BIODIESEL AND FEEDSTOCKS - POSSIBILITIES AND CHARACTERISTICS: A REVIEW

by

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Different crops can be used for biodiesel production, most often: oil palms, soybean, rapeseed, sunflower, algae, Jatropha, corn, Karanja, peanut, even mustard, Mahua, cotton, castor, coconut, etc. Biodiesels produced from such different feedstocks and with variations in the processing base oils technological processes often have characteristics that may deviate from the characteristics required by the relevant biodiesel standards. Research on diesel engines with such biodiesels may result in incorrect or insufficiently precise conclusions. The paper presents the potential of certain plant raw materials for biodiesel production and the characteristics of biodiesels (density, viscosity, Flash point, CFPP, CP, Cetane number, Iodine number, oxidation stability and heating value) made from different feedstocks. This is important when choosing biodiesel for research or practical use, but also for the potential mixing of different biodiesels, to obtain biodiesel with appropriate characteristics.

Key words: *biodiesel feedstock, oil content, yield, biodiesel properties.*

1. Introduction

The potential raw material base to produce vegetable oils, which are then used to produce biodiesel, can be extensive and depends on a range of factors, such as climate and soil, as well as local, traditional habits and peculiarities [1, 2]. In theory, any organic matter that contains oil can be a raw material base. However, in practice, it depends on oil content, yield per unit of land area, land quality and composition, oil and biodiesel characteristics (particularly concerning its use in diesel internal combustion engines) and impact on engine operation and emissions [3, 4]. Together, these factors determine the appropriateness of using specific plant or animal materials for biodiesel production. Different research results, reviewed in this paper, have shown that biodiesel characteristics vary depending on the raw materials used. These variations are not a concern if the characteristics remain within the limits prescribed by relevant biodiesel standards: EN 14214 (EU), ASTM D6751 (USA), IS 15067 (India), JASO M360 (Japan), ANP 42 (Brazil), SANS 1935 (South Africa), etc. [5, 6]. However, even when derived from the same raw materials, biodiesel may exhibit properties that deviate from these standards. Such deviations highlight challenges or inefficiencies in the technological processes involved in biodiesel production, as well as limitations in achieving standardized biodiesel characteristics from certain raw materials. In addition to pure biodiesel (B100), biodiesel is often blended with conventional diesel fuel in various ratios (B5, B7, B20, etc.) for use in diesel engines [7, 8]. In Brazil, it is mandatory to blend biodiesel into diesel at 14%, in Japan the maximum biodiesel blend is 5%, in South Africa a blend of up to 55% is allowed, while in the USA standards regulate blends of 5, 10 and 20%. In EU, the Renewable Energy Directive 2018/2001/EU (RED II) sets the imposing a limit on the use of crop-based biodiesel at maximum of 7% blend and progressive phase out of biodiesel with high Indirect Land Use Change (ILUC) risk from 2023 to 2030, with exception for biodiesel certified with low-ILUC-risk. Studies that explore blending two or more oils for biodiesel production [9, 10] or mixing different biodiesels in various proportions [10, 11] are particularly noteworthy. These approaches not only enable the production of biodiesel with enhanced properties but also help address seasonal availability constraints by reducing reliance on a single raw material. Knowledge of a wide database on the biodiesel characteristics from different feedstocks and the characteristics of biodiesel feedstocks enables the application of some of the multi-criteria decision analysis and optimization methods [12, 13] in the selection of biodiesels (and feedstocks) mixtures and the possibility of quality management in production processes [14], which is especially important for small and medium biodiesel production enterprises.

In the biodiesel production from waste materials - collectively referred to in this paper as WFO (waste fish oil, chicken oil, pig fat and other animal fats) or WCO (waste, used cooking oil) - the diversity of the raw material is particularly pronounced [15].

2. Cultivable areas, oilseed crops and production of vegetable oils

Over 1.2 billion hectares of land worldwide were used to grow various crops in 2022, including grains, oilseeds, protein plants, sugar and fibre crops, fruits, vegetables, nuts, etc. Most of these crops were intended for human consumption, either directly or indirectly through livestock feed, while only about 6% of the land was dedicated to biofuel production (Fig. 1).

