Research Article

Biodiesel production from slaughter wastes of broiler chicken: a potential survey in Iran

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Received: 26 May 2020 / Accepted: 21 December 2020 / Published online: 10 January 2021

Abstract

Biodiesel is a kind of biofuels that can be mixed with diesel and used as fuel. Selecting cheap and available feedstock is a prominent step in producing biodiesel economically. This paper presents the pros and cons of biodiesel and its production methods. The diesel demand is significantly high in Iran, especially in the transportation sector; On the other hand, the amount of produced waste is significant in chicken slaughterhouses. Considering this type of feedstock as a source to produce biodiesel not only can reduce the associated environmental problems, but also can supply some of the diesel needs. Hence, this paper also estimates biodiesel production potential from poultry slaughter waste and its cost. Based on the results, 736 kilotonnes of poultry slaughter waste is produced annually in Iran, which can be used as feedstock to produce 112 million liters of biodiesel by transesterification process with the production cost of around 14,277 rial/liter; i.e. 30% of diesel demand in the transportation sector can be supplied by B2 (98% diesel and 2% biodiesel) or diesel demand growth in this sector converted to B20 to increase economical and environmental sustainability.

Keywords Biodiesel · Chicken fat oil · Cost estimation · Production potential · Transesterification process

1 Introduction

The total global energy consumption has been rising due to the population growth, industrialization and increase of the living standards level. In 2017, the world total energy consumption was 609.5 quadrillion Btu and it is expected to reach 910.7 quadrillion Btu in 2050 with 49% growth rate [1]; More than 80% of the world energy demands are supplied by non-renewable fossil fuels (natural gas, crude oil and coal) [2]. This increasing trend, not only causes a serious crisis in energy supply, but also leads to numerous environmental issues such as climate change and global warming, caused by greenhouse gases emissions [3]. Renewable and non-fossil fuels could be a great alternative to solve this problem. In 2017, 14.6% of total world energy consumption was supplied by renewable energies [4]. The use of biofuels is growing as an option in developed countries. In 2017, 1.0% of the total global energy consumption was provided by biofuels which is equivalent to 6.8% of total renewable energies [4].

Iran is a developing country located in the Middle East, with a population of about 80 million and highly dependent on low-price fossil fuels [3, 5]. In 2017, the total primary energy consumption was 285.7 Mtoe (million tonnes of oil equivalent, 1 Mtoe = 41,868,000 GJ), more than 90% of which was supplied by crude oil and natural gas resources as indicated in the Fig. 1 [6]. In this year, 217 million liters/day of various types of petroleum products were consumed in Iran, 38% of which (equals to 30,277 million liters/year) was diesel. This presents 90% of total diesel production in Iran, about 2394 million liters of which has been exported this year (Fig. 1); However, compared to the previous year, diesel consumption has been reduced in all sectors while is increased in the transport sector (the second largest part in

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SN Applied Sciences (2021) 3:57 | https://doi.org/10.1007/s42452-020-04045-7

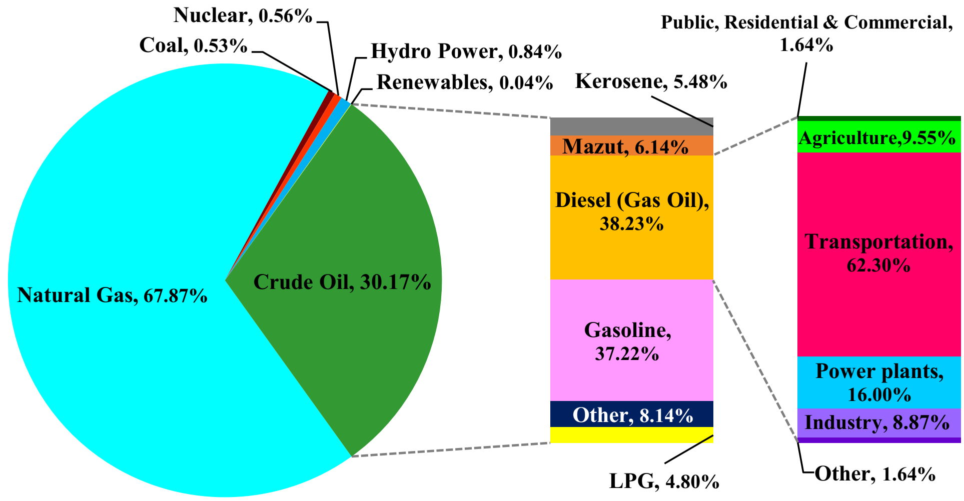

Fig. 1 Primary energy consumption of Iran by carriers and sectors, 2017 [6, 7]

