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Research Article

An Overview of Energy Recovery from Local Slaughterhouse-Based *Gallus gallus domesticus* Greasy Residues and Latest Applications

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Gallus domesticus is one of the world's most consumed animals, with a significant presence in all parts of the planet. Chicken oil appears to be a credible raw material in the context of alternative energy research. This study focuses on a literature review to highlight the chicken's energy potential and the application of energy recovery from local slaughterhouse-based *Gallus gallus domesticus* greasy residues and it is proposed to make biodiesel from the fatty residues of *Gallus gallus domesticus*. The transesterification reaction takes place at 60°C. Methanol is used in a 1 : 6 oil-to-alcohol mass ratio. Catalysis is carried out with 1% (m/m) potassium hydroxide (KOH). The accepted reaction time under light agitation is 120 minutes. The reaction yield is estimated to be 85.6%, and the biodiesel produced is characterized. The postcharacterization values are consistent with the EN14214 biodiesel standard. Gas chromatography coupled with mass spectrometry reveals the intrinsic composition of the acids derived from the developed biodiesel methyl esters. The latter reveals a predominance of oleic acids with a value of 29.47% and palmitic acids with a value of 29.21%. The viscosity of greasy residues appeared to be relatively high at 69.32 mm/s. The low calorific value is 38775.363 KJ/Kg and the cetane index is 50. It has been observed that, for 1000 g of fat waste, it is possible to extract by cooking 507.807 g of oil, or an extraction yield of 51%. Fatty chicken residues from tropical market areas can be used as a raw material for biofuel development.

1. Introduction

For more than a century, the global economy has relied on fossil fuels as energy sources, such as oil, natural gas, and coal. Furthermore, the transportation sector is expanding at an exponential rate, which will inevitably increase energy demand [1, 2]. Indeed, according to the most optimistic scenarios, peak oil will occur between the late 2020 and the late 2030[3]. According to the most pessimistic scenarios, we have already passed this peak and production is gradually declining [1, 2]. Petroleum products (petrol, diesel, and kerosene) currently meet 93 percent of the world's transportation energy needs, but they face numerous criticisms. Oil is distributed unevenly across the globe and its sporadic oil shortage is resulting in conflicts over ownership of existing deposits [4]. In addition, the combustion of petroleum leaves out many polluting particles, including greenhouse gases, the main one being CO_2. It is for this reason that petroleum and its byproducts are accused of causing global warming.

Researchers interested in achieving sustainable societies are concerned about the transition to a noncarbon society. The need to reduce greenhouse gas emissions (GHGs) and avoid worst-case climate change scenarios, as well as anticipate the depletion of fossil fuels, motivates decarbonization efforts such as considering alternatives to petroleum

products in the transportation sector. The following three approaches are questionable realities when considering alternatives to petroleum products in the transportation sector: (i) reducing the need for travel, (ii) lowering the energy consumption of modes of transportation, and (iii) changing the nature of the energy source. The latter approach entails optimizing the electric motor or substituting natural gas, hydrogen, or biofuels for petroleum products. Of all these solutions, biofuel is the one that least changes the habits of users and manufacturers [5]. Biofuels are fuels whose raw materials come from biomass [6]. They are ecofriendly compared to fossil fuels [7]. Bioethanol from sugar and starchy plants and biodiesel from oilseed plants or animal fats are the most widely used biofuels [8, 9].

Several studies have shown that biofuel is a viable alternative to fossil fuels [1, 10]. Biodiesel is biodegradable, and its exhaust gases contain fewer pollutants than diesel fuel [4, 10]. Biodiesel can be produced from animal or plant waste [7]. It is primarily made (95%) from edible oils such as rapeseed (84%) sunflower oil (13%), palm oil (1%), and soybean oil (2%). In some countries, this predisposition has negative consequences for food self-sufficiency. Famine, hunger wars, food shortages, and rising food prices are thus observed. This disruption is caused by the use of human-consumed products as an energy source.

The intensification of monoculture and land grabbing by certain lobbies in less developing countries has a significant impact on air, soil, and biodiversity [6, 7, 9, 11]. The cost of agricultural inputs accounts for 59 to 91 percent of the cost of production, which explains why biodiesel is not yet economically competitive with diesel [12]. This disparity is most likely due to the cost of the raw materials. Indeed, the use of farms and fields to grow energy plants or specific animals incurs maintenance costs. The cost of converting raw materials into biofuel is also determined by the technology used.

When economies of scale are considered, the ratio between quantities produced and those demanded by the market remains relatively low, with an impact on the final cost of the product. Specific tax provisions, as well as the recovery of byproducts and industrial waste, allow the sector to become profitable. Furthermore, in response to the challenges posed by the conflict between food security and energy deficit on the one hand, and plant occupation of arable land on the other, the use of inedible raw materials with no direct economic benefits for humans has grown in importance [12].

Nonedible oils include Jatropha curcas, castor, and used frying oils. Animal fats have also been discovered in the category of nonedible materials: chicken, pork, and beef. These fat residues, which have a low cost and a high energy potential, are becoming more popular [8, 10].

Mali et al. [13] studied the transesterification of fat sheep residues into biodiesel. The findings showed an intriguing biodiesel performance. Awad et al. [3] investigated the biodiesel transesterification of frying oil residues. Transesterification processes can be used to transform these residues. The transesterification of triglycerides primarily produces biodiesel. This straightforward method involves substituting fat glycerin for short-carbonated alcohols like methanol and ethanol [10], with a catalyst to speed up the reaction. Figure 1 depicts Emaad's [14] equation describing the transesterification reaction. In general, methanol outperforms ethanol in the transesterification process.