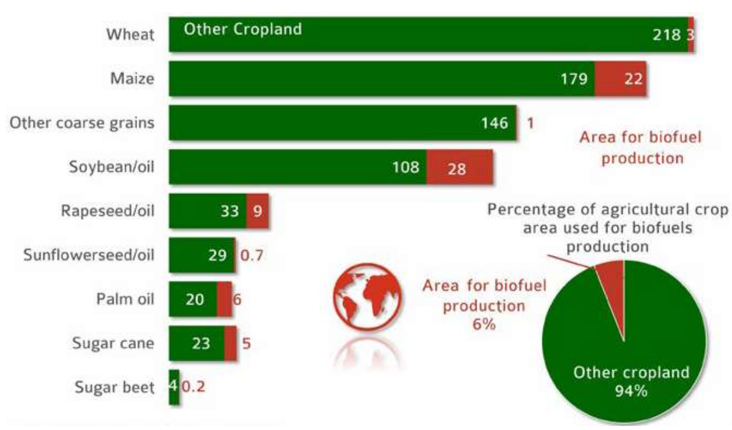

Figure 1. Shares of total cultivation area (arable land + permanent crops) used for selected crops for biofuel production, worldwide, in 2022, in million hectares; Note: 1. Other cropland (green colour) = area was not used in biofuels production; 2. Other coarse grains = millet, mixed grains, oats [6]

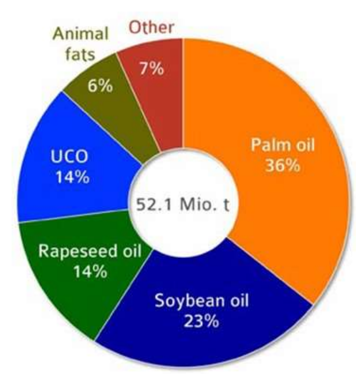

Figure 2. Feedstock use in biodiesel production, worldwide, in 2022 [6]

Biofuel production typically occurs in countries with an excess of feedstock, such as maize, palm oil, and soybean oil. Without biofuel production, this surplus would flood the global market, driving down already low prices. Converting these crops into biofuels helps manage the surplus, adds economic value, and reduces the need for importing crude oil or fossil fuels, which is particularly beneficial for poorer nations. Additionally, biofuel production yields high-quality protein feed, which is in high demand and influences feedstock prices and land use, especially for soybeans [6]. While the production of raw materials can indeed be an opportunity for developing countries, it should be mentioned that in many places, this can result in deforestation and the disruption of natural ecosystems. To prevent them, all stakeholders in the "cultivation–processing–use" chain must follow regulations, assess both benefits and risks, and integrate research findings into industry practices to ensure sustainable biodiesel production.

Biofuels are not the main cause of rising commodity prices, as some might think. The raw materials used for biofuel can also be diverted to food production, if necessary, as seen during Ukraine crisis with rapeseed and sunflower oil [6, 16]. However, if agricultural practices are reduced for political reasons, such as the EU's strategy to cut down on fertilizers and plant protection under the "Green Deal" - the ability to use biofuel production as a "buffer" for food demand would be lost [6].

Oilseed crops vary in oil and protein content, fatty acid composition, and climate and soil requirements, all of which influence their market prices. Protein quality is especially crucial, with soybeans being the most valuable source of protein. The increase in soybean areas is about 15% compared to 2015/16. Soybean is the leading oilseed crop worldwide, representing 46% of global acreage of oilseed crops. Rapeseed follows with 42 million hectares, a slight increase from the previous year but with an increase of about 24% compared to 2015/16 [5, 6]. Global production of vegetable oils in 2023/24 is estimated at around 223 million tonnes, a new record high, with an increase of around 7% compared to 2019/20, i.e., about 27% more compared to 2015/16 [6]. Palm and soybean oil make up about 63% of the world production of vegetable oil. Rapeseed oil ranks third with almost 15% and then sunflower oil with 10% of world production [6]. The production and market of vegetable oils were already under pressure in 2020/21 by the COVID-19 crisis and related lockdowns, but the situation worsened significantly after the start of the war in Ukraine in 2022 [6, 16]. Uncertainty about the possibilities and volume of exports of agricultural products from Ukraine had shaken the market, leading to an unprecedented increase in prices. In addition, the sharp rise in energy costs and problems in logistics further contributed to the rise in prices. Although vegetable oil prices have increased, they have not remained at prominent levels. Falling commodity prices and reduced demand put pressure on the market. Since the second half of 2023, prices have stabilized [6, 16].