energy consumption and the largest diesel consumer in Iran) with a growth rate of 2.6% [7]. In 2017, 72% of suspended particulate matter (SPM), 34% of Nitrogen oxides (NO_x) and 58% of Sulphur oxides (SO_x) emissions, were released due to diesel consumption in the energy sector of Iran [7]. In other words, 8.2, 16.9 and 10.6 tonnes of SPM, NO_x and SO_x are produced per million liters of diesel consumption, respectively. These contaminants are the basic factors to corrosion, acid rain, and damages to trees and plants. In addition, diesel combustion and its greenhouse gases emissions cause reduction in visibility and ground-level ozone. Furthermore, organic compounds coming out of diesel engines exhaust contain carcinogens like nitro- polyaromatic hydrocarbons [8]. Therefore, the consumption of this petroleum product is the main cause of the most dangerous pollutants emissions in Iran which should be replaced by non-carbon biofuels such as biodiesel. Studying biodiesel production methods, as a carbon–neutral fuel can be certainly an important stride in substituting this clean energy with diesel. The potential assessment can support planning for the sustainable development of the bioenergy system.

The first purpose of this paper is to evaluate the various feedstocks as well as explain a brief overview of the technologies currently used for biodiesel production. The second purpose is to assess the potential of biodiesel production and consumption from chicken fat as feedstock and its cost in Iran, which research methodology is described in Sect. 3. According to the results and discussion, Sect. 4 concluded weather biodiesel is an acceptable and sustainable alternative for diesel in Iran or not?

2 Biodiesel: feedstocks and production methods

The mono-alkyl ester of long chain fatty acid is called biodiesel. It is a renewable alternative for the petroleum-derived diesel which has non-renewable nature [9, 10]. The impressive features of biodiesel made it acceptable in the energy market. However, it is worth noting that these biofuels have some disadvantages too. The pros and cons of biodiesel is tabulated in Table 1 [8–14].

Figure 2 shows the world's largest producing countries in 2017. In this year, U.S. was the largest biodiesel producer in the world, generating 6 billion liters; To produce this amount of biodiesel, in U.S. during 2017, various feedstocks were used, including soybean oil (52%), recycled feeds (13%), corn oil (13%), canola oil (12%) and animal fats (10%) [15].

One of the major challenges in biodiesel production is the supply of raw materials, because more than 70% of the total cost of biodiesel production depends on it. Another challenge is the availability of feedstock which depends on various factors, including the geographical conditions of the region and the nature of the oil resources. In general, biodiesel is divided into five types based on feedstock that are introduced and discussed in Table 2 [8–10, 16–20]. Currently, more than 95% of biodiesel production in the world is based on 1st generation feedstocks that are commonly used in rich countries in terms of agricultural land and water resources. However,

Table 1 Advantages and disadvantages of biodiesel in contrast with diesel

Advantages	Disadvantages
Renewability [9, 11, 12, 14]	More expensive [11]
Local production [10–12]	Lower oxidation stability [9, 10]
More cost efficient	Corrosion of the fuel tank, pipe and injector
Higher biodegradable [11, 14]	Higher copper and brass strip corrosion [11, 12, 14]
Non-flammable and non-toxic [11, 12, 14]	Fuel system blockage, seal failures, filter clogging and deposit at injection pump
Lower noxious fumes and odors [12]	Lower volatility [10, 14]
Higher cetane number [10, 14]	Higher required injector pressure
Lower ignition delay	Incomplete combustion
Lower vapour pressure and higher flash point [10, 11, 14]	Higher cloud and pour point [10, 12, 14]
Safe transportation, handling, distribution, utilization and storage	Unfeasible for cold climates
Better lubricating quality [10–13]	Higher viscosity (11–18 times) [10, 12]
Lower engine wear	More difficult pumping, combustion and atomization in the injector system of a diesel engine
Higher engine efficiency	Development of gumming
Without the need for additional lubricant	Ring sticking
Lower sulfur content [8, 14]	Higher density [11, 13]
78% lower net CO_2 emission [9, 10, 14]	Need to use the blends in sub-freezing conditions
20% lower hydrocarbons (HC) [8]	2% lower brake thermal efficiency [8]
90% lower total unburned HC [8]	13% higher specific fuel consumption [8]
75–90% lower polycyclic aromatic HC [8]	12% lower energy content [10, 13, 14]
30% lower carbon monoxide (CO) [8]	2–10% higher fuel consumption
50% lower smoke [8]	Necessity of engine modification for higher blends [10, 12, 14]
Lower SO_2, and PM emissions [12]	10–11% higher oxygen content [10, 14]
No required engine modification up to B20 [10, 12, 14]	Advance in fuel injection and timing
10–11% higher oxygen content [10–12, 14]	Earlier start of combustion
Higher combustion efficiency	10–14% higher NO_x emission