When combined with basic catalysts such as KOH or NaOH, methanol is a reactive product that adapts well to the transesterification reaction. Many studies, however, note the toxic nature of the vapours of this alcohol, as well as its relatively high cost and not always obvious availability [14]. However, when ethanol is used, the efficiency of transesterification reactions is lower than when methanol is used under the same experimental conditions. The results obtained, however, are generally very close to those obtained with methanol. As a result, given its availability and relatively nontoxic nature, ethanol appears to be a low-cost adjuvant. Depending on the alcohol used, two types of biodiesels are commonly obtained. Ethyl ester when the alcohol used is ethanol and methyl ester if it is methanol. Generally, ethanol, methanol or diluted ethano-methanol solution are commonly used. Although some authors sell the merits of NaOH from the point of view of availability, KOH is the most widely used catalyst in the literature. The method of transesterification has evolved greatly thanks to scientific investigations initiated by authors. Combinations are used, as well as the introduction of new types of catalysers.

Zhang et al. [15] investigated the effect of in situ ultrasound on biodiesel production. The oleaginous yeast, *Trichosporon oleaginous,* was grown in waste water sludge in order to produce lipids. The obtained biomass was used to investigate the effects of ultrasonic treatment on transesterification and lipid extraction. Water, hexane, and methanol were among the solvents investigated. The capacity of various solvents in lipid extraction with ultrasonic treatment was investigated. Within 20 minutes, the author obtained maximum lipid evaluated to 11.8, 35.3, 62.0, and 95.3 percent (w/w) with water, hexane, methanol, and a mixture of chloroform and methanol (1 : 1 v/v). Chloroform and methanol performed relatively well. Transesterification: biodiesel yield of 95% (w/w) was obtained in 60 min with ultrasonication assistance, whereas 24 h was required to achieve a similar experience without the assistance of ultrasonication.

In a study conducted by Mohadese, lipase from *Rhizomucor miehei* (RML) and lipase B from *Candida Antarctica* (CALB) were covalently immobilized into epoxy-functionalized silica in a study conducted by Mohadese et al. [16]. A multienzyme system was developed in this study to produce biodiesel from waste cooking oil and methanol. To increase biodiesel production yield, the author used a mixture of 1,3-specific lipase (RML) and nonspecific lipase (CALB). The response surface methodology (RSM) and a central composite rotatable design (CCRD) were used to investigate the effects of four factors on fatty acid methyl ester (FAME) yield: CALB : RML ratio, t-butanol to oil (wt. percent), water adsorbent content (wt. percent), and reaction time. FAME yield of 91.5%, relatively close to the predicted value of 95.6%, was obtained.

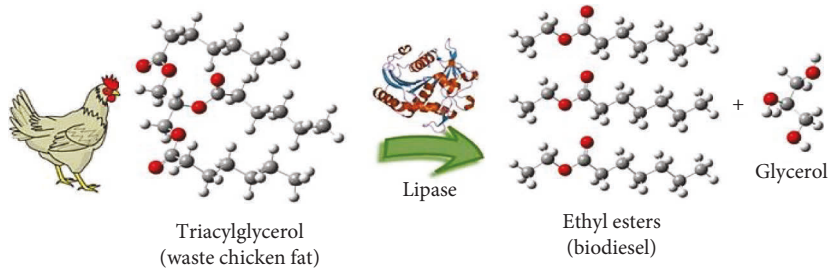

Figure 1: Transesterification reaction of chicken fatty acids by [14].

Singh et al. [17] used coprecipitation to create a heterogeneous catalyst, magnesium zirconate ($Mg_2Zr_5O_{12}$). Transesterification was used to produce biodiesel from the obtained product. As a feedstock, kusum oil was used. TGA, XRD, ATR FTIR, SEM, and EDX were used to characterize the catalyst. The parameters of the catalyst were determined, including particle size, zeta potential, BET surface area, and basicity. The catalyst catalyzed the transesterification reaction, allowing for economically viable biodiesel production. Response surface methodology (RSM) based on Box–Behnken design was used to optimize various reaction parameters such as molar ratio (methanol: oil), catalyst concentration, and reaction time in the presence of $Mg_2Zr_5O_{12}$. The catalyst was reusable for up to seven runs, with a 75% conversion rate in the seventh. The author obtained a maximum conversion of 97.98% FAME at 18 : 1 M ratio (methanol: oil), 2.5 wt% of catalyst at 65°C temperature for 150 min.

Bayat et al. [18] carried out an experiment. An optimized method for preparing $Fe_3O_4Al_2O_3$ as an efficient nanocatalyst for waste cooking oil transesterification to biodiesel was presented in this study. The catalyst with an Al_2O_3/Fe_3O_4 mass ratio of 0.5 produced the highest oil conversion. XRD, SEM, TEM, DLS, FTIR, TPD, and VSM analysis were used to characterize it. The XRD pattern appears to agree with the standard cubic Fe_3O_4 XRD pattern. Temperature programmed desorption (TPD) of NH_3 revealed a broad peak in the 400–450°C temperature range. An analysis of variance (ANOVA) revealed that the effects of time and temperature were far more significant than the M/O ratio. On August 1, 2010, this entry was published. The interaction between temperature and time was more important than the other experimental interactions. The recovery of the catalyst was successfully performed at 400°C, and the performance of the catalyst was acceptable after four cycles of recovery. These different methods are of proven effectiveness but require specific and specialized instrumentation. The exploitation of animal fats and fatty residues is widely reported in the literature. The use of chicken fats in the biofuel manufacturing process has been experimented with by the authors. Table 1 provides a summary of the work on obtaining biodiesel by transesterification of chicken fats.

