IV \quad (11)$$

2.4.9. Gas Chromatography-Mass Spectroscopy (GC-MS) Analysis. Gas chromatography stands out among other methods of analysis of fatty acids because it allows their easy separation and quantification. However, to analyze fatty acids by this technique, it is necessary to increase the volatility of the fatty acids by converting them in to methyl ester derivatives [16]. The esterification procedure followed was the method described by Bannon et al. [17]. Approximately 300 mg each from the sheep, goat, and hide fleshing oil were weighed. About 10 mL of KOH in 0.5 mol/L methanol was added to each sample. The mixture was heated under reflux for 3 minutes. Next 10 mL BF₃ (14%) in methanol was added. Then the mixture was heated under reflux for another 3 minutes. After cooling 6 mL heptane and approximately 30 mL saturated NaCl were added and vigorously stirred for 15 seconds. After phase separation, the top phase was collected and 2.5 μL for each samples was injected into the gas chromatographer

2.5. Fleshing Waste Treatment and Oil Extraction. One percent (Wt. / Wt.) boric acid was added with sufficient water in order to neutralize the pH. The fleshing waste was soaked with the acid for an hour at atmospheric conditions. Then, the

fleshing waste was chopped into smaller sizes and the oil was extracted in a Soxhlet extraction apparatus a little above the boiling point of the extraction solvent. Finally, the oil and the solvent mixture was subjected to rotator vapor for separation using the boiling point differences. The yield of the fleshing oil was calculated as follows:

$$\begin{aligned} \text{Yield (\%)} &= \frac{\text{Total weight of dried oil}}{\text{Total weight of flesh waste sample}} \times 100\% \quad (12) \end{aligned}$$

2.6. Pre-Treatment of Extracted Oil. In this study degumming was used as options of oil pretreatment. The degumming technique employed in this study was chemical degumming using 2% v/v (orthophosphoric acid/oil) and 3% v/v (distilled water/oil) at 70°C, 200 rpm mixing intensity for an hour. Then the gum was separated from the oil using a centrifuge at the speed of 800 rpm for 20 minutes. The acid value, FFA, pH, and saponification values of the degummed and non-degummed oil were measured.

2.7. Transesterification. After degumming pretreatment experimental work that lowered the FFA below 1% the next experimental stage in the production of biodiesel was transesterification. In this study alkali catalyzed transesterification was employed to convert the purified and pretreated oil. The catalyst (KOH) and the alcohol (CH₃OH) were mixed via vigorous stirring. Fifty milliliters of pretreated oil was charged to the experimental reactor. It was heated for 30 minutes at 100°C to dehumidify the oil to avoid parallel saponification reaction. The alcohol-catalyst mixture was charged to the reactor containing dehumidified, pretreated oil. The alcohol-catalyst-oil mixture was agitated at 750 rpm using magnetic stirrer for an hour. The temperature of reaction, catalyst to oil weight basis ratio, and alcohol to oil molar ratio were varied, to obtain a large range of methyl ester yields. Heating and stirring were then stopped, and the product was allowed to settle, to allow the two phases to be separated. The top phase consists of biofuel, whereas the lower phase contained a mixture of impurities. The upper layer was purified using distilled water and then dried over anhydrous sodium sulfate (Na₂SO₄). In this sense, 0.5 g of anhydrous sodium sulfate was added for every 100 mL of fatty acid methyl ester, stirred for 15 min, and then allowed to settle and be decanted. To remove solid traces from biofuel after the purification step, a filtration process was needed. This step was performed with the help of a vacuum pump and a 27 μm diameter filter paper. For each oil sample, three replications were performed. The optimum of each parameter involved in the process was determined while the rest of them remained constant. After each optimum was attained, this value was accepted and considered to be constant during the optimization of the next parameter. Ester yield results (given as percentages) were related to the weight of oil at the start (weight of ester/weight of oil). The biodiesel yield was determined as

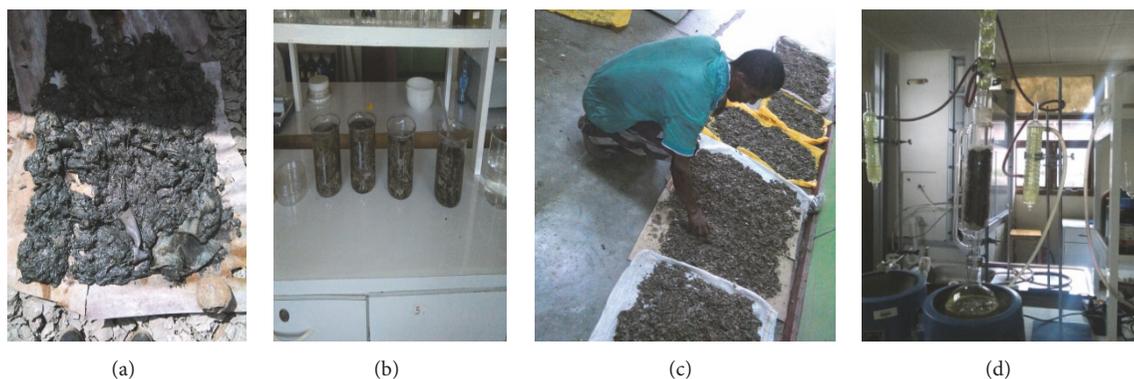


FIGURE 1: Preparation of waste and extraction of oil ((a) fleshing waste, (b) fleshing waste soaked with boric acid, (c) chopped and air dried fleshing waste, and (d) oil extraction using Soxhlet.

Yield (%)

$$= \frac{\text{Total weight of fatty acid methyl Ester}}{\text{Total weight of oil in the sample}} \times 100\% \quad (13)$$

2.8. Experimental Design. Response surface methodology (RSM) is a useful statistical technique which has been applied in research into complex variable processes [18]. It employs multiple regression and correlation analysis as tools to assess the effects of two or more independent factors on the dependent variables. Optimization of transesterification reaction was undertaken, where the alcohol to oil molar ratio, catalyst amount, and reaction temperature were investigated within one hour and 750 rpm mixing intensity. In order to optimize the central composite experimental design (CCD), a three-level-three-factor central composite design was employed in this study, which generates 20 experimental runs. Considering the treatments as in dependent variables, difference in means of each treatment that was compared at a significance level of p value 0.05 was considered throughout the study.

3. Results and Discussion

3.1. Physical Characterization of Raw Material. The raw material (Figure 1(a)) used in this study had unique characteristics; its color was grayish brown with a characteristic pungent odor. The odor decreases markedly after each consecutive water washing and deliming using boric acid (Figure 1(b)). The pH of the hide and sheep fleshing wastes was found to be 10.6, whereas the goat flesh had originally a pH of 12.25. The pH values are attributed to the alkalinity values of soaking conditions.

After washing with water to neutralize and wash out the alkalis about 1% (wt./wt.) boric acid was added with sufficient water in order to neutralize the pH. The fleshing waste was soaked with the acid for an hour at atmospheric condition (Figure 1(b)). Then, the flesh was chopped into small size and dried with the atmospheric air before extraction was commenced (Figure 1(c)). It was possible to reduce the pH of hide and sheep fleshing waste to 6.5 and that of goat to

8.6. The high fat content made the fleshing waste vulnerable for fermentation with different species bacterium such as *Lactobacillus plantarum*. Therefore, the fleshing waste was kept in a refrigerator, i.e., controlled environment that does not allow the growth of the bacterium. The physical parameters of liming and delimed fleshing waste are presented in Table 1.

The density of the goat fleshing oil was reduced to 906 kg/m^3 , viscosity to $57.8 \text{ mm}^2/\text{s}$, acid value to 1.13 mg KOH/g of oil, and free fatty acid to 0.56 %, at the oil pretreatment stage. The experimental results of the physicochemical characteristics of fleshing oils and pretreated oils are shown in Table 2.