3. Biodiesel feedstocks

To produce vegetable oils used for biodiesel, various plant fruits (most often seeds) are processed, including those from oil palm, soybean, rapeseed, sunflower, Jatropha, peanut, mustard, Mahua, cotton, Karanja, castor, corn, coconut, algae, etc. Additionally, waste cooking oil (WCO), animal fats, and fats from meat processing can be used for biodiesel production. At the global level, during 2022, biodiesel was mostly produced from Palm oil (36%), Soybean oil (23%), Rapeseed oil (14%) and Waste (Used) Cooking Oil (WCO, UCO) (14%). These four raw materials accounted for a total of 87% of raw bio-oil for biodiesel production (Fig. 2).

In the following text of this chapter, an overview of the basic characteristics and potentials of different biodiesel feedstocks are given.

Palm oil is an edible vegetable oil obtained from the mesocarp (reddish pulp) of the oil palm genus, primarily the African variety *Elaeis guineensis* and to a lesser extent, from the American varieties *Elaeis Oleifera* and *Attalea maripa* [5]. It is naturally reddish in colour due to its high beta-carotene content. The mass fraction of oil in the fruit is 30-60%, with an oil yield of up to 6000 l/ha [5, 17]. The production of palm oil recorded an intensive growth of about 2.7 times in the period 2000-2015. year [5], and then with a growth of about 34% until 2023/24 [6]. Since 2004, it has been the most produced vegetable oil in the world. In 2013, the share of produced palm oil reached 35% of the total production of vegetable oils [5], and this share was maintained until 2024. With current production of around 79.5 million tonnes (an increase of 1.9 million tonnes compared to 2022/23) and a share of around 35% of total world oil production, palm oil remains the most important vegetable oil globally [6]. The largest producers of palm oil in the world are Indonesia and Malaysia, which cover about 80% of world production [5]. The organic matter (waste) that remains during the extraction of palm oil is used to produce pellets, which are used as biofuel. Palm oil participates with about 36% of all oils in the production of biodiesel in the world. Apart from economic reasons (price per unit area, oil content in the fruit, yields, etc.), the reason is also the excellent quality of biodiesel obtained from this oil.

Soybean oil - soy is a type of legume originating from East Asia. Soy is cultivated all over the world because of the numerous benefits of the fruit - soybean seeds, which are rich in proteins [6]. There are numerous soy products that are used as food or in industry. It is also classified as an oilseed with up to 23% oil in the fruit [6] and a yield of up to 636 l/ha [8, 18]. In the USA, it has the importance of a strategic product in agriculture and is the main raw material base for obtaining biodiesel. The solid organic matter that remains during the extraction of soybean oil (soybean meal) is used as animal feed. Soybean oil production is expected to rise to a new record level of around 62 million tonnes, based on higher harvests [6]. China remains the primary producer of soybean oil with a production of 18.5 million tons (about 30% of world production), but also the most important importer of soybeans in the world with a volume of 100 million tons. The USA is in second place with 12.9 million tons (about 21% of world soybean oil production) [19].

Rapeseed oil - oilseed rape (*Brassica napus*) is an oilseed from the *Brassicaceae* family, with light yellow flowers. It is grown to produce animal feed, vegetable oil for human consumption and the production of biodiesel and industrial needs. The oil content in the fruit is up to 46% [1, 17, 20] with a yield of about 1200 l/ha [5, 17, 20]. The production of rapeseed oil recorded an intensive growth of about two times in the period 2000-2015. [5], and then with a growth of about 22% until 2023/24 [6]. Global rapeseed oil production will increase by 0.9% to 33.1 million tons, despite lower global rapeseed oil supply [6]. The leading producers of rapeseed are the EU, Canada, China and India [6]. Biodiesel produced in the EU is predominantly made from rapeseed oil. Additionally, the solid organic matter that remains after oil extraction is used as animal feed.

Sunflower oil is obtained from sunflower seeds (*Helianthus annuus*). It is used in human nutrition and industry, especially in the production of cosmetic preparations. The world's largest producers of sunflower oil are Ukraine and Russia [6]. The oil is light amber in colour, with a mild and pleasant taste. Refined oil is pale yellow in colour. The oil content in the fruit is up to 36% [1, 5, 17, 20] and in the kernel mass up to 55% [5] with a yield of about 950 l/ha [17, 20]. The solid organic matter that remains during oil extraction is also used as animal feed. The production of sunflower oil recorded a growth of about 1.7 times in the period 2000-2015. [5], and then with a growth of about 47% until 2023/24 [6]. Sunflower oil production is likely to increase by 1.9% to 22 million tons in 2023/24 compared to the previous year, due to higher harvests in Eastern Europe and the EU [6].