The use of biodiesel as a fuel for compression ignition engines has generated a lot of interest. Metin et al. [21] looked into using chicken fat biodiesel in a diesel engine. The performance of a typical B10 blend fuel was compared to that of traditional diesel. The tests were carried out at speeds ranging from 1800 to 3000 revolutions per minute. The use of B10 fuel increases engine torque by 10% while increasing specific consumption by 5.2 percent over B0. The authors attribute the rise in specific consumption to the cut's low calorific value. There was also an increase in cylinder pressure peak and an advance in ignition time. CO emissions and sorely needed decrease by 13% and 9%, respectively, in terms of the environment. Observation causes a 5% increase in NO.

Sierra-Vargas et al. [22] investigated the effect of chicken oil use on the performance of a generator powered by a 13.45 kWe diesel engine. Under laboratory conditions, biodiesel was developed and introduced into the thermal engine. Total electrical efficiency, heat release, fuel consumption, and the polluting content of exhaust gases are all factors to consider. The author discovered that the genset's yield increased to 38.79 percent, which is 22.5 higher than the 35.08 percent obtained for fossil diesel. This performance is justified by the addition of a sustainable biofuel, such as biodiesel based on chicken fat. Under the same conditions, the released CO_2 level decreases by approximately 2.9 $kg{\cdot}CO_2{\cdot}h^{-1}$.

These studies show that chicken fat is a potential fuel with energy and environmental benefits. There is a definite interest in the value of chicken fats. Chicken is edible. It is an animal of the subspecies *Gallus gallus domesticus*, generally bred for its flesh, making it a comestible animal [23, 24]. The production conditions of broilers differ from those of laying hens that are raised for their eggs. Chicken farming is done with large numbers of animals in closed buildings for an average of 35 days, which gives it an intensive character (approximately one to three million chickens). However, next to this modern breeding is grafted small-scale breeders whose herds are between 100 and 1000 chickens.

Some other types of food by their composition make it possible to obtain fatter chickens with faster growth. As a percentage of mass, chicken meat contains two to three times more polyunsaturated fats than most red meats. Chickens are considered to be, of all the most numerous land animals, being bred. The fat in the chicken is located in the abdomen and skin. This lipid reserve is a potential raw material for the biofuels sector and an energy source for thermal engines. Unlike formal slaughterhouses in safe and organized environments, informal slaughterhouses end up in marginal locations. These identifiable places in African markets in general are reserved for the skinning of chickens purchased by private individuals to facilitate culinary operations. About

Table 1: Summary work on obtaining biodiesel by transesterification of chicken fats.

Operating conditions	Experimental results	References
Methanol and lipids in a molar ratio of 6 : 1 and a methanol-ethanol-lipids mixture in a molar ratio of 3 : 3:1 reacted with 1% KOH catalyst ethanol-lipids molar ration of 6 : 1; 1% sodium ethoxide.	Amounts of biodiesel were 771.54 mg/mL ± 15.28,722.98 mg/mL ± 37.38 and 714.86 mg/mL ± 29.99 from methanol, ethanol, and a mixture of methanol/ethanol (3 : 3)	[10]
140°C, 4 h of reaction time and a molar ratio of transesterification reactions of chicken fat/methanol 1 : 31.	The yield was of 98% under of 140°C, 4 h of reaction time, and a molar ratio of chicken fat and methanol of 1 : 31. Viscosity: 6.3 mm·2/s; density: 895.9 kg/m^3.	[11]
Enzymatic transesterification reactions of residual chicken fat with ethanol without cosolvents. Ten lipases tested.	CALB provided a 96% yield of ethyl biodiesel with 20 mg of the enzyme. After 10 h, the yield: 90%. Temperatures up to 50°C tolerated by the enzyme, reused.	[19]
Chicken fats/oil or WCO, methanol or ethanol (50 ml), n-hexane (50 ml), and HCl (2 ml) taken in a flask fitted with a condenser and refluxed at water bath at 100°C for 24 hours separately.	The significant yields of fats and oils obtained from waste chicken fats and WCO were 38% and 80%, respectively.	[20]
Synthetic Mg additive studied in a single-cylinder, direct injection (DI) diesel engine and its effects on engine performance. A two-step catalytic process was chosen for the synthesis of the biodiesel. Organic-based synthetic magnesium additive doped into the biodiesel blend by 12 μmol Mg.	The engine torque was not changed significantly with 10% chicken fat biodiesel. The specific fuel consumption increased by 5.2%. In-cylinder peak pressure slightly rose, and the start of combustion was earlier. CO and smoke emissions decreased by 13% and 9%, respectively, but NOx emissions increased by 5%.	[21]
Acid-base and base-catalyzed transesterification. Hydrochloric acid and potassium hydroxide with methanol used. Transesterification of fried chicken oil monitored by TLC technique. Blending with petrodiesel using three volume percentages (10, 30, and 50% v/v).	Two-step base-catalyzed transesterification was better. The average molecular weight of FCO 878, the acid value of CFO was 2.80 mg; KOH/g oil. Density and KV of FCO 0.9222 g/mL and 50 mm^{2}S^{-1}; the IN and PP values of FCO were 61 mgI2/100 g; oil and 6, respectively, whereas CCI was 61.15.	[22]

100 chickens can be gutted in these places, and the residues stored in barrels without special care. This abundant raw material is likely to be converted into biodiesel [25, 26].