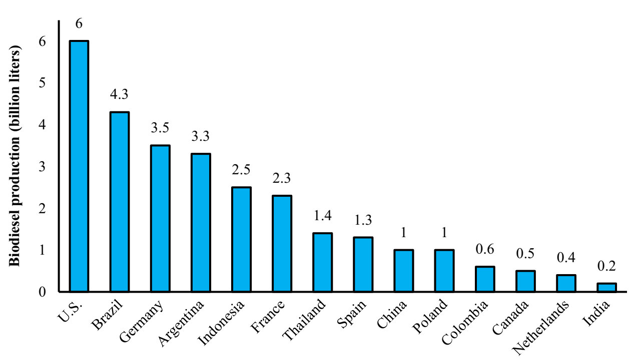

Fig. 2 Biodiesel production in different countries, 2017 [4]

producing this type of biodiesel results in increasing land use change (LUC) and reducing land allocation for cultivation of food crops, leading to food shortages and price increase [21–23]. The 2nd generation of biodiesel production does not compete with food production plans but affects LUC criterion. In addition, the use of chemical fertilizers, irrigation and harvesting is inevitable in order to achieve the maximum yield of 2nd generation feedstocks. The approach of using waste sources (waste oil produced from the consumption of edible oil and animal waste) for biodiesel production not only avoids the extra cost and environmental problems but also eliminates competition for food, water and land. In addition, it ensures the supply of feedstocks for biodiesel production thanks to their variety and plenitude [24]. Extensive research directed on biodiesel production from 4th and 5th generation feedstocks that showed production cost is high compared to petroleum-derived diesel. Therefore, only 3rd generation biodiesel production is possible in viewpoint of cost and feedstock sustainability.

However, the direct use of pure oil from these types of feedstocks are not satisfactory and practical in diesel engines as it results in polymerization during storage and combustion and, subsequently, gum formation, carbon deposit and incomplete combustion, due to its high viscosity, acid composition and free fatty acid content. To resolve this problem, either pure oil needs to be diluted or its hydrocarbon chains have to be broken down into

Table 2 Biodiesel feedstock classification based on the sustainability issue

Type of biodiesel	Feedstocks	Examples	Consequences	References
Fossil fuel	Mineral diesel	–	Finite unsustainable reserves Deep GHG footprint Toxic pollutants Causing acid rain	[8]
1st generation	Edible oil crops	Palm, rapeseed, sunflower, soybean, Linseed, Cotton seed	Land use change GHG footprint Food competition High cost of feedback/biodiesel	[8–10, 16–19]
2nd generation	Non-edible oil crops/lignocellulosic residues	Jatropha, camelina, pongamia, neem, rice straw, castor oil	Land and water usage GHG footprint Fertilizer and pesticides	[8–10, 16–19]
3rd generation	Waste Industrial and commercial waste Animal waste	 Food waste, used cooked oil, sewage waste Fish oil, tallow, poultry fat	No GHG footprint No land/water use Low cost sustainable feedstock Solution for waste disposal No food competition	[8, 10, 16–20]
4th generation	Algae Microalgae Macroalgae	 Chlorella vulgaris, Nannochloropsis sp., Arthrospira platensis, Arthrospira maxima Cladophora fracta	No GHG footprint No land/water use No food competition Sustainable feedstock in long term	[8–10, 17, 18]
5th generation	Genetically engineered crops	–	No GHG footprint No land/water use No food competition Sustainable feedstock in long term	[8, 17]

simpler components. It can be performed in several methods: physical methods, including direct use and blending (dilution) and microemulsion; and chemical methods, including pyrolysis (thermal cracking) and transesterification (alcoholysis). Today, transesterification is the most common method used in industry [25–28]. The comparison of these four main techniques is shown in Table 3 [12, 17, 19, 29–40].