Jatropha oil - Jatropha is a genus of flowering plants in the *Euphorbiaceae* family. The name comes from the Greek words *ιατρος* (iatros), meaning "doctor" and *τροφη* (trophe), meaning "nutrition". As with many members of the *Euphorbiaceae* family, Jatropha contains compounds that are highly toxic. It is resistant to drought (e.g., thrives in the desert areas of Egypt, India and Madagascar) and pests, with an oil content in the fruit of about 40% [1, 5, 20], even up to 60% [21, 22] and a yield of 740 l/ha [8, 18], 1900 l/ha [17, 20] and up to 2500 l/ha [2, 22]. Oil from *Jatropha curcas* is mainly used for biodiesel production. The solid organic matter that remains after pressing can be used for feeding fish or animals (if previously detoxified), as biomass, for obtaining biogas or high-quality organic fertilizer - as a biopesticide and for medical purposes.

Peanut oil is a vegetable oil with a mild taste, obtained from the fruit of the peanut - *Arachis hypogaea*. It is used in Chinese and Southeast Asian cuisines, both for food preparation and for additional flavouring. Peanut fruit contains 40 - 50% oil with a yield of about 1050 l/ha [1, 8, 17, 20].

Coconut oil is the oil extracted from the core (meat) of ripe coconuts harvested from coconut palms (*Cocos nucifera*). It is used in nutrition and cosmetics. Many health organizations advise that regular consumption of coconut oil, due to its elevated levels of saturated fat, may increase the risk of cardiovascular disease. The kernel of the coconut contains 50 - 65% oil, while the oil yield is about 2700 l/ha [1, 5, 8, 17, 20]. The Philippines, Vanuatu, Samoa and several other tropical countries use coconut oil as a feedstock to produce biodiesel to power diesel engines and power generators.

Mustard oil - mustard is a plant from the *Brassica* and *Sinapis* families. Mustard seeds are mainly used as a spice. Oil is obtained by pressing the seeds, while the leaves are edible. Mustard seeds have a diameter of 1-2 mm and can be pale yellowish to black in colour and affect the colour of the oil. The oil content in the seed mass is about 30% and the oil yield is about 570 l/ha [5, 8].

Mahua oil - Mahua (*Madhuca Longifolia*) is an Indian tropical fast-growing tree that can reach a height of up to 20 m and belongs to the *Sapotaceae* family. It is grown for its oil-rich seeds (yield between 20 and 200 kg of seeds per tree per year [2, 5] depending on the age and size of the tree with oil yield of up to 2900 l/ha [5]), flowers and wood. The oil is used for skin care, the production of soaps and detergents, and as heating oil. In the production of biodiesel, it is mainly treated as non-edible biodiesel feedstock. Organic matter (after oil extraction) is used as fertilizer. Mahua seeds contain about 16% protein [5] and from 20 to 50% oil [2, 5, 20, 22]. The flowers are used to produce an alcoholic drink, characteristic of the tropical regions of India.

Karanja (Pongamia) oil is obtained from the seeds of the fruit of the *Millettia Pinnata* tree, also known as *Pongamia Pinnata* or *Pongamia glabra*, originating from tropical and temperate areas of Asia. The plant is also known as *Indian Beech, Pongam*, *Karanja*, *Honge*, *Kanuga* and *Naktamala*. The tree of the plant grows up to 15 - 25 m in height with a canopy that spreads the same width. The plant produces pods from about the fifth year, increasing yields until about the tenth year. The seeds weigh from about 1.1 to 1.8 g, and the yield per tree varies from about 10 to more than 50 kg, depending on the conditions and age of the plant. The fruits and shoots, together with the seeds, are used in traditional medicinal preparations, while the oil and the rest of the plant can cause nausea and vomiting if swallowed. The seeds contain up to 50% oil [1, 5, 17, 20, 21, 22] with a yield of 225-9000 kg oil/ha [5, 17, 22]. Apart from the production of biodiesel, it is also traditionally used as lamp oil, soap making and as a lubricant.

Castor oil - castor bean (*Ricinus communis*) is a secretory plant from the *Euphorbiaceae* family, native to the southeast of the Mediterranean basin, East Africa and India, but it is also widely distributed in tropical regions and is cultivated elsewhere as an ornamental plant. The root and leaf of the plant, as well as the flower, fruit and oil, are used in medicine, pharmacy, cosmetics, for making jewellery, the production of paints, coatings, inks, waxes, varnishes, feeding the silkworm (India). The tree of the plant can reach a height of 2 - 3 m. It is used to a lesser extent to produce biodiesel (e.g., Brazil - *Mammon* oil). The seeds contain up to 53% oil [1, 2, 5, 17, 18, 20, 22] with a yield of 1200-1400 l/ha [8, 17, 18, 20, 22]. It is mostly grown in India.