Chicken-based biodiesel has been mentioned in the literature. The raw material is generally derived from formal settings. The raw material in these environments is well preserved following the requirements of the sector [27, 28]. Fats and oils from these environments have proven their effectiveness as the raw material for biodiesel. In informal slaughterhouses, storage and handling conditions do not meet prescriptive requirements. It is essential to characterize these residues to develop the required technical data for the energy recovery of this abundant raw material and the less expensive production of biodiesel [29, 30]. The purpose of this study is to recover slaughterhouse fatty residues by formulating a chicken oil methyl ester using the transesterification method.

The transformation of fatty residues of *Galus galus domesticus* from informal slaughterhouses into biodiesel is carried out in this study. The characterization to highlight the physical properties of fatty residues is carried out to produce low-cost biodiesel and because of the availability of the primary material and the relative operational simplicity of the transesterification method.

2. Materials and Methods

An average of 150 chickens, with a mass varying from 1.5 kg to 3 kg, are slaughtered per day. A mass of 10.5 g of fat, on average, was extracted from a 100 g chicken. The average fat recovered in similar studies presented in the literature is estimated between 11 and 14 g by specialized means of extraction.

Male and female chickens of 60 days on average are bought by housewives. A group of volunteers is responsible for disemboweling the poultry, extracting the viscera, and storing them in plastic drums. The collection of greasy residues is done at the end of the day. The oil is extracted immediately after the recovery of the fat residues. It is cooled and stored in sanitized and hermetically sealed glass boxes.

2.1. Materials. Methanol was used as alcohol and KOH as a catalyst in the transesterification reaction. The Marie bath was used to ensure the transesterification reaction at a temperature of 60°C. A gas-phase chromatograph coupled with thermo-scientific trace 1300 GC mass spectrometry was used to determine the methyl ester composition of fatty acids from the developed biodiesel.

2.2. Oil Extraction. In this study, fat chicken residues were collected from PK14 market slaughterhouses in Douala, Cameroon. The humid climate, the high heat (approximately 27°C in the shade), and flies' permanent presence are potentially detrimental to preserving fats. The first step in extracting chicken oil was to clean up greasy residues with drinking water to remove solid particles, blood, and protein residues. The grease was then placed in a steel container for cooking at a temperature of 90°C to extract the oil and avoid degrading the raw material. Once the first traces of oil were observed, freshwater was added to ensure the complete extraction of the oil. The oil was extracted by evaporation of the

water. It was later filtered. This method is laborious, and its performance depends on the quality of the instrumentation. Figure 2 presents the protocol for extracting chicken oil.

2.3. Characterization of Extracted Chicken Oil and Biodiesel. The purpose of the characterization is to determine the chemo-physical property of the methyl ester and the chicken oil from which it derives.

2.3.1. Acid Index. The acid index was evaluated experimentally and deduced by (1) according to Tsai's method [10].

$$I_a = \frac{5.611 \times V \times F}{mHP}. \quad (1)$$

The constant 5.611 represents the product of the molar mass of the KOH and the concentration of the solution (0.1 N); V: volume in ml of consumed KOH solution needed to transfer the mixture; F: 0.1 MOL potency of KOH solution, which has a value of 1 because the KOH is a monobase; mHP: g mass of chicken oil used.

2.3.2. Iodine Index. The iodine index was also subsequently determined following the WIJS method. This index was deduced by the following equation:

$$\text{Iodine} = \frac{M' \times 100}{M}. \quad (2)$$

M' represents the formed diode mass; M represents the mass of the fat waste.

The biodiesel iodine index was empirically determined by the approved formula (4) proposed by Kalayasiri et al. in 1996 [31]:

$$\text{Iiode} = \frac{\sum (254 \times D \times Ai)}{Mwi}. \quad (3)$$

Ai represents the percentage of methyl fatty acid ester (I) found in biodiesel; Mwi represents the molar mass of methyl fatty acid ester (I) present in biodiesel; D denotes the number of double bonds contained in methyl fatty acid ester (I)

2.3.3. Lower Calorific Value (LCV). The low calorific value is determined by the high calorific value (HCV) and the hydrogen content of the oil or biodiesel. (4) calculates ICH after the experimental phase on a PARR-type calorimetric bomb.

$$LCV = HCV - 50.45 \times (\%H),$$
$$\%H = 26 - 15 \times d. \quad (4)$$

$\%H$ represents the hydrogen mass content of the oil or EMHPB developed; (d) represents the density of crude oil or EMHPB (g/cm^{-3}).

2.3.4. Biodiesel Saponification Index. The biodiesel saponification index is determined by an empirical formulation based on the molar mass and the percentage of fatty acid esters present in biodiesel.

$$Is = \frac{\sum (560 \times Ai)}{Mwi}. \quad (5)$$

Ai represents the percentage of the fatty acid methyl ester present in biodiesel; Mwi represents the molar mass of the fatty acid methyl ester present in biodiesel.

2.3.5. Indice de Cétane. The cetane index was determined by the empirical equation:

$$Ic = 46.3 + \frac{5458}{Is} - 0.225 \times \text{Iiode}. \quad (6)$$

It represents the saponification index of elaborate biodiesel or chicken oil; Iiode means the diode index of biodiesel or chicken waste fat.