3 Materials and methods

3.1 Feedstock

Chicken slaughterhouse wastewater is often discharged directly (untreated) to municipal wastewater or in most cases to surface water sources and their solid waste is also usually burned or buried. These disposal methods will result in environmental pollution as outflows in the slaughterhouse industry have a lot of BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand). In addition, the presence of pathogenic microorganisms in this waste type results in its decomposition into the environment and odor production and uncontrolled greenhouse gas emissions to the atmosphere; Consequently, it threatens the health of residents near disposal sites.

It is proved that chicken fat is a promising feedstock for biodiesel production [14, 41, 42]; Although slaughter waste requires pre-processing, compared to low fatty acid sources. It is considered as one of the cheapest industrial products to produce biodiesel [43–45]. Furthermore, the amount of non-edible oil produced from chicken fat extraction is by far more than the related counterpart for vegetable oil; Rendering it is more cost-effective compared to the other feedstock. Chicken oil contains high energy content (Its calorific value is 39.4 MJ/kg [46], which is just a bit lesser than that of petroleum fuel). In biodiesel production, The highest yield has been acquired from chicken fat (approximately 99.1% [42]) in comparison with other types of biodiesel feedstock and it can be used as a solvent to improve alcohol and diesel properties (since it is more lubricant than petroleum diesel) [11, 47–49]. In this paper, the potential and cost of biodiesel production from chicken fat is investigated in Iran.

3.2 Calculation of biodiesel production potential from chicken fat

In Iran, there is no accurate data on the amount of produced waste in poultry slaughterhouses. Only, there are some statistics on the number of chickens and live chicken weight. The 2017 statistics, separated by province, are presented in Table 4 [50].

Table 3 Comparison of four main methods for biodiesel production

Method	Definition	Advantages	Disadvantages
Direct use and blending (dilution)	Oil dilution with such materials as diesel fuels, solvent or ethanol [31]	Simple process [17, 32, 33, 35]	Unstable [33, 34]
		Easy implementation [34]	Low volatility [33–35]
		Low capital and production costs [35]	Poor atomization [35]
		Absence of technical modifications [34]	High viscosity [33–35]
		Does not required any chemical process (non-polluting) [34]	High free fatty acid (FFA) [35]
			Higher air pollution emission [35]
			Higher engine maintenance costs [35]
			Higher engine wear [35]
			Gum formation [35]
			Solidification of blend at cold temperatures [35]
			Oil deterioration [35]
			Lubricating oil thickening [35]
			Unsaturated hydrocarbon chains reactivity [35]
			Incomplete combustion [32]
			Formation of carbon in engine [32]
			Difficulty in handling by conventional engines [34]
			Engine durability reduction [35]
			Injector nozzles plugging [35]
			Improper spraying pattern caused by an increase in vegetable/animal oil portion [36, 37]
Microemulsion	The isotropic mixture of at least two immiscible liquids including diesel fuel, oil, solvents (alcohols such as methanol and ethanol as viscosity reducer), higher alcohols (as surfactants) and alkyl nitrates (as cetane improvers) at appropriate ratios [30, 40]	Simple process [17, 32, 34]	Low stability (the addition of ethanol can enhance the quantity of surfactant required to maintain the state of microemulsion) [17, 32, 34]
		Non-polluting [34, 35]	Low volatility [17, 32]
		Higher liquidity [35]	High viscosity [17, 32, 34]
		Lower viscosity [35]	Lubricating oil thickening [35]
		No by-product or waste formation [35]	Incomplete combustion [35]
		Single phase [35]	Random injector needle sticking [34, 35]
		Thermodynamically stable colloidal equilibrium dispersion of biodiesel fluid [35]	Carbon deposition [34, 35]

Table 3 (continued)