As depicted in Table 2 degumming has reduced the density of the oil. The density of the oil is affected by contamination. It also shows the unsaturation level. Density values of oil samples depend on their fatty acid composition, as well as their purity. On the one hand, density increases with decreasing chain length and increasing number of double bonds, explaining high values for fuels rich in unsaturated compounds. The higher the unsaturation, the higher the density of fuels. A widely used method for density prediction of vegetable oils was developed by Lund and discussed by Halvorsen et al. [19]. The Lund relationship is $\text{sg}(298.15 \text{ K}) = 0.8475 + 0.00030 \text{ SV} + 0.00014 \text{ IV}$ where sg is the specific gravity of oil at 298.15 K, SV is the saponification value, and IV is the iodine value of the oil. The results obtained experimentally are in close agreement with the values calculated by using the suggested correlation. The density of the oil is inversely related to the temperature. Higher density values may increase the required fuel/air mixture, which increases emission of pollutants, including hydrocarbons, carbon monoxide, and particulate matter. Low values may favor the formation of a lean air/fuel ratio, leading to loss of engine power and consequent increased fuel consumption. Experimental data showed that biodiesel density decreased with increasing unsaturation levels of FAME [20]. The results obtained from this experiment agree with this fact. The density of the sheep, goat, and hide oils before and after degumming is presented in Figure 2.

TABLE 1: Physical parameters of liming and delimed fleshing waste.

S.N ^o .	Parameters	Limed fleshing waste			Delimed fleshing waste		
		sheep	hide	goat	goat	hide	sheep
1.	Color	Greyish brown	Greyish brown	Greyish brown	Pinkish brown	Pinkish brown	Pinkish brown
2.	Odor	pungent	pungent	pungent	normal	normal	normal
3.	Moisture Content	(63±0.5)%	(58±0.1)%	(82±0.2)%	(61±0.4)%	(60±0.3)%	(80±0.4)%
4.	Ash content	(3.06±0.2)%	(3±0.05)%	(2.8±0.1)%	(2.05±0.2)%	(1.8±0.45)%	(1.6±0.26)%
5.	Total fat content	Not determined	Not determined	Not determined	(23.08±0.25)%	(12.05±0.05)%	26.7±0.15%
6.	pH	10.6±0.15	0.6±0.2	12.5±0.4	6.5±0.25	6.5±0.1	8.6±0.3

TABLE 2: Physicochemical characterization of untreated and treated fleshing oil.

S.No	Parameters	Unit	Fleshing oil before treatment			Fleshing oil after treatment		
			goat	sheep	hide	goat	sheep	hide
1.	Density @ 298.15 K	Kg/m ³	911	905	900	906	900	895
2.	Water content @ 378.15 K	% mass	0.4	0.3	0.15	0.32	0.24	0.04
3.	Kinematic viscosity @ 313.15 K	mm ² /s	70.8	40.2	30.9	57.8	27.65	21.23
4.	Acid value	mg KOH/g	6.1	3.5	3.25	1.13	2.8	2.7
5.	FFA	%	3.05	1.75	1.63	0.56	1.4	1.35
6.	Saponification value	mg KOH/g	165.6	198.6	191.57	148.1	170.5	171.3
7.	Higher heating value	MJ/Kg	42.2	40.2	42.43	42.38	40.86	43.13
8.	Iodine value	g/100g	66	74	80	65.13	65	75

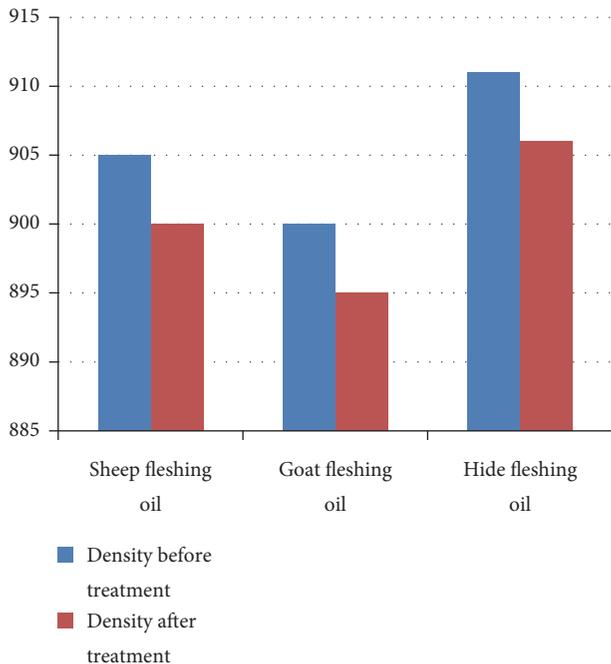


FIGURE 2: Density of the sheep, goat, and hide oils before and after degumming.

3.2. Physicochemical Characterization of the Fleshing Oil and Biodiesel

3.2.1. Kinematic Viscosity of Oil and Biodiesel. Viscosity is the measurement of a fluid's resistance to flow defined as the force is required to move a surface one square centimeter in area past a parallel surface at a speed of one centimeter

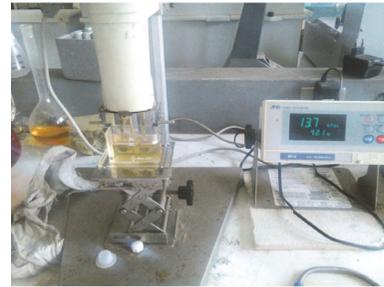


FIGURE 3: Determination of kinematic viscosity using viscometer.

per second, with the surfaces separated by a fluid film one centimeter thick. Laboratory measurements of viscosity normally use the force of gravity to produce flow through a capillary tube (viscometer) at a controlled temperature. This measurement is called kinematic viscosity. Kinematic viscosity is absolute viscosity of a fluid divided by its density at the same temperature of measurement. It is the measure of a fluid's resistance to flow under gravity, as determined by test method ASTM D 445 [21]. To determine kinematic viscosity, a fixed volume of the test fluid is allowed to flow through a calibrated capillary tube (viscometer) that is held at a closely controlled temperature (Figure 3).

The dynamic viscosity of the treated oil and the biodiesel was measured at different temperatures. The kinematic viscosities were calculated using equation (5) under Section 2.4.2 and the results are presented using graphs on Figures 4 and 5.

3.2.2. Iodine Values of Oil and Biodiesel. The iodine values of the crude and degummed oil samples were measured using

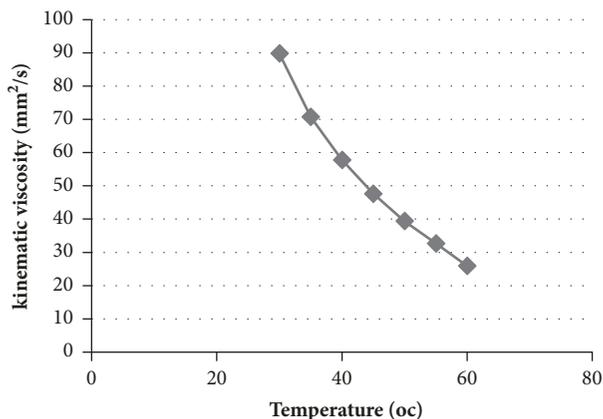


FIGURE 4: Effect of temperature on kinematic viscosity of degummed goat fleshing oil.

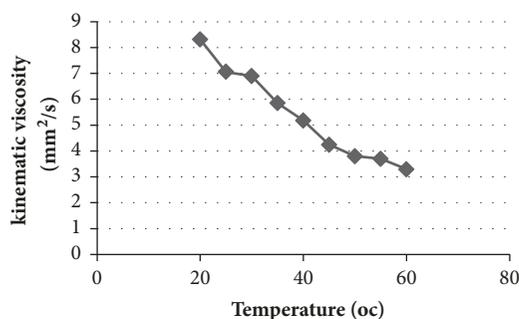


FIGURE 5: Effect of temperature on kinematic viscosity of goat fleshing biodiesel.

the method discussed on Section 2.4.6 using (9). The average value of the triplicate result was recorded.