Cotton seed oil is an edible oil obtained by extraction from cotton seeds of various species, mainly *Gossypium hirsutum* and *Gossypium herbaceum*. This crop is primarily grown for cotton fibres (for the needs of the textile industry), fodder and oil production (for the food industry and cosmetics). The seeds make up about 15% of the crop weight [5] with 17-40% oil [2, 5, 17, 20, 21, 22] and a yield of 300-650 l/ha [2, 17, 20, 22].

Sesame oil - sesame (*Sesamum indicum*) is a flowering plant of the genus *Sesamum*, native to sub-Saharan Africa and India. Very drought tolerant and grown where many crops cannot succeed. It is widely naturalized in tropical regions around the world and is cultivated for its edible seeds, which grow and develop in capsules. Sesame seeds are one of the oldest known oilseeds (about 4000 years old). Seeds are mainly used in food, while sesame seed oil, apart from food, is used in medicine, cosmetics, the chemical industry and less often for biodiesel production. The biggest sesame producers are Myanmar, India, China and Sudan. Sesame seeds contain about 48% oil, about 17% protein [5], with a yield of about 700 l/ha [20].

Corn oil is obtained from corn kernels. Corn kernels are used in human and animal nutrition, as well as in industry. The oil content of corn kernels is around 30-48% [5, 17, 18, 20] with a yield of around 170 l/ha [8, 17, 18, 20]. In terms of raw material to produce alternative fuels, corn is quite represented in the production of ethanol, biogas and biomass in general, and less so in the production of biodiesel. The world's largest corn producers are the USA, China and Brazil.

Algae oil - algae are a very respectable potential source of raw material to produce oil and then biodiesel. The oil content (depending on the type of algae) can be 30-70% [1, 5, 18] with a yield of 50,000 - 140,000 l of oil/ha [8, 18, 23]. During growth and development, in the process of photosynthesis, they use a significant amount of CO_2, which makes them an even more attractive potential ecological raw material base for biodiesel production. The initial high capital and operating costs of cultivation have been reduced over the years due to technological advances in cultivation and processing and financial incentives (from government institutions). This may allow the production of biodiesel from algae to become an economically very commercial agro-industrial branch. Technologically modern plants for growing algae (e.g., Bioreactor plants) enable the production of oil from which 100 (and more) tons of biodiesel can be obtained per hectare of land [5], which may be land unsuitable for other agricultural crops, technologically with minimal impact on freshwater resources, considering that saline solution and wastewater can be used.

Waste (used) **cooking oil** (WCO, UCO) is one of the liquid food wastes that can be recycled. Recycling WCO and converting it into biodiesel is an excellent way to reduce the negative impact on the environment and efficiently use resources [1, 17, 22, 24, 25]. This option not only represents a sustainable waste management solution, but also offers economic benefits, as it enables the creation of new markets and jobs in sectors related to WCO collection and processing. The EU has an advanced WCO recycling system, supported by various directives promoting renewable energy sources. The share of WCO as a raw material base in the biodiesel production in the EU has reached 20% in 2022 [6]. The processed oil is used to produce biodiesel that powers local buses, contributing to cleaner air and reducing waste in urban areas.

The same raw materials used to produce biodiesel can also be used to create a biofuel known as hydrotreated vegetable oil (HVO). HVO is a biofuel produced through the hydrotreatment of vegetable oils, fats, or waste cooking oil. HVO fuel produced through hydrotreatment is called green diesel or renewable diesel and differs from biodiesel obtained through esterification. Regarding the use of HVO as fuel for diesel engines, just like with regular biodiesel, there are no technical barriers to its use. HVO production in the USA has noticeably accelerated in recent years and today it even has a larger share than biodiesel [19]. UFOP (*Union Zur Förderung von Oel- und Proteinpflanzen)* expects that similar developments will occur in Germany and the European Union in the future, as HVO allows for higher blending percentages in diesel fuel without violating standards [19]. With adjustments to regulatory policies regarding potential raw materials for production, HVO holds great potential.