Method	Definition	Advantages	Disadvantages
Pyrolysis (thermal cracking)	A chemical change caused on oil by the application of thermal energy in the absence of air or oxygen, or by the application of heat in the presence of a catalyst [30, 31, 40]	Simple process (not required washing, drying or filtering) [17, 32–34]	High temperature requirement [32–34]
		Non-polluting [32–34]	Complex and expensive equipment requirement [17, 32–35]
		Less waste [34]	High production cost [35]
		Suitable for areas with well-established hydro-processing industry [35]	No oxygenated value [35]
		Generation of value-added by-products like syngas [35]	Low purity (contain heterogeneous molecules including ash and carbon residues) [17, 32–34]
		Biofuel with satisfactory physical and chemical properties [35]	Producing short chain molecules with more similarities to gasoline than diesel fuel [35]
Transesterification (alcoholysis)	A reversible reaction between triglyceride molecules present in oil and alcohol under pressure and/or heat which if a catalyst is added to the reaction, it will be accelerated [29, 38, 39]	The most common method for production of biodiesel [12, 35, 39]	Complex equipment requirement [35]
		Fuel properties are closer to diesel [17, 32–34]	Expertise requirement [35]
		High conversion efficiency [32–34]	Large amount of generated wastewater [36, 37]
		Low cost [33, 34, 39]	Required low free fatty acid and water content (for base catalyst) [33, 34]
		Applicable for industrial-scale production [17, 33, 34]	Pollution production following washing and neutralizing products [33]
		Mild reaction conditions [34]	Extensive separation and purification steps [34]
		Unreacted feedstock can be recycled [35]	Accompanied by side reactions [33, 34]
		The by-product (i.e., glycerol) can be converted into value-added products [35]	Difficult reaction products separation [33, 34]
			Glycerol must be efficiently separated to avoid generation of hazardous gases (i.e., acetaldehyde, formaldehyde) [35]
			Dry alcohol and oil must be used to increase biodiesel yield by avoiding saponification [35]

The amount of slaughter waste production in each region varies based on feeding conditions, the number and type of slaughter as well as the percentage of waste from each animal; However, at least 28% of the weight of a live broiler chicken constitutes solid waste [51, 52] (Table 5). 35% of the waste is converted to high protein meal and 1.09 kg of Chicken fat oil (with density equal to 0.87 kg/l) can be extracted by rendering 7.5 kg waste [53]. Efficiency of converting chicken fat oil to biodiesel is 88.1% by transesterification process in the presence of homogeneous alkaline catalyst KOH. Finally, according to all these, the potential of biodiesel production is calculated for broiler slaughter waste [42, 54].

3.3 Estimation of the cost of biodiesel production from chicken fat

Chicken fat is a by-product in the rendering process of chicken slaughter waste for meal preparation (Fig. 3). So, it is free and only the cost of collection and transportation is considered.

In this paper, the transesterification process with methanol as alcohol (due to its low cost, better physical and chemical properties and easy removal from glycerin) and KOH as catalyst (due to its low cost, high catalytic activity and mild operating conditions) were considered to estimate the cost of biodiesel production from chicken fat [41, 54, 55]; The

Table 4 Amount of live broiler chicken produced in each province in Iran according to the data in 2017 [50]

Province	Weight of live poultry (tonne)	Number of one-day old broiler chick (1000 pieces)
East Azarbaijan	95,331	35,661
West Azarbaijan	91,980	40,127
Ardabil	34,901	14,917
Isfahan	176,246	78,821
Alborz	9272	4564
Ilam	43,851	18,759
Bushehr	31,696	15,945
Tehran	18,584	7672
Chaharmahal and Bakhtiari	24,085	10,538
South Khorasan	62,424	31,545
Razavi Khorasan	200,238	87,629
North Khorasan	17,975	8094
Khuzestan	92,654	46,055
Zanjan	44,171	18,058
Semnan	61,898	25,221
Sistan and Baluchestan	23,801	12,607
Fars	167,201	78,575
Qazvin	64,905	26,122
Qom	32,054	13,270
Kordestan	99,665	39,927
Kerman	51,580	23,598
Kermanshah	54,691	23,359
Kohgiluyeh and Boyer-Ahmad	11,107	5204
Golestan	230,485	95,257
Gilan	190,818	83,410
Lorestan	83,695	35,889
Mazandaran	317,334	132,045
Markazi	62,545	26,989
Hormozgan	29,205	15,094
Hamedan	55,008	21,613
Yazd	60,361	28,353
Total	2,539,761	1,104,918

Table 5 Poultry slaughter wastes and their potential uses [51, 52]

Type of waste	% of live weight	Uses
Feathers	7–8	Bedding material, decorative purpose, sporting equipment, manure or fertilizers and feather meal
Heads	2.5–3	Poultry meal
Blood	3.2–3.7	Blood meal
Gizzard and proventriculus	3.5–4.2	Edible and source of chitinolytic enzyme
Feet	3.5–4	Soup and technical fat/poultry grease
Intestines and glands	8.5–9	Gat sport, meat meal, poultry grease and active principles (hormones and enzymes)