Iodine value is a measure of total unsaturation within a mixture of fatty acid. It is expressed in grams of iodine which react with 100 g of the respective sample when formally adding iodine to the double bonds. The iodine value of a vegetable oil or animal fat is almost identical to that of the corresponding methyl esters [22]. Iodine value is a measure of total unsaturation of fatty acids. The more the unsaturation present in the oil, the higher the iodine value [23]. The lower iodine value, i.e., superior oxidative stability of the sheep fleshing oil dictates it to be more preferable for biodiesel production. All the fleshing oils have iodine value limits below the maximum value expressed by EN-norm. This result is similar to the result obtained by Eshetu Getahun and Nigus Gabiyye [9]. The low iodine index indicates less susceptibility to oxidation by oxygen. Decreasing the chain length and/or increasing the number of double bonds (i.e., higher iodine value (IV)) of FAAE results in an increase in NO_x emissions [24].

3.2.3. HHV of the Oils and Biodiesel. The high heating value (HHV) is not specified in the EN 14214 and ASTM D6751 biodiesel standards. However, European standard for using biodiesel as heating oil (EN 14213) specifies a minimum

HHV of 35MJ/kg. The HHV increases with increasing chain length and decreases with increasing unsaturation, and it is important for estimating the fuel consumption: the greater the HHV, the lower the fuel consumption. Factors that influence the energy content include the oxygen content and carbon to hydrogen ratio. Generally, as the oxygen content of FAAE is increased, a corresponding reduction in energy content is observed.

3.3. Biodiesel Production and Analysis of Effects of Parameters

3.3.1. Transesterification Process. The transesterification process was carried out using the method described in Section 2.7. In this study biodiesel was produced from goat leather fleshing oil using homogenous base catalysis. Since the oil extracted was of high quality grade, i.e., significantly low acid value, direct base catalyzed transesterification after degumming was selected to produce the biodiesel. The acid values of the sheep and hide fleshing oils obtained in this study are significantly different from the values reported by Eshetu Getahun, Nigus Gabiyye [9], and Abebe Reda [8]. This variation might be due to the extraction method used. While Getahun and Gabiyye used extractive boiler, Reda used heating and decantation. In this study Soxhlet extraction was employed. Using Soxhlet extraction high quality oils were obtained. Only degumming was enough to reduce the acid values to go for direct transesterification reaction. Fifty milliliters of degummed goat fleshing oil was used for each run.

The Design Expert 7.0.0 software was used for the regression and graphical analysis of the data. The maximum values of percentage of yield of biodiesel were taken as the response of the design experiment for transesterification process. The experimental data obtained by the above procedure was analyzed by the response surface regression using the following second-order polynomial equation.

$$y = B_0 + \sum_{i=1}^k B_i X_i + \sum_{i=1}^k B_{ii} X_i^2 + \sum_{i>j}^k \sum_j^k B_{ij} X_i X_j \quad (14)$$

where y is the response, i and j are the linear and quadratic coefficients, respectively, x_i and x_j are the uncoded independent variables, β_0 is the regression coefficient, and k is the number of factors studied and optimized in the experiment. Statistical analysis of the model was carried out to evaluate the analysis of variance (ANOVA). The equation was also validated by carrying out confirmatory experiments. The actual results obtained from average values of triplicate of the 20 runs were recorded in Table 3.

From different models such as the linear, 2FI, quadratic, and cubic; quadratic is selected on the bases of p values and lack of fit test and R-square. A P value ($P < 0.0001$) indicates the significance of quadratic model. In addition, absence of any lack of fit ($P > 0.05$) strengthened the reliability of the model.

The predicted model equation that relates the response to the parameters affecting the response in terms of actual and coded factors is displayed below.

TABLE 3: Actual and predicted value of biodiesel yield.

Run	Factors			Biodiesel (ml)		% Biodiesel yield		Residuals
	Catalyst (wt. /wt. %)	Methanol to oil molar ratio	Temperature °C	Actual	Predicted	Actual	Predicted	
1	1.50	9.00	55.00	38.20	38.230	76.4	76.46	-0.061
2	0.50	3.00	65.00	36.00	35.970	72	71.94	0.059
3	1.00	6.00	60.00	48.55	48.405	97.1	96.81	0.290
4	1.00	6.00	55.00	45.00	45.015	90	90.03	-0.025
5	0.50	9.00	55.00	34.70	34.670	69.4	69.34	0.035
6	1.00	6.00	65.00	44.00	43.985	88	87.97	0.035
7	1.00	6.00	60.00	48.25	48.405	96.5	96.81	-0.310
8	0.50	3.00	55.00	35.50	35.525	71	71.05	-0.051
9	0.50	6.00	60.00	44.50	44.495	89	88.99	0.015
10	0.50	9.00	65.00	34.00	34.04	68	68.08	-0.081
11	1.00	6.00	60.00	48.40	48.405	96.8	96.81	-0.011
12	1.00	9.00	60.00	43.00	42.985	86	85.97	0.035
13	1.00	6.00	60.00	48.50	48.405	97	96.81	0.190
14	1.00	6.00	60.00	48.20	48.405	96.4	96.81	-0.410
15	1.50	3.00	65.00	34.40	34.430	68.8	68.86	-0.061
16	1.00	3.00	60.00	42.75	42.765	85.5	85.53	-0.025
17	1.50	9.00	65.00	35.75	35.725	71.5	71.45	0.049
18	1.50	3.00	55.00	35.9	35.86	71.8	71.72	0.079
19	1.50	6.00	60.00	45.5	45.505	91	91.01	0.000
20	1.00	6.00	60.00	48.52	48.405	97.05	96.81	0.240

Final equation in terms of coded factors is

$$\begin{aligned} \% \text{ biodiesel yeild} = & 96.81 + 1.01 A + 0.22 B - 1.03C \\ & + 1.61 AB - 0.94 AC - 0.54 BC \quad (15) \\ & - 6.82 A^2 - 11.07 B^2 - 7.82 C^2 \end{aligned}$$

where A is catalyst, B is methanol to oil molar ratio, and C is temperature

The model is best fitted to quadratic response surface model as observed in the ANOVA (Table 4).

The model F-value implies the model is significant. There is only a 0.01% chance that a “model F-value” this large could occur due to noise. Values of “Prob > F” less than 0.0100 indicate that model terms are significant. In this case A, B, C, AB, AC, BC, A^2 , B^2 , and C^2 are significant model terms. The “lack of fit F-value” of 0.08 implies the lack of fit is not significantly relative to the pure error. There is a 99.21% chance that a “lack of fit F-value” this large could occur due to noise. Nonsignificant lack of fit is good; we want the model to fit. As can be seen from p values of the model coefficients, the value of temperature and catalyst mass in both linear and quadratic is much more less than 0.001. This indicated that both parameters are more significant than the third parameter, i.e., methanol to oil molar ratio. The nonsignificant lack of the ANOVA indicated that the model represents the actual relationships of reaction parameters.

The predicted R^2 of 0.9995 is in reasonable agreement with the adjusted R^2 of 0.9996. A rule of thumb is that the adjusted and predicted R^2 values should be within 0.2 of each other. Here the values are within the order of 0.0001.

Adequacy precision measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 185.787 indicates an adequate signal. This model can be used to navigate the design space (Table 5). The plot between predicted versus actual (Figure 6) is a good tool to study the significance of suggested model. The responses predicted from the empirical model are in agreement with the observed values in the range of the operating variables. Maximum points are on the line. The normal probability plot is shown in Figure 7. The general impression from examining this display is that as the plot resembles a straight line so there is not much of a problem with the normality of the data. Outlier detection was done using index plots of externally studentized residuals (Figure 8).

Linearity and quadratic effect of the independent variables and their interactions on the response variable were evaluated by analysis of variance (Table 4). The ANOVA of the regression model showed that the model was highly significant due to a very low probability value ($P < 0.0001$).

The P values were used as a tool for checking the significance of each coefficient, which in turn might indicate the interaction patterns between the variables. The smaller the P value, the more significant the corresponding coefficient.