4. Biodiesel properties

Several of the most important properties of biodiesel derived from the 19 feedstocks are summarized in Figures 3-7. Numerous literature sources (identified in Tab. 1) were reviewed to create these profiles. The vertical green columns (in Figures 3-5 and 6 left) represent the limit values of these properties in accordance with the EU EN 14214 standard for biodiesel. The average value of the lower heating value of standard diesel fuel is represented by the vertical green column in Fig. 7.

Table 1. Literature sources of biodiesel properties

Feedstock	References
Palm	[7, 17, 20, 21, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37]
Sunflower	[7, 17, 20, 26, 31, 32, 34, 35, 36, 37]
Algae	[8, 17, 18, 27, 29, 31, 34, 38, 39]
Jatropha	[2, 7, 17, 20, 21, 26, 27, 31, 32, 33, 34, 35, 36, 37, 38, 40, 41]
Castor	[2, 17, 20, 25, 26, 29, 33, 34, 37, 42, 43, 44]
Cotton	[2, 7, 17, 21, 26, 34, 35, 36, 37, 45, 46, 47]
Karanja	[2, 7, 17, 21, 26, 27, 31, 34, 35, 37, 40, 42, 46, 48]
Rapeseed	[7, 17, 20, 26, 27, 28, 29, 31, 32, 33, 34, 35, 36, 37, 40, 46, 49]
Coconut	[7, 17, 20, 25, 26, 32, 33, 34, 35, 36, 37, 45, 50, 51, 52]
Mahua	[2, 7, 20, 21, 26, 34, 35, 37, 53, 54]
Soybean	[17, 20, 26, 27, 28, 29, 31, 32, 33, 34, 35, 36, 37, 52]
Corn	[7, 17, 20, 32, 33, 34, 37, 37, 40, 49, 55, 56, 57]
Peanut	[7, 17, 20, 26, 34, 35, 37]
Mustard	[26, 31, 34, 35, 37, 42, 58]
Polanga	[2, 7, 21, 27, 34, 37, 44, 53]
Olive	[17, 20, 26, 35, 37]
Linseed	[17, 20, 21, 26, 27, 34, 37]
WCO	[7, 15, 17, 24, 25, 26, 28, 34, 49, 59]
WFO	[7, 17, 26, 27, 28, 32, 34, 35]

The properties of biodiesel from palm and rapeseed oil (density, viscosity, Flash point, etc.) of different regular producers generally meet the requirements of EN 14214. There are exceptions shown in Figures 3-6. The properties of biodiesel from soybean oil can generally meet the requirements of regulatory standards, with attention to the Iodine number value and oxidation stability (Fig. 5), but some soybean biodiesel also has problems with density, Cetane number, CFPP (in the winter) or Flash point (less often) values. Although the properties of Jatropha biodiesel can generally meet the requirements of regulatory standards, should be careful about the kinematic viscosity (Fig. 3 right), oxidation stability (Fig. 5 right) and CFPP (in the winter) values and less often about the cetane number (Fig. 4 right) value.

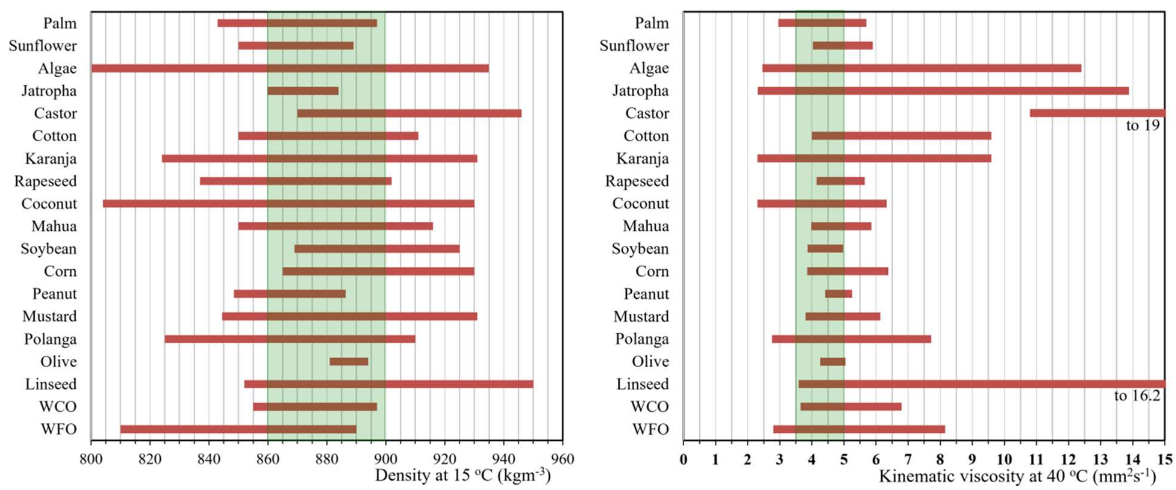

Figure 3. Density (left) and kinematic viscosity (right) of biodiesel from different feedstocks