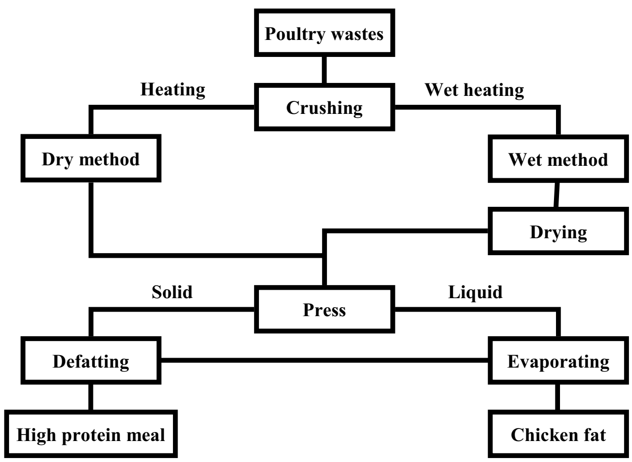

Fig. 3 Rendering process of poultry wastes [42], with permission from "Elsevier" Copyright© 2020

most important parameters of this process are: reaction temperature, alcohol to oil ratio, type and amount of catalyst, mixing intensity and type of raw oil. The various stages of the process are shown in Fig. 4 [54]. Chicken fat is slowly melted and then filtered. 1000 ml of chicken fat oil is poured into a volumetric flask; volumetric flask is manually shaked and simultaneously heated. When the raw oil temperature reaches 60 °C, methanol (200 ml) and KOH solution (7.5 g) are added separately to the oil and the volumetric flask door is closed. Then, the solution is stirred at high speeds. The temperature should not exceed 60° C as methanol evaporates, if temperature passes 60 °C. This solution is stirred for an hour and transferred to a separating glass conical flask. Upon separation, biodiesel accumulated at the top and glycerin at the bottom. By opening the valve, the conical flask is cleared from the glycerin. At this time, the biodiesel is repeatedly washed with distilled water at 50 °C to clean the soap thoroughly. Finally, it is heated to temperature above 100 °C to evaporate the water. The result is ready-to-use chicken fat biodiesel. The data and assumptions needed to estimate the net cost of biodiesel production are presented in Table 6.

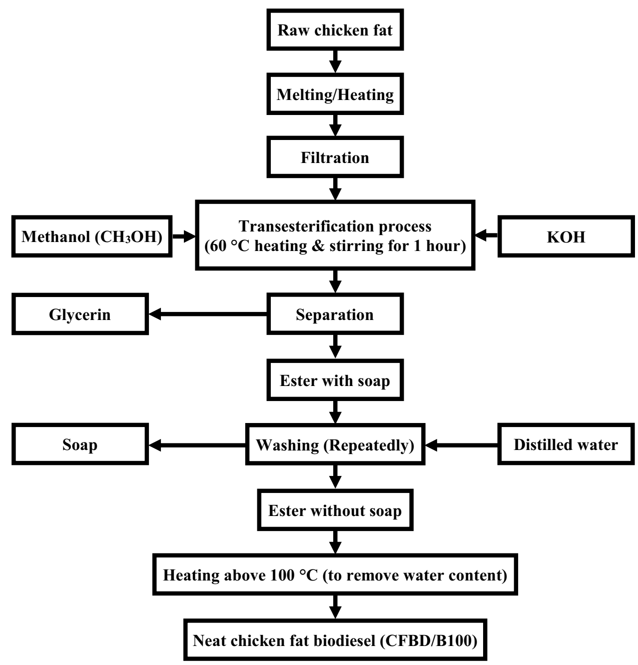

Fig. 4 Various stages of chicken fat biodiesel production by transesterification process [54]

4 Results and discussion

In 2017, 2,539,761 tonne live chickens were bred per 1,104,918,000 chickens in Iran (2.30 kg per chicken). The amount of poultry slaughter waste was estimated at 7.632×10^5 tonne. Figure 5 shows the amount of waste generated based on its type. 2.671×10^5 tonne of high protein meals and 110.918×10^3 tonne of chicken fat oil can be obtained from this produced waste.