As the fitted model presented in (14) offered a good estimate to the experimental conditions, so the given model was employed to predict the best possible values of the transesterification process variables for obtaining a maximum yield of FAME. Optimum conditions are depicted by bold font in Table 3.

The optimal experimental conditions for biodiesel production using goat leather fleshing oil acquired using the

TABLE 4: Analysis of variance (ANOVA) table for response surface quadratic model.

Source	Sum of Squares	df	Mean Square	F value	P-value Prob > F	Significance
Model	2492.56	9	276.95	5790.64	< 0.0001	Significant
A	10.2	1	10.2	213.29	< 0.0001	
B	0.48	1	0.48	10.12	0.0098	
C	10.61	1	10.61	221.82	< 0.0001	
AB	20.8	1	20.8	434.92	< 0.0001	
AC	7.03	1	7.03	147.01	< 0.0001	
BC	2.31	1	2.31	48.32	< 0.0001	
A ²	127.76	1	127.76	2671.19	< 0.0001	
B ²	336.75	1	336.75	7040.95	< 0.0001	
C ²	167.99	1	167.99	3512.5	< 0.0001	
Residual	0.48	10	0.048			
Lack of Fit	0.036	5	7.24E-03	0.082	0.9921	Not significant
Pure Error	0.44	5	0.088			
Cor Total	2493.03	19				

TABLE 5: Adjusted versus predicted R-squared.

Std. Dev.	0.22	R- squared	0.9998
Mean	83.96	Adjusted R- squared	0.9996
C.V. %	0.26	Predicted R- squared	0.9995
PRESS	1.34	Adequacy Precision	185.787

model were as follows: catalyst concentration (%) on weight basis 1, reaction temperature (°C) 60°C, and molar ratio of methanol to oil 6:1 for 1-hour reaction time and 750 rpm mixing intensity. Under these optimal conditions, the model predicted a maximum response of 96.81 percentage yield of biodiesel from the oil.

3.3.2. Main Factors Affecting the Yield of Biodiesel. The effects of individual parameters and interaction factors are subsequently discussed in the proceeding subsections. The factors selected for this study are temperature, catalyst concentration, and methanol to oil molar ratio.

(1) Effects of Individual Process Variables on Yield. Methanol-to-oil molar ratio is one of the important factors that affect the transesterification process (Figure 9). The stoichiometric ratio for transesterification requires three moles of alcohol and one mole of triglyceride to yield three moles of FAME and one mole of glycerol. However, transesterification is an equilibrium reaction in which a large excess of alcohol is required to drive the reaction to the right side of reaction products [25]. In the present work, the effect of a methanol-to-oil molar ratio varying from 3:1 to 9:1 on conversion to biodiesel was studied. When the methanol-to-oil molar ratio was 3:1, the conversion to biodiesel was 85.5% (Table 3). The maximum conversion to biodiesel was obtained at 6:1 and a further increment did not result in higher conversion to biodiesel since the excess of methanol deactivated the catalyst [26]. The excess methanol, with one polar hydroxyl group,

could act as an emulsifier and thereby increase the solubility of glycerol in the ester phase, making the separation more difficult. The glycerol that remained in solution could drive the equilibrium back to the left, reducing the ester conversion. Consequently there will be recombination of esters and glycerol to MAGs in the excess of methanol [27]. However, at industrial scale increasing the amount of methanol is not a problem in terms of yield, since methanol is recovered from ester and glycerol phases [28]. Even in industrial set-up further increase in the amount beyond the optimal ratio will increase the cost of alcohol recovery. The use of excess methanol will shift the equilibrium to the right and improve FAME yield, but beyond a certain value (6:1 in this case) the excess methanol causes dilution.

(2) Effect of Reaction Temperature. Temperature clearly influences the reaction and yield of the biodiesel product. The reaction temperature was varied at six different levels to determine the effect of reaction temperature on GLFO biodiesel production. As can be seen from Table 4 when the reaction temperature was 60°C, the conversion to biodiesel reached 97.1%. Initially increased biodiesel yield was observed as temperature increased due to the fact that viscosity of oils decreases at high temperature which results in an increased reaction rate. With further increase in reaction temperature, there was little increase in conversion to biodiesel. The reaction temperature above the boiling point of methanol (65°C) should be avoided since, at higher temperature, methanol tends to be lost and high temperature accelerates saponification of the glycerides by alkaline catalyst [29].

The results obtained in this study confirmed that the higher temperature of 65°C was not beneficial for transesterification and a decrease in conversion to biodiesel was observed. The temperatures in the range from 62 to 70°C caused evaporation of methanol and reduced the overall ester yield [27]. Although a reflux condenser was used to avoid methanol losses, the ester yield significantly decreased

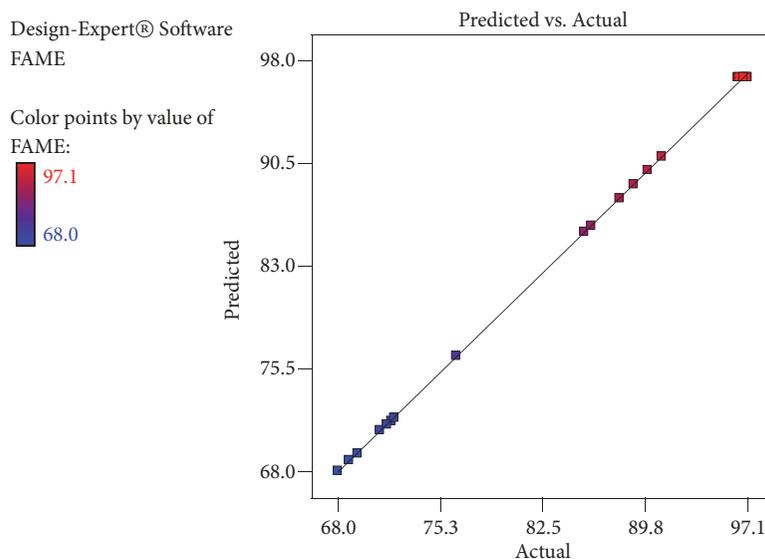


FIGURE 6: Plot of actual versus predicted percentage yield of biodiesel.

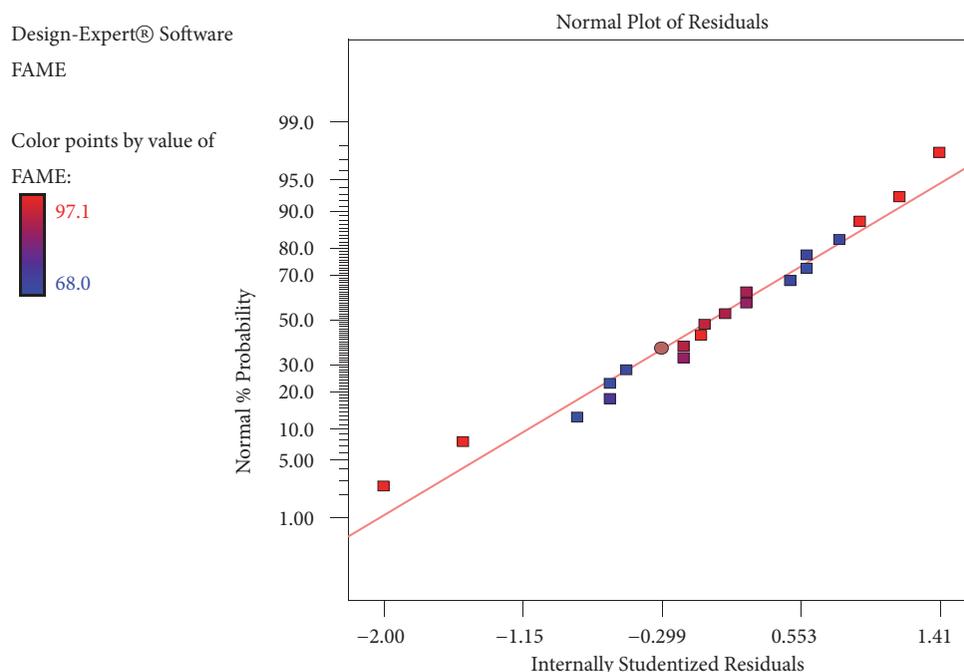


FIGURE 7: Normal probability plot of residuals.

at temperatures of greater than 60°C , probably because of a negative interaction between temperature and catalyst concentration, due to side reactions, such as soap formation completion of the alcoholysis (Figure 10).