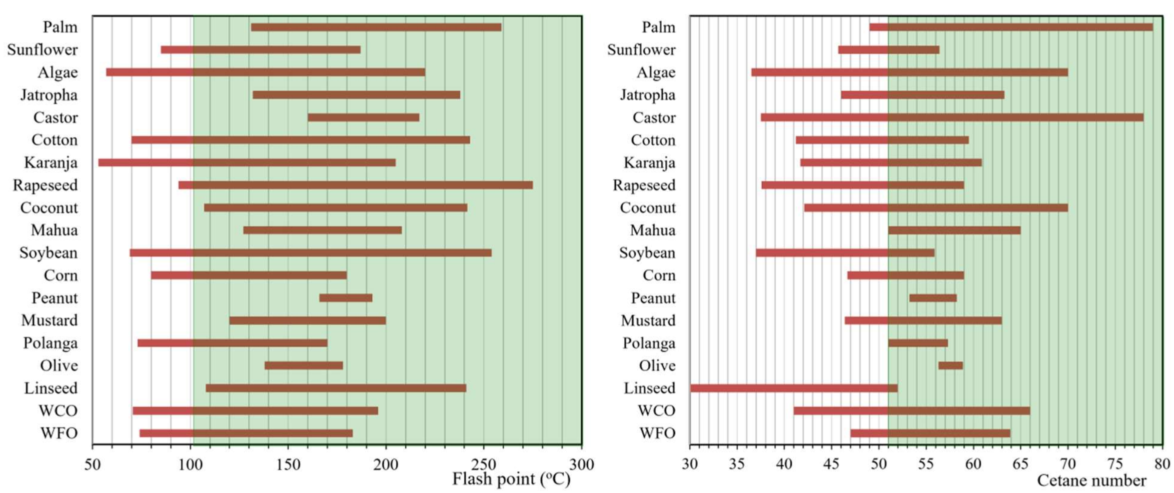

Figure 4. Flash point (left) and Cetane number (right) of biodiesels from different feedstocks

Density values outside the EN 14214 standard occur with some biodiesels, and special attention should be paid to biodiesels made from algae (very wide range of values), Karanja, coconut, castor, corn, mustard, Polanga, linseed and WFO (Fig. 3 left). The required values for kinematic viscosity can be achieved by almost all biodiesels except castor oil (too high). Excessive viscosity values also occur in some biodiesels produced from algae, Jatropha, cotton, Karanja, linseed and WFO and attention should also be paid to other biodiesels, which also have deviations but are not as pronounced (Fig. 3 right).

Regarding Flash point values, most samples are within the required limits, but there are also some samples with lower Flash point values than standard (Fig. 4 left). A pronounced problem with Cetane number values is with linseed biodiesel. Lower Cetane number values may also occur with some other biodiesel fuels, as shown in Fig. 4 right.