2.3.6. The Density of Oil or Biodiesel. The density of biodiesel or oil from fat waste is obtained from a densimeter.

2.4. Transesterification of Chicken Fat Waste. The transesterification reaction is achieved using the Tsai method [10]. Methyl fatty acid esters were synthesized from a methanol and oil substrate in a mass ratio of 6 : 1, with 1% (m/m) KOH as a catalyst. A mass of 80.041 g of chicken oil, for 13.32 g of methanol and 0.803 g of KOH, was measured. At first, the catalyst is dissolved in alcohol using a magnetic agitator. When the catalyst is wholly dissolved, one gets a mixture of alkoxide. The resulting alkoxide is poured into a conical vial with the chicken oil preheated to a light temperature. The mixture was placed in a double boiler and heated to a temperature of 60°C and for 120 minutes under light agitation. At the end of the reaction, the vial contents are poured into a decanting light bulb and left to rest for 1 hour. Glycerol, which is not miscible with esters, settles at the bottom of the bulb, retaining a large part of the catalyst. The upper phase containing methyl ester of organic chicken oil (EMHPB) with excess alcohol, glycerol, and catalyst is recovered and washed with water heated at 70°C to avoid emulsions that may lower yield. After washing and decanting, the resulting biodiesel was heated to a temperature of 100°C in a Marie bath for a few minutes to remove the remaining water particles and recover purified biodiesel. Figure 3 presents the protocol for the transesterification of chicken oil.

3. Results and Discussion

3.1. Characterization of Chicken Oil. The experimental results, the acid indices obtained from the literature as well as the properties of chicken fat-based biodiesels are presented in Table 2.

The chicken oil acid index studied is 0.44 mgKOH/g, which is relatively lower than that of 5.72 mgKOH/g and 26.89 mgKOH/g [5, 32]. However, this result is similar to that of Lin and Tsai [10]. This observation would reflect that the fatty residues of chicken from informal slaughterhouses do not suffer significant degradation concerning acidity during the stay in the storage places. The viscosity of chicken

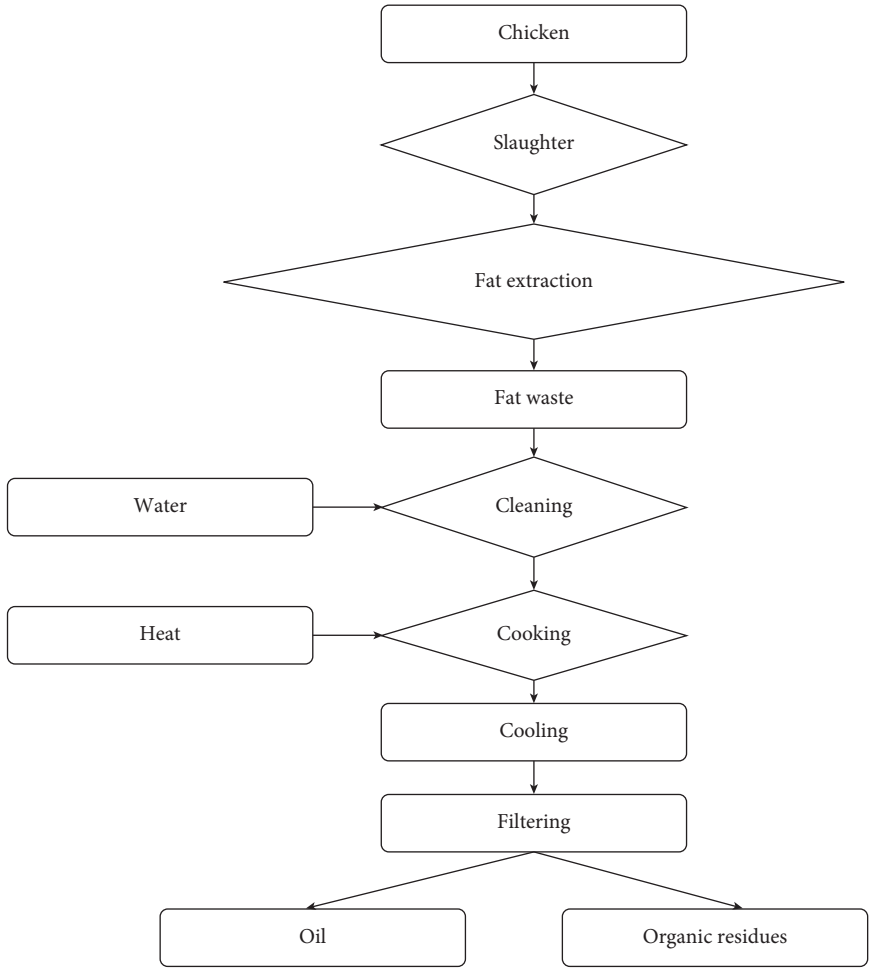

Figure 2: Chicken oil extraction protocol.

oil determined at 25°C has a value of 94.32 mm^2/s. The chicken oil extracted has a relatively high tendency to solidify. The observed pasty form of the oil after extraction could be a consequence of its high viscosity.

3.2. Characterization of Developed EMHPB (Biodiesel)

3.2.1. Characteristic Indices. Methyl oil esters of *Gallus gallus domesticus* $EMHP_B$ were subject to characterization to determine their physical-chemical properties. Table 3 shows the results obtained and compared to the values required by EN14214 and the physical and chemical properties of diesel (D100). The yield on the transesterification reaction is 85.6%. This resulted in a biodiesel mass valued at 63.522 g.