The potential of biodiesel production is given for each province in Table 7. Based on these results, 127.492 million liters of chicken fat oil can be produced with the potential of producing 112.321 million liters of biodiesel in Iran. The highest contributions are determined for the provinces of Mazandaran (12.49%), Golestan (9.08%), Razavi Khorasan (7.88%), Gilan (7.51%), Isfahan (6.49%), and Fars (6.58%).

Table 6 Data and assumptions for net cost estimation of biodiesel production from chicken fat

Data and assumptions	Value	Unit
Consumption chicken fat	1000	liter/day
Requirement of methanol	200	liter/day
Requirement of KOH	7.5	kg/day
Requirement of water	4000	kg/day
Price of chicken fat	0	rial/liter
Price of collection and transportation and melting chicken fat	6000	rial/liter
Price of methanol	24,000	rial/liter
Price of KOH	180,000	rial/kg
Price of electricity	720	rial/kWh
Basic temperature	20	°C
Power of motor for Stirring methanol and KOH	10	kW
Power of motor for Stirring during transesterification process	15	kW
Duration of stirring methanol and KOH	15	min/day
Duration of Stirring during transesterification process	1	h/day
Efficiency	0.9	–
Maintenance of temperature about 60 °C	600,000	rial/month
Specific heat of waste chicken fat	1.97	kJ/kgK
Specific heat of water	4.18	kJ/kgK
First cost of equipment	300,000,000	rial
Equipment life	15	year
Interest rate	0.1	–
Labor cost	27,000,000	rial/month
Rent	3,000,000	rial/month
Maintenance	600,000	rial/month
Glycerin produced	50	liter/day
Price of glycerin	15,000	rial/liter

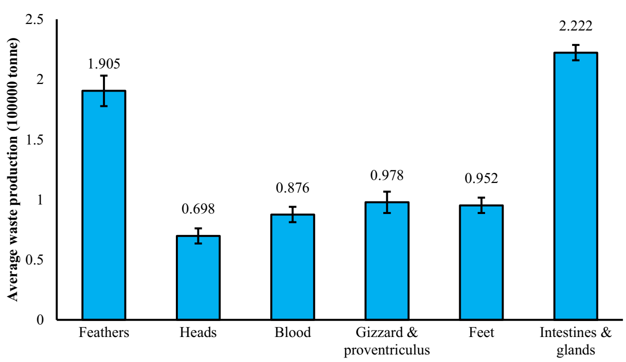

Fig. 5 Estimated average quantities of produced waste from poultry slaughter in Iran, 2017

In other words, these Six provinces can produce approximately half of the total biodiesel production potential from slaughter wastes in Iran. This amount of biodiesel production potential is equal to 0.6% of consumed diesel in the transportation sector in 2017. By managing that, 561.602 million liters of B20 (80% diesel and 20% biodiesel) can be replaced with required diesel for transportation, which is approximately equivalent to increasing diesel consumption in this sector compared to 2016; Or supplying 30% of diesel consumption in the transportation sector as B2 (98% diesel and 2% biodiesel). This will be efficient for reducing the emission of pollutants, especially SPM and SO_x. Although the potential of biodiesel production from edible oilseeds is estimated at 721 million liters [56], oilseeds are consumed only in the food sector in Iran. Also, using poultry slaughter waste to produce biodiesel can solve the problem of disposal.

The annual cost was estimated to produce biodiesel from 1000 L/day of chicken fat (as feedstock consumption); The results of cost evaluation are presented in Table 8. Despite the use of free feedstock (chicken fat), these results show that 90% of the biodiesel production cost is related to raw materials (collection and transportation and melting chicken fat, Methanol and KOH), 51% of which is related to chemicals. Income comes around 270 million rial/year from producing glycerin, which can cover 6% of biodiesel production cost. Therefore, the net cost of biodiesel production is 4590.889 million rial/year equals 14,277 rial/lite from chicken fat. According to the declaration of the National Iranian Oil Refining and Distribution Company (NIORDC), the price of diesel is 3000 rials [57]

Table 7 Amount of produced waste from broiler chicken slaughter and its biodiesel potential in each province of Iran according to the data in 2017