(3) *Effect of Catalyst Mass/Concentration.* The biodiesel yield was increased as the catalyst concentration increased up to a certain level. Further increasing catalyst concentration beyond optimum values caused a decreased biodiesel yield (Figure 11). The addition of an excessive amount of catalyst gives rise to the formation of an emulsion, which increases

the viscosity and leads to the formation of gels. These hinder the glycerol separation and, hence, reduce the apparent ester yield. These results are in good agreements obtained by other investigators [30].

(4) *Effects of Interaction of Process Variables on Percent Yield of Biodiesel.* The three-dimensional plots of interaction effects of process variables over the FAME yield were drawn and subsequently descriptions are given. Each plot represents effects of two process variables while holding the third at constant level.

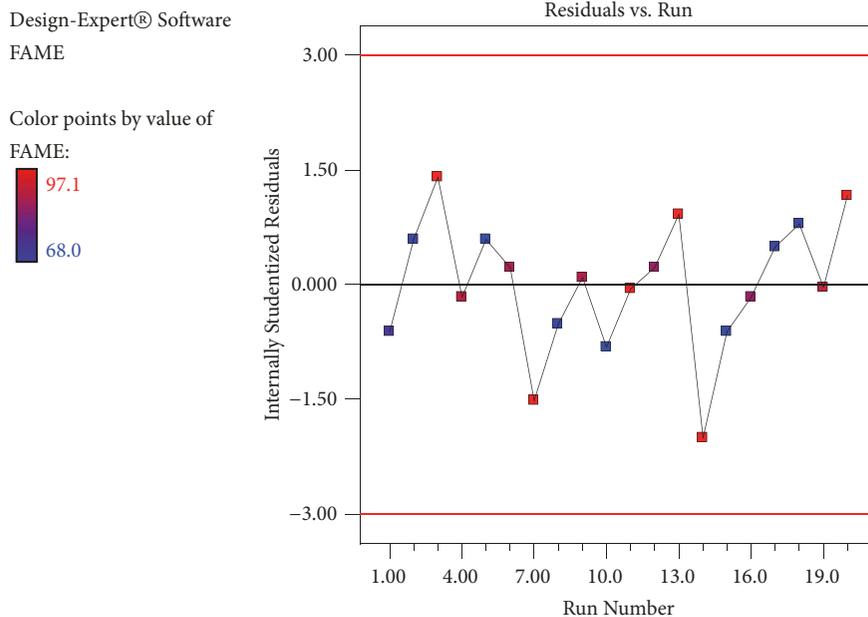


FIGURE 8: Index plots of internally studentized residuals.

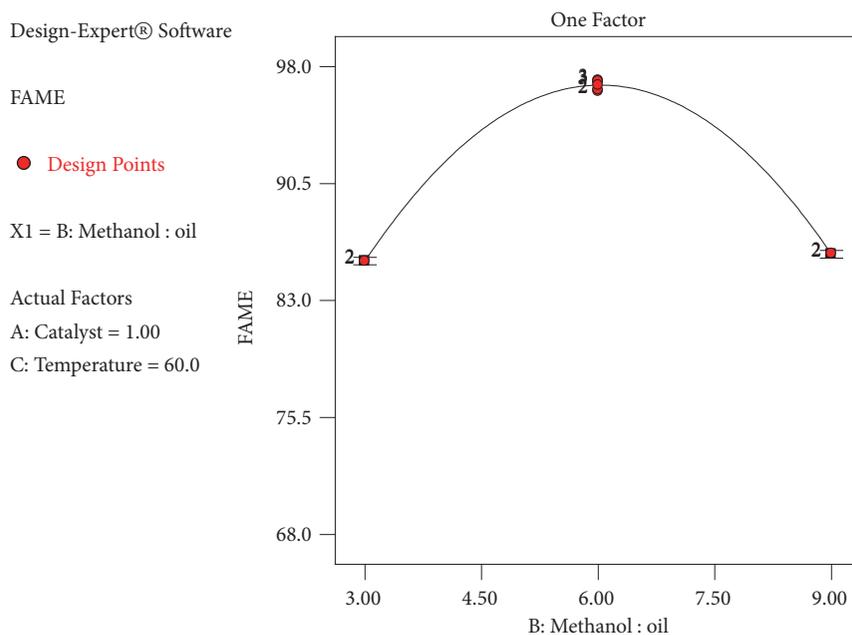


FIGURE 9: Effect of methanol to oil molar ratio on percentage yield of biodiesel.

(a) *Effect of Methanol to Oil Molar Ratio and Temperature on Yield.* The plot in Figure 12 shows the effect of varying temperature and methanol to oil molar ratio while the catalyst concentration; i.e., weight by weight catalyst to oil is at 1. Initially the effect of low level of methanol to oil molar ratio and temperature produces low level of FAME percentage yield. Further increase of both process variables will enable optimum amount of yield whereas an increase beyond some levels decreases the yield. The effect of increasing temperature

beyond the boiling point of methanol will decrease the interaction of the oil with methanol which leads to a decreased yield.

(b) *Effect of Methanol to Oil Molar Ratio and Catalyst on Biodiesel Yield.* It is possible to see from the plot (Figure 13) that initially percentage FAME yield increases with increasing catalyst and methanol to oil molar ratio. Further increase of both the methanol and the catalyst decreases the percent

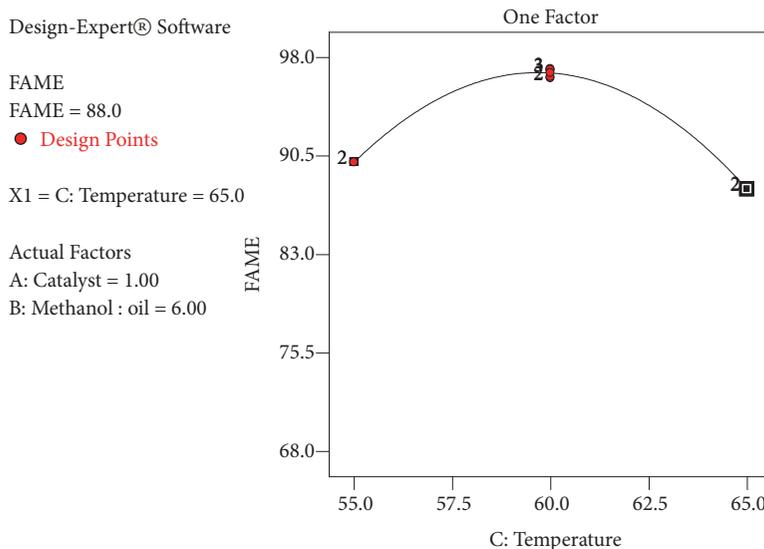


FIGURE 10: Effects of temperature on percentage yield of biodiesel.