The acid index is 0.44 mgKOH/g, 12% below the upper limit value set (0.5 mgKOH/g) by the EN14214 standard. The acid index of the developed $EMHP_B$ is similar to that of the oil from which it derives. This similarity in the oil acid index with biodiesel developed was observed by Lin and Tsai [10]. The oxidation stability of biodiesel is related to its free fatty acid content, which is measured by the acid index. The experimental results of this study reveal a low acid value of the elaborate methyl ester. This predisposition is likely to facilitate the long-term operation of an engine powered by biofuel based on fatty chicken residues from informal slaughterhouses. The iodine index of the $EMHP_B$ was determined and estimated at 68.2 $gI_2/100$ g or 43% lower than the value set by the standard EN14214 (120 $gI_2/100$ g). The value found is similar to that found by Panneerselvam [33] and Lopes [32]. The density of the $EMHP_B$ obtained is 0.860 g/cm^{-3}. This value is 3.13% higher than that of diesel. This value found is close to Haq and Mohammad [7] and is within the range set by the EN14214 standard. The kinematic viscosity at 40°C, the kinematic viscosity of $EMHP_B$ is estimated at 4.96 mm^2/s, 10.22% higher than that of diesel. This viscosity is consistent with the value required by EN14214. The $EMHP_B$ cetane index, determined by the saponification index and the $EMHP_B$ cetane index, is estimated at 60.483, or about 8% and 26% higher, respectively, than the lower and upper limits of the diesel cetane index. The values found in this study are similar to those of Haq and Mohammad [7].

Gas chromatographic analysis and mass spectrometry determined the methyl ester composition of fatty acids from the developed biodiesel. This analysis indicates that the chemical structure contains carbon, hydrogen, and oxygen, respectively. This presence of oxygen, combined with the absence of sulfur, and the aromatic compound, is potentially

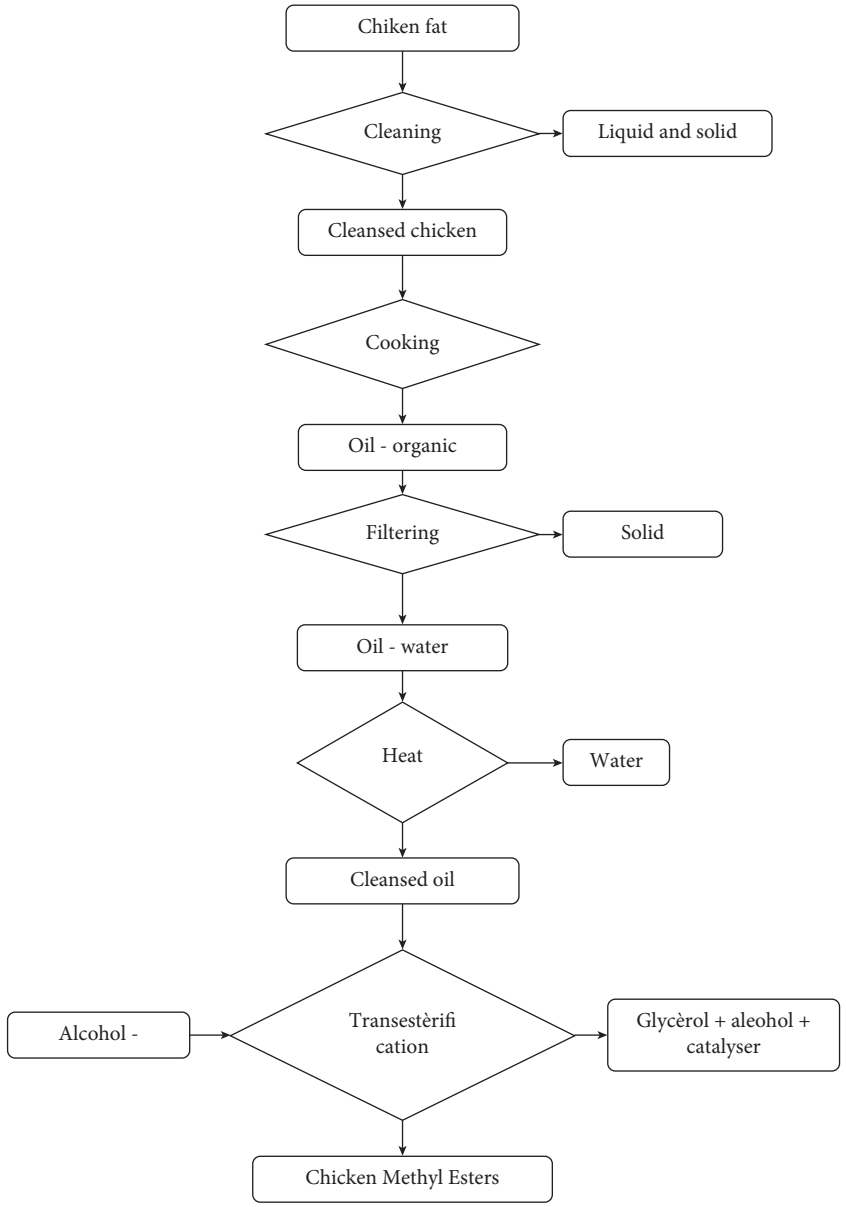

Figure 3: Biodiesel production protocol from fatty chicken residues.