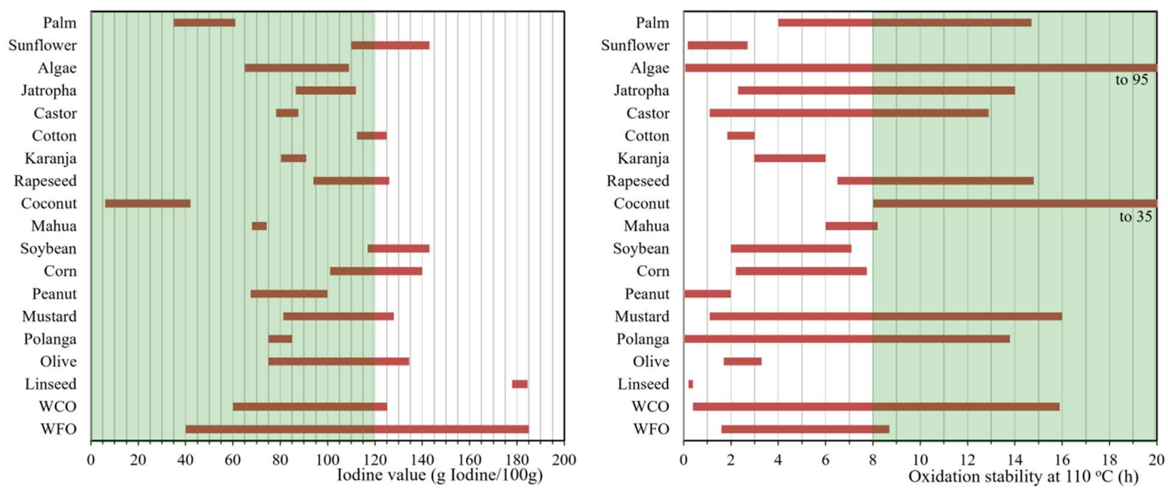

Figure 5. Iodine value (left) and oxidation stability (right) of biodiesels from different feedstocks

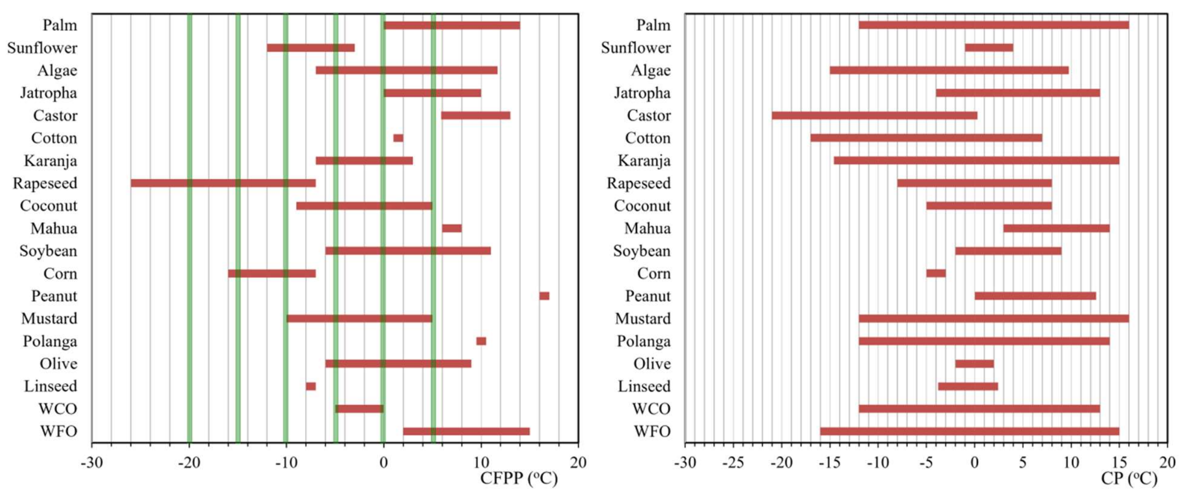

Figure 6. Cold Filter Plugging Point (left) and Cloud Point (right) of biodiesels

Iodine value values are generally in accordance with EN 14214 except for linseed biodiesel (Fig. 5 left). Sunflower, cotton, soybean, corn and specially WFO biodiesels Iodine number values should also be considered to analyse when planning the use of these fuels. Achieving oxidation stability values of at least 8 h (EN 14214) for some biodiesels is clearly a problem, especially for biodiesels from sunflower, cotton, Karanja, Mahua, Soybean, corn, peanut, olive, linseed oils and WFO but also for some biodiesel samples from palm, algae, Jatropha, castor, mustard, Polanga oils and WCO.

Some samples of algae and coconut biodiesel achieve extremely high oxidation stability values, which can be important when selecting oil blends for biodiesel production or using biodiesel blends. The ranges of CFPP and CP values of different biodiesels are presented in Fig. 6 on the left and right. There is a certain inconsistency here in the sense that lower values of CP should also be expected for lower CFPP values. This occurs because the papers often do not show values for both parameters, but only for CP or only for CFPP. However, it is obvious that there is a problem of reaching the maximum value of CFPP in winter conditions (EN 14214: B100, limits for temperate climates, grades A, B, C, D, E and F, max. temperatures +5, 0, -5, -10, -15, -20 °C, per grade, in order).

The values of the lower heating value of biodiesels are, as expected, lower than the average lower heating value of the conventional diesel fuel (Fig. 7). In some biodiesel samples, this is more pronounced. It is known that this will lead to lower values of the output parameters of the diesel engine (e.g., power, torque) when using biodiesel compared to diesel fuel.