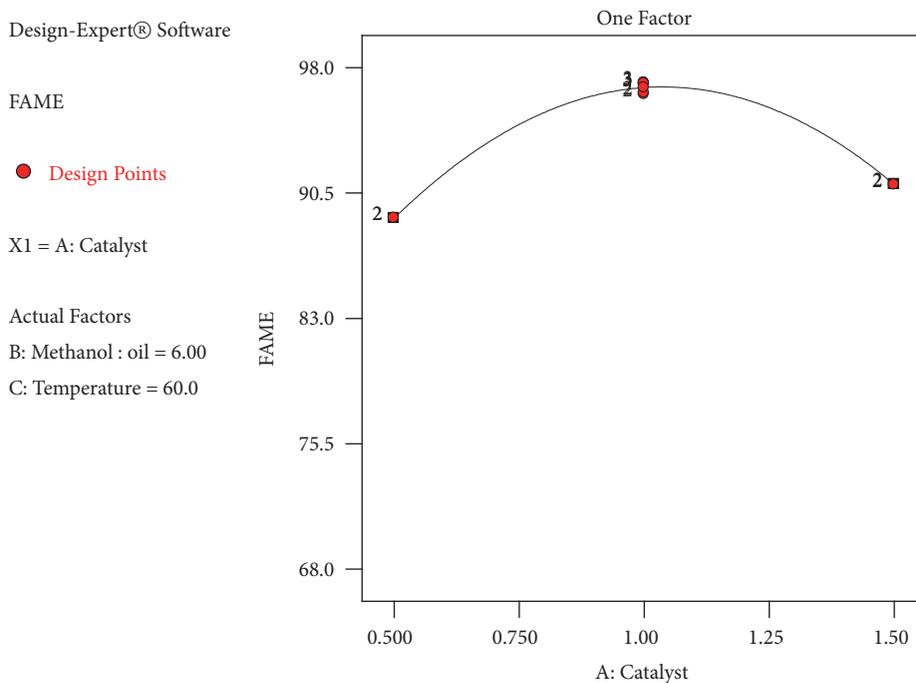


FIGURE 11: Effect of catalyst concentration on percentage yield of biodiesel.

yield. This might be due to the fact that increasing catalyst mass favors formation of soap than the biodiesel and an increase in methanol beyond the limit will hinder the conversion of fatty acids to FAME. This might be due to the inactivation of the catalyst or emulsification of the glycerol by the alcohol.

(c) *Effect of Temperature and Catalyst Mass on Biodiesel Yield.* It can be observed from Figure 14 that initial increase in both the temperature and the catalyst increases the yield of FAME. As both the temperature and the catalyst increase the FAME

percent yield starts to decline. The result might be due to the fact that an increase in temperature will lead to evaporation of the alcohol and an excessive amount of catalyst gives rise to the formation of an emulsion, which increases the viscosity and leads to the formation of gels that hinder the glycerol separation and, hence, reduce the apparent ester yield (see Figure 13).

(d) *Effect of Methanol to Oil Molar Ratio and Catalyst on Biodiesel Yield.* It is possible to see from (Figure 15) that initially percentage FAME yield increases with increasing

Design-Expert® Software

FAME



X1 = B: Methanol : oil

X2 = C: Temperature

Actual Factor

A: Catalyst = 1.00

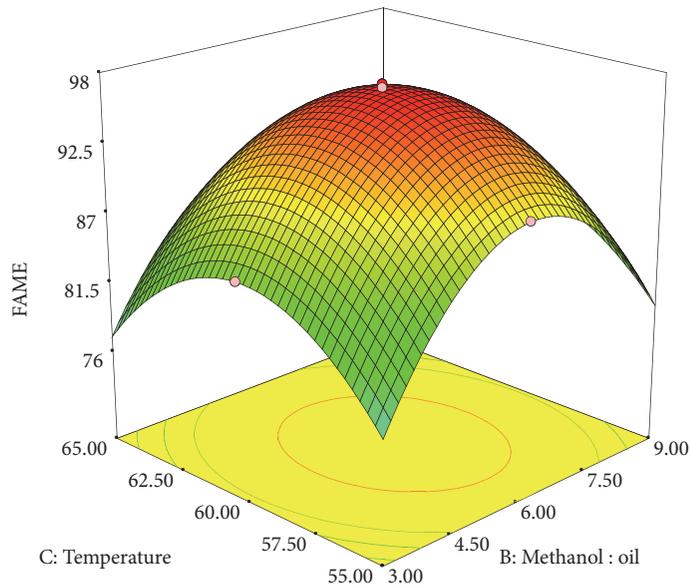


FIGURE 12: The effect of methanol to oil molar ratio and temperature on FAME percentage yield.

Design-Expert® Software

FAME



X1 = A: Catalyst

X2 = B: Methanol : oil

Actual Factor

C: Temperature = 60.00

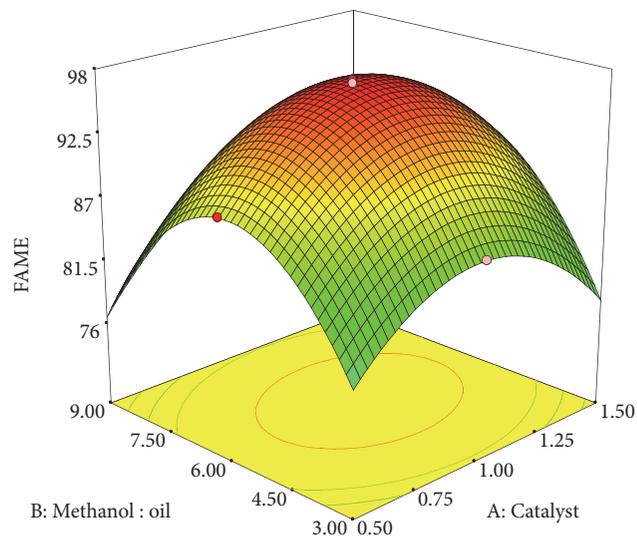


FIGURE 13: The effect of methanol to oil molar ratio and catalyst mass on FAME percentage yield.

catalyst and methanol to oil molar ratio. Further increase of both the methanol and the catalyst decreases the percent yield. This might be due to the fact that increasing catalyst mass favors formation of soap than the biodiesel and an increase in methanol beyond the limit will hinder the conversion of fatty acids to FAME. This might be due to the inactivation of the catalyst or emulsification of the glycerol by the alcohol.

(e) Effect of Temperature and Catalyst Mass on Biodiesel Yield.

It can be observed from Figure 16 that initial increase in both the temperature and the catalyst increases the yield of FAME. As both the temperature and the catalyst increase the FAME percent yield starts to decline. The result might be due to the fact that an increase in temperature will lead to evaporation of the alcohol and an excessive amount of catalyst gives rise to the formation of an emulsion, which increases the viscosity

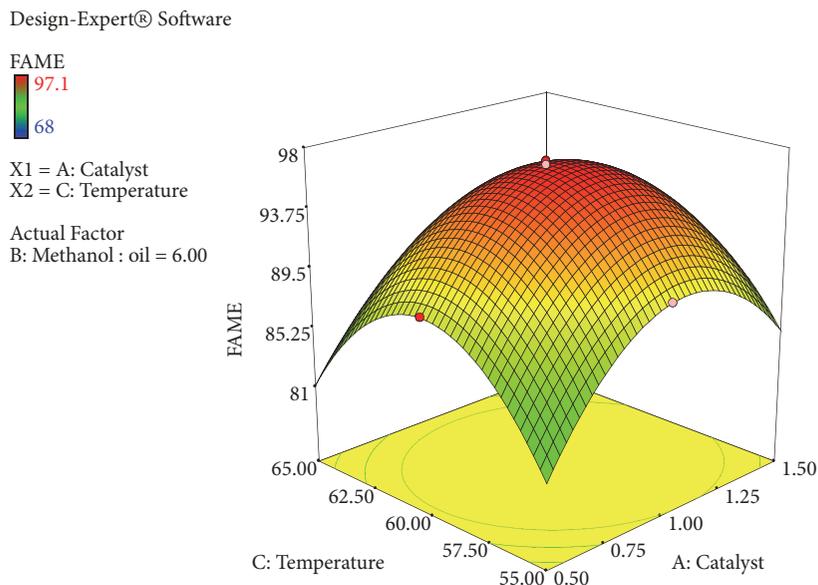


FIGURE 14: The effect of temperature and catalyst mass on FAME percentage yield.