Table 2: Comparison of experimental results with those obtained by other authors.

Properties	Studied chicken fat waste	Lopes et al [32]	Tsai et al. [10]	Ertan et al. [5]	Mohiddin [31]	Ramirez-Ortiz et al. [11]
Acid index (mgKOH/g)	0.44	5.72	0.13 0.01	26.89	1.72	6.6
Saponification index (mgKOH/g)	255.816	—	148.62 6.18	—	—	203
Iodine index (gI_2/100 g)	77.4	—	—	—	—	65.9
Cinematic viscosity at 25°C (mm^2/s)	94.32	—	—	59.2	38.10	—
Density ($g.cm^{-3}$)	0.916	—	—	0.932	0.926	0.9074
Cetane index	50.22	—	—	—	—	—
Lower calorific value (KJ/Kg)	36789.18	—	—	—	—	—

Table 3: Physical-chemical property of chicken fat waste compared to those obtained in the literature.

Properties	Chicken fat waste studied	Lopes et al. [32]	Tsai et al. [10]	Ertan et al. [5]	Mohiddin [22]	Ramirez-Ortiz et al. [11]
Acid index (mgKOH/g)	0.44	5.72	0.13 0.01	26.89	1.72	6.6
Saponification index (mgKOH/g)	255.816	—	148.62	—	—	203
Iodine index (gI_2/100 g)	77.4	—	—	—	—	65.9
Cinematic viscosity at 25°C (mm^2/s)	94.322	—	—	59.2	38.10	—
Density ($g.cm^{-3}$)	0.916	—	—	0.932	0.926	0.9074
Cetane index	50.22	—	—	—	—	—
Low calorific value (KJ/Kg)	36789.18	—	—	—	—	—

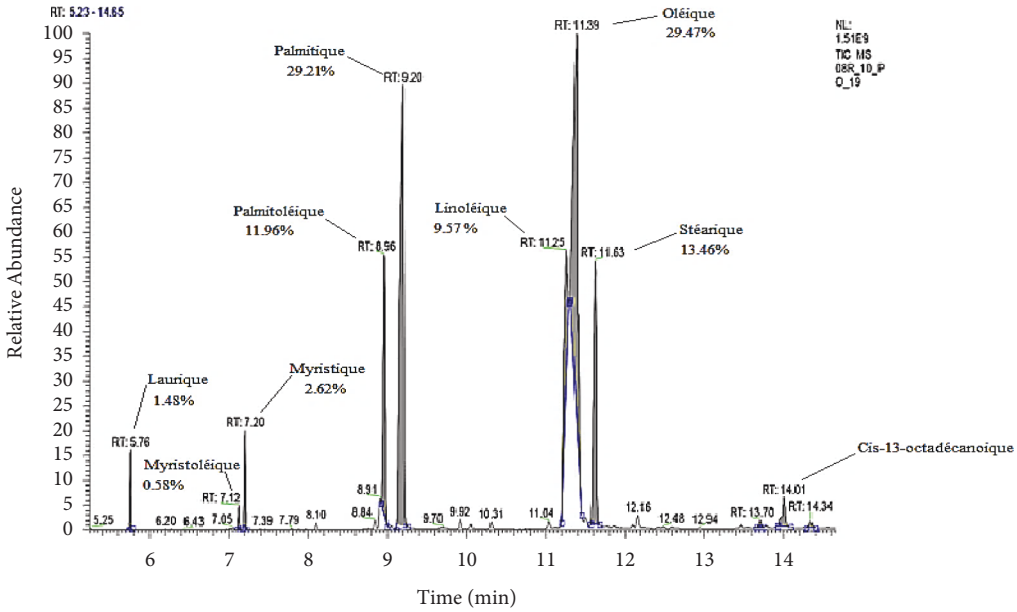

Figure 4: Spectrum of methyl esters present in the $EMHP_B$.

Table 4: Methyl fatty acid esters identified in biodiesel sample.

Common names	Fatty acyl ester	Formula	Retention time (min)	Composition (%)
Palmitoléic	C16 : 0 methyl	$C_{17}H_{32}O_2$	8.96	11.96
Palmitic	C16 : 0 methyl	$C_{17}H_{34}O_2$	9.20	29.21
Linoléic	C18 : 2 methyl	$C_{19}H_{34}O_2$	11.25	9.57
Oléic	C18 : 1 methyl	$C_{19}H_{36}O_2$	11.39	29.47
Stéaric	C18 : 0 methyl	$C_{19}H_{38}O_2$	11.62	13.46
Myristic	C14 : 0 methyl	$C_{15}H_{30}O_2$	7.20	2.62
Myristoléic	C14 : 1 methyl	$C_{15}H_{28}O_2$	7.12	0.58
Lauric	C12 : 0 methyl	$C_{13}H_{26}O_2$	5.76	1.48
cis-13-Octadécanoïc	C18 : 1 methyl	$C_{18}H_{34}O_2$	14.01	1.63

interesting. Indeed, this predisposition would offer the developed biodiesel the advantage from the point of view of reducing emissions of unburned hydrocarbons, particulate matter, and sulfur oxides when burning in a diesel engine. The absence of sulfur in biodiesel is essential for the life of the biofuel user engine Figure 4 presents the spectra of methyl esters identified in the chicken fat waste biodiesel sample. Figure 4 presents the physical-chemical properties of chicken fat waste methyl ester.