Province	Average wastes (ton)	High protein meal (ton)	Chicken fat oil (million liters)	Biodiesel (million liters)
East Azarbaijan	28,646.966	10,026.438	4.785	4.216
West Azarbaijan	27,639.990	9673.997	4.617	4.068
Ardabil	10,487.751	3670.713	1.752	1.543
Isfahan	52,961.923	18,536.673	8.847	7.794
Alborz	2786.236	975.183	0.465	0.410
Ilam	13,177.226	4612.029	2.201	1.939
Bushehr	9524.648	3333.627	1.591	1.402
Tehran	5584.492	1954.572	0.933	0.822
Chaharmahal and Bakhtiari	7237.543	2533.140	1.209	1.065
South Khorasan	18,758.412	6565.444	3.134	2.761
Razavi Khorasan	60,171.519	21,060.032	10.052	8.855
North Khorasan	5401.488	1890.521	0.902	0.795
Khuzestan	27,842.527	9744.884	4.651	4.098
Zanjan	13,273.386	4645.685	2.217	1.953
Semnan	18,600.349	6510.122	3.107	2.737
Sistan and Baluchestan	7152.201	2503.270	1.195	1.053
Fars	50,243.901	17,585.365	8.393	7.394
Qazvin	19,503.953	6826.383	3.258	2.870
Qom	9632.227	3371.279	1.609	1.418
Kordestan	29,949.333	10,482.266	5.003	4.408
Kerman	15,499.790	5424.927	2.589	2.281
Kermanshah	16,434.646	5752.126	2.745	2.419
Kohgiluyeh and Boyer-Ahmad	3337.654	1168.179	0.558	0.491
Golestan	69,260.743	24,241.260	11.570	10.193
Gilan	57,340.809	20,069.283	9.579	8.439
Lorestan	25,150.348	8802.622	4.201	3.701
Mazandaran	95,358.867	33,375.603	15.930	14.034
Markazi	18,794.773	6578.170	3.140	2.766
Hormozgan	8776.103	3071.636	1.466	1.292
Hamedan	16,529.904	5785.466	2.761	2.433
Yazd	18,138.481	6348.468	3.030	2.669
Total	763,198.181	267,119.363	127.492	112.321

per liter and the subsidy is paid more than 65,500 rials per liter of diesel. The use of biodiesel can reduce subsidies. Also, consuming biodiesel instead of diesel can reduce external cost.

5 Conclusion

The growing need for new sources of energy has become a major problem in recent years. This energy crisis has led to widespread use of exhaustible and non-renewable fossil fuel resources and severe environmental problems. Therefore, replacing fossil fuel sources with renewable biofuels is essential for achieving sustainable development, environmental protection and controlling greenhouse gas emissions. Biodiesel is known as an alternative fuel for diesel. In addition to reviewing feedstock types and biodiesel production methods, this paper evaluated the potential of biodiesel production from slaughter wastes of broiler chicken. According to the results, in 2017, 763 kilotonnes of poultry slaughter waste was produced in Iran; The biodiesel production potential was estimated at 112 million liters from this source that Mazandaran province has the highest potential for producing biodiesel with 14 million liters per year. The results of this study show that we can supply 30% of the diesel demand in the transportation sector by B2 by this amount of biodiesel production. The cost of biodiesel production was estimated to be less than

Table 8 Cost of biodiesel production from chicken fat

Type of cost/income	10^6 rial/year
Cost	
Raw materials	
Chicken fat	2160
Methanol	1728
KOH	486
Electricity	
Heating of oil from 20 to 60 °C for transesterification process	5.484
Stirring methanol and KOH	0.648
Stirring during transesterification process	3.888
Maintenance of temperature about 60 °C	7.2
Heating of water from 20 to 50 °C for water washing	40.128
Heating of oil to 110 °C for removing water if present	12.340
Equipment	50
Other	367.2
Total	4860.889
Income	
Glycerin production	270

15,000 rial/liter from chicken fat by transesterification process with methanol and KOH; This cost will even become minimal if socio-economic benefits like reducing pollution and employment generation are considered. In the following, it is suggested to evaluate the potential of biodiesel production from various types of animal fat waste in Iran and to identify the provinces with the highest potential. This knowledge helps to better plan for sustainable development of the bioenergy system.

Authors' contribution All authors contributed to study idea of project. Material preparation, data collection and analysis were performed by ZFM, ZK and KFM. The first draft of the manuscript was written by ZFM and edited by ZK. MK was responsible for leadership and advisement. KFM was responsible to the management and coordination for the research activity planning and execution. All authors commented on previous versions of the manuscript and approved the final manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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