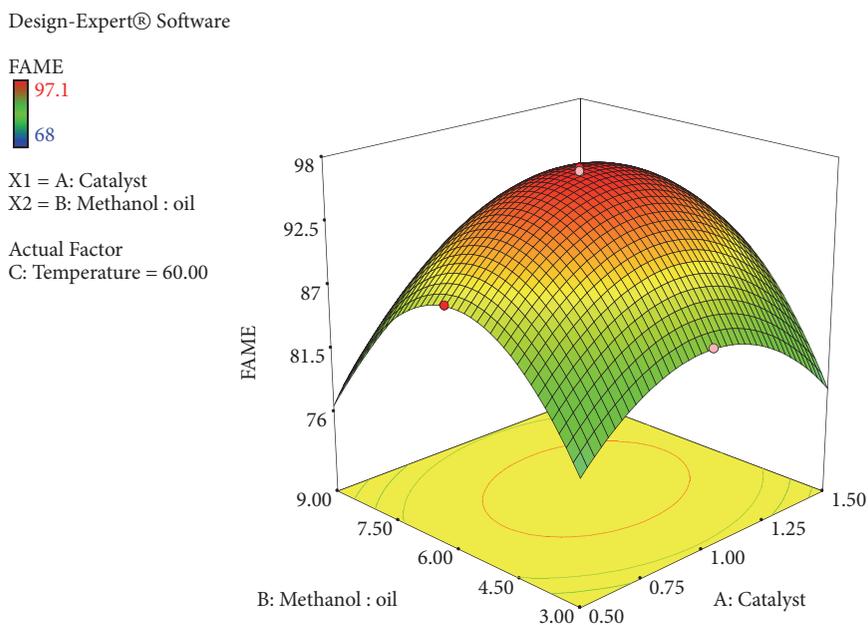


FIGURE 15: Effect of methanol to oil molar ratio and catalyst mass on FAME percentage yield.

and leads to the formation of gels that hinder the glycerol separation and, hence, reduce the apparent ester yield.

3.4. Optimization of Process Variables. The optimization of process variables within the selected ranges for maximum conversion of the oil to FAME was evaluated using Design Expert 7.0.0. The optimum result predicted by the model was found to be 96.891% FAME at catalyst weight by weight percent of 1.04, temperature of 59.64°C, and methanol to oil molar ratio of 6.05 (Table 6).

3.5. Gas Chromatograph-Mass Spectroscopy Analysis of the Produced Biodiesel. The samples for sheep (Figure 19), goat

(Figure 17), and hide (Figure 18) fleshing FAMEs were prepared according to the method described in Section 2.4.9. The method employed for identification of species was the internal standard. Individual fatty acids of the oil were identified by comparing retention time, i.e., the time at which the peak is observed and the chromatographic profiles of the samples. The gas chromatograms of FAMEs of the sheep, goat, and hide fleshing oils are presented subsequently in Figures 17–19.

3.6. Properties of the FAME from Goat Fleshing Oil. The physicochemical analysis of the biodiesel was conducted. The procedures followed were those discussed in the materials and methods section.

TABLE 6

(a) Optimization of process variables

Constraints Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Catalyst	in range	0.5	1.5	1	1	3
Methanol to oil molar ratio	in range	3	9	1	1	3
Temperature	in range	55	65	1	1	3
FAME	maximize	68	97.1	1	1	5

(b) Solution

Solution number	Catalyst	Methanol to oil molar ratio	Temperature	% yield of FAME	Desirability	Remark
1	1.04	6.05	59.64	96.891	0.993	selected

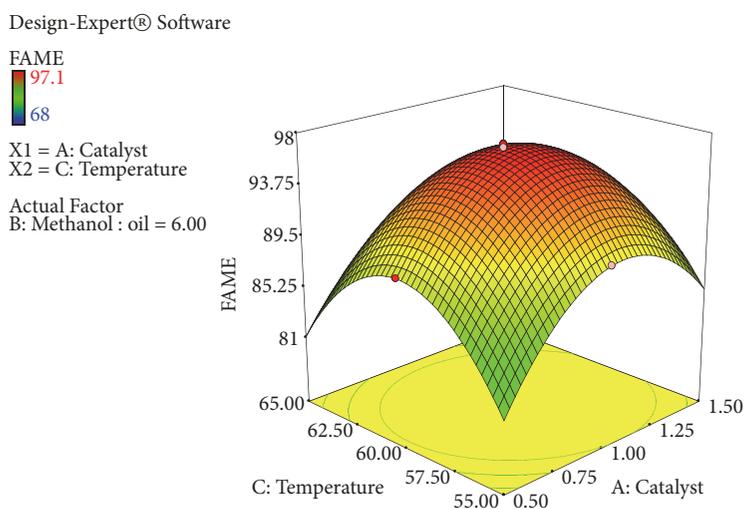


FIGURE 16: The effect of temperature and catalyst mass on FAME percentage yield.

3.6.1. Density of the FAME of the Goat Fleshing Oil. The density of the biodiesel was measured at different temperature using Pycnometer. The result of the biodiesel density measurement at different temperatures is depicted in Figure 20.

The density of biodiesel is a factor which influences the efficiency of atomization and depends on alkyl ester content and remaining amount of alcohol. The density value of biodiesel at 25°C is adopted to be between 860 and 900 kg/m³ by EN14214 standard and between 875 and 900 kg/m³ ASTM D 6751-02. The result obtained from the experiment, i.e., 880 kg/m³, was found to be within the range.

3.6.2. Kinematic Viscosity of the FAME of the Goat Fleshing Oil. The viscosity of biodiesel is influenced primarily by the experimental conditions and the extent of transesterification reaction [31]. Therefore, it is possible to find different viscosity values for esters originated from the same type of feedstock due to incomplete reaction, i.e., presence of acyl glycerol and inherent biodiesel purification. The kinematic viscosity of the treated oil and the biodiesel was measured and the result was depicted under Section 3.2.1. The method to calculate the kinematic viscosity was discussed under Section 2.4.2.

The standard values for kinematic viscosity biodiesel at 40°C are EN14214 (3.5-5.0 mm²/s) and the ASTM D6751 (1.9-6.0 mm²/s). The experimental result 5.9 mm²/s was slightly higher than the limits dictated by EN.

3.6.3. Acid Value of the FAME of the Goat Fleshing Oil. The acid value of the biodiesel was determined employing the similar procedure stated under Section 2.4.3. The result obtained was 0.48 mg KOH/g.

3.6.4. Moisture and Ash Contents of the FAME of the Goat Fleshing Oil. The moisture and ash contents of the produced biodiesel were measured using procedures mentioned under Section 2.3. The moisture and ash contents were 0.023 and 0.021, respectively.

3.6.5. Iodine Value of the FAME of the Goat Fleshing Oil. The iodine value of the produced biodiesel was calculated using (9) that was discussed under Section 2.4.6. Iodine value is a measure of total unsaturation within a mixture of fatty acid. It is expressed in grams of iodine which react with 100 g of biodiesel when formally adding iodine to the double bonds. It

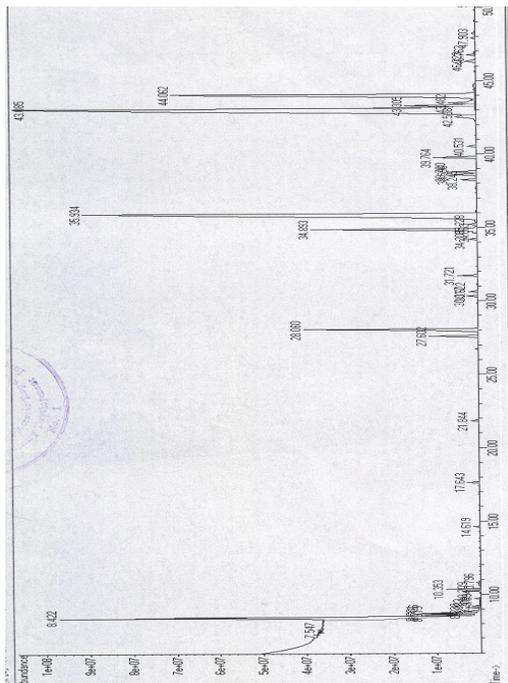


FIGURE 17: Goat fleshing FAME chromatogram.