The abscis axis represents the retention time of the compounds, and the axis of the order is that of the predominance of the compound present in the $EMHP_B$. The blue coloration in the spectrum makes it possible to differentiate the surfaces of the spectra of the different

Table 5: Comparison of methyl fatty acid esters in biodiesel developed with those obtained in the literature.

Fat acid ester	$EMHP_B$	Lopes et al. [32]	Tsai et al.	Bhatti et al.	Ortiz et al.
(%)	(%)		[10]	[7]	[3]
Caprylic methyl ester (C8:0)	—	—	—	0.0144	—
Capric methyl ester	—	—	—	0.0285	—
Lauric methyl ester (C12 : 0)	1.48	—	—	0.7901	—
Tridécanoic methyl ester	—	—	—	0.2465	—
Myristic methyl ester (C14 : 0)	2.62	0.28	—	0.2286	6.1
Myristoléic methyl ester (C14 : 1)	0.58	—	—	0.0827	—
Palmitic methyl ester (C16 : 0)	29.21	24.85	7.97	24.654	29.6
Palmitoléic methyl ester (C16 : 1)	11.96	6.13	—	6.9231	—
Heptadécanoic methyl ester	—	—	—	0.1419	0.4
Margaric methyl ester (C17 : 0)					
Stéaric methyl ester (C18 : 0)	13.46	6.23	6.19	6.2515	4.6
Oleic methyl ester (C18 : 1)	29.47	41.19	36.21	45.1812	42.1
Linoléic methyl ester (C18 : 2)	9.57	20.94	16.11	12.5832	15.9
Linolénic methyl ester (C18 : 3)	—	<LD*		0.3832	1.3
cis-13-Octadécanoïc methyl ester (C18 : 3)	1.63	—	—	—	—

*Below the detection limit.

Table 6: Physical-chemical properties of chicken fat waste methyl ester.

Properties	$EMHP_B$	Tsai and Lin [3]		Mohiddin et al. [12]		Ramírez-Ortiz and Jorge [3]	Panneerselvam and Parthiban [33]	Diesel (D100)	EN 14214
Acid index (mgKOH/g)	0.44	0.144	0.183	0.301	0.15	3.64	0.16	—	0.5 max
Iodine index (gI_2/100 g)	68.2	—	—	—	—	—	80	—	120 max
Cinematic viscosity (mm^2/s)	4.96 (à 40°C)	4.469	4.594	4.822	4.24	6.3	4.386	4.50 (à 40°C)	3.5–5.0
Density ($g.cm^{-3}$)	0.860	879.6	874.7	879.6	874	895.9	870	0.83	0.86–0.90
Cetane index	60.483	—	—	—	—	—	—	48–56	51 min
LCV (KJ/Kg)	38775.363	—	—		—	—	42820	—	

compounds. The results of Table 4 indicate the dominant presence of oleic acid (C18 : 1), followed by palmitic acid (C16 : 0) in the developed biodiesel. This high content of oleic and palmitic acid is also noted by Lin and Tsai [10], Haq and Mohammad [7], and Jorge and Merced [11].

The literature indicates that saturated esters are predisposed to higher calorific and cetane indexes than unsaturated esters [1, 2]. On the other hand, the double bonds intrinsic to unsaturated esters are more sensitive to chemical deterioration such as self-oxidation and polymerization [3, 34, 35]. Investigations by Mittelbach [36] reveal that soy oil-based biodiesel containing a high level of unsaturated fatty esters can lead to the formation of deposits in the engine and the deterioration of lubrication oil. However, the developed $EMHP_B$ has an ester content of unsaturated fatty acids of 53.21% and a saturated fatty acid content of 46.77%. This biodiesel could be exposed to chemical damage. Awad et al. [3] advise adding antioxidants to this type of biodiesel and bringing it to a temperature of 60°C before its possible introduction into the engine to avoid the formation of deposits in the engine. The comparative presentation between the methyl ester composition of fatty acid from the developed biodiesel and the results from the literature are contained in Table 5.

Usually, the fat will be with a higher FFA. The reason for the decline in FFA in this study can be attributed to the transformation of recovered fats into biofuel about four hours after the hens have been slaughtered. The use of appropriate tanks for fat recovery probably limited their contact with oxidizing agents that could increase the rate of FFA. Physical-chemical properties of chicken fat waste methyl ester are shown in Table 6.

4. Conclusion

The oil extracted has been characterized, revealing that it has physical and chemical properties of interest for energy application. A transesterification reaction to basal catalysis with methanol at specific proportions (alcohol/oil mass ratio of 6 : 1, 1% (m/m) KOH) was achieved. The transesterification reaction took place over 120 minutes. The conversion of the oil to biodiesel was assured with a yield of 85.6%. Biodiesel has been characterized and has properties following EN14214:

(i) The density of the $EMHP_B$ obtained is 0.860 g/cm^{-3}, 3% higher than that of diesel.

(ii) Chromatographic analysis coupled with mass spectrometry indicates the fatty residues *of Gallus gallus domesticus* have an oleic and palmitic dominant composition, 29.49% and 29.21, respectively.

(iii) The cetane index of the fatty residues *of Gallus gallus domesticus* is estimated at 60.483.

(iv) The fundamental analysis of the biodiesel obtained would make it possible to formulate the biofuel chemically obtained.

(v) Experimenting with other thermochemical treatment methods could improve performance. Conservation and conservation methods do not irreversibly alter the properties of the raw material.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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