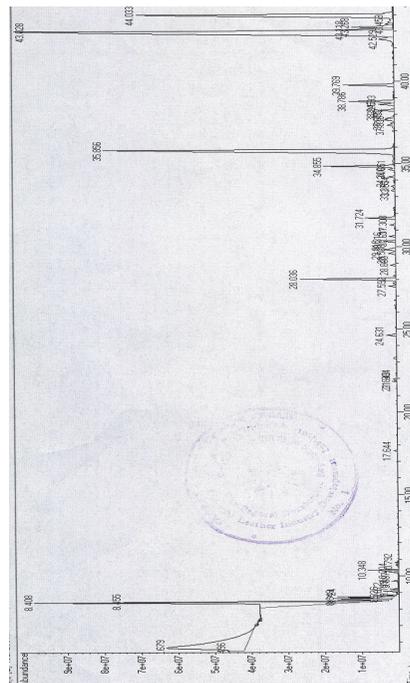


FIGURE 19: Sheep fleshing FAME chromatogram.

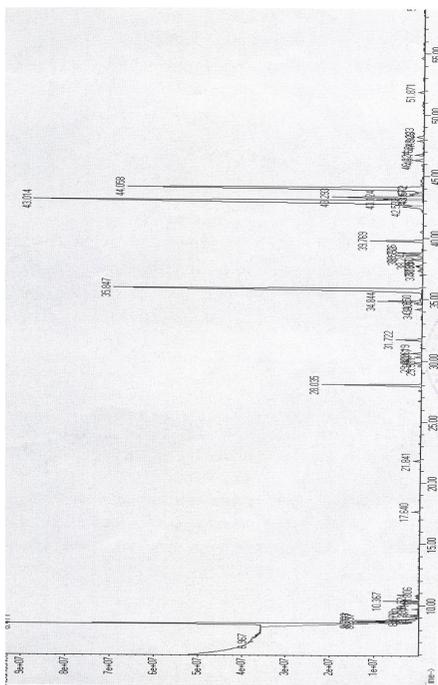


FIGURE 18: Hide fleshing FAME chromatogram.

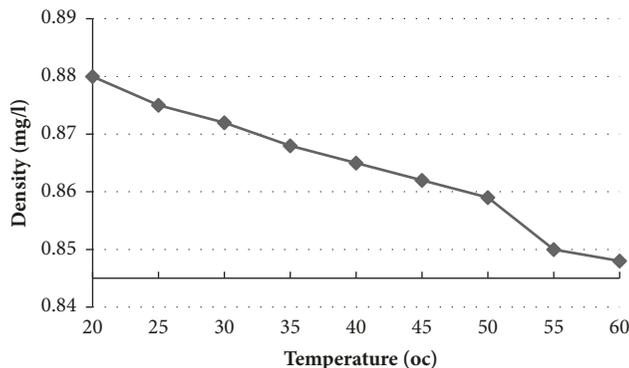


FIGURE 20: Density of goat leather fleshing biodiesel at different temperature.

is limited to 120 g I₂/100 g in the European biodiesel standard EN 14214. The iodine value of the biodiesel was found to be 65.13 g I₂/100g.

3.6.6. Cetane Number of the FAME of the Goat Fleshing Oil. The cetane number (CN) is a dimensionless number for diesel just as the octane number is for gasoline and is associated

with ignition delay time, i.e., the time between fuel injection the beginning of ignition. The shorter the ignition time, the higher the cetane number. It is the calculated value based on (11) under Section 2.4.8. Cetane number (CN) is determined in accordance with ASTM D 613 and is one of the primary indicators of diesel fuel quality. It is related to the ignition delay time a fuel experiences once it has been injected into a diesel engine’s combustion chamber. Generally, shorter ignition delay times result in higher CN and vice versa. Hexadecane, also known as cetane (trivial name), which gives the cetane scale its name, is the high-quality reference standard with a short ignition delay time and an arbitrarily assigned CN of 100 [32]. The cetane number of the biodiesel was calculated to be 68.5.

3.6.7. Higher Heat Value of the FAME of the Goat Fleshing Oil. The higher heat value of the biodiesel was calculated

TABLE 7: Comparison of experimental biodiesel with standards.

Physicochemical properties	Unit	Experimental biodiesel	EN 14214	ASTM D 6751-10	Diesel	Test method
Density at 25°C	kg/m ³	880	860-900	875-900	840-860	(EN ISO 3675 & ASTM D 5002)
Kinematic viscosity at 40°C	mm ² /s	5.99	3.5-5.0	1.9-6.0	1.9 - 3.8	ASTM D 445
Acid value	mg KOH/g	0.48	≤ 0.5	≤ 0.8	-	ASTM D 664
HHV	MJ/kg	42.38	-	-	43.3-46.7	-
Iodine value	g I ₂ /100g	65.13	120 max	-	-	ASTMD 5558
Cetane number	-	68.5	-	46 - 70	47 - 55	ASTM D613
Moisture content	% w/w	0.023	-	< 0.03	-	-
Ash content	% w/w	0.021	<0.02	<0.03	-	ASTM D482

using (10) under Section 2.4.7. The calculated value was 42.38 MJ/kg.

3.7. Comparison of the Biodiesel Properties with ASTM and EN Standards. The general comparison of the biodiesels produced in this experiment with international standards is illustrated in Table 7. As it can be observed in the table, the majority of the physicochemical properties of the fleshing oil biodiesel were in agreement with the international standards.

4. Conclusion

The fat obtained from the leather industry fleshing wastes was used successfully for the production of acceptable quality biodiesel. It was proved that fleshing wastes from tanneries whose storage and disposal are both troublesome and costly could be transformed to a fuel with low emission values and a performance close to diesel fuel. The GC-MS analysis result showed that all three types of waste, i.e., goat, sheep, and hide fleshing wastes, can be acceptable candidates for producing biodiesel. Degumming only was sufficient to reduce the FFA level to proceed with direct homogenous base catalyzed transesterification. The physicochemical analysis result shows that majority of the parameters fall within the range of values established by EN and ASTM. Therefore environmental polluting leather fleshing waste can be converted to useful energy generating product. Effect of blending the oils from goat, sheep, and hide fleshing oils at different proportions and blending with other feed stocks should be studied to use the advantage of the qualities each of them has individually. This study has focused on homogenous base catalyzed transesterification; a complimentary heterogeneous, super critical, and biological catalysis should be tried for better environmental protection. Exhaust gas emission profile studies and engine performance studies should be carried out. The economic feasibility study on large scale production and commercialization should be undertaken. Since gum, glycerol, and compostable waste residues are produced as side products during the production process, additional studies on using these products for different applications shall be initiated.

5. Limitation of the Study

This study is undertaken at laboratory scale and large scale production of biodiesel may not be the same as laboratory

scale controlled production. This study does not focus on the economic feasibility of biodiesel production from leather fleshing waste. In the current study level of heavy metals in the feedstock and biodiesel was not determined.

Abbreviations

ANOVA:	Analysis of variance
ASTM:	American Society for Testing Materials
°C:	Degree celsius
FAME:	Fatty acid methyl ester
FFA:	Free fatty acid
LIDI:	Leather Industry Development Institute
LFW:	Limed fleshing waste
PPM:	Parts per million.

Data Availability

Data will be made available upon request to the primary author.

Ethical Approval

Ethical clearance was obtained from the Institutional Review Board of the Addis Ababa Institute of Technology and an official letter was submitted to the Addis Ababa Tannery share company administrators.

Consent

Verbal informed consent was obtained from the company administrators. This manuscript does not contain any individual person's data.

Disclosure

There were no risks due to participation in this research project. The collected data were used for this research purpose only and kept with complete confidentiality.

Conflicts of Interest

None of the authors have any conflicts of interest in the manuscript.

Authors' Contributions

All the authors actively participated during conception of the research issue, development of a research proposal, laboratory work, analysis, and interpretation, and writing various parts of the research report. All the authors read and approved the final manuscript.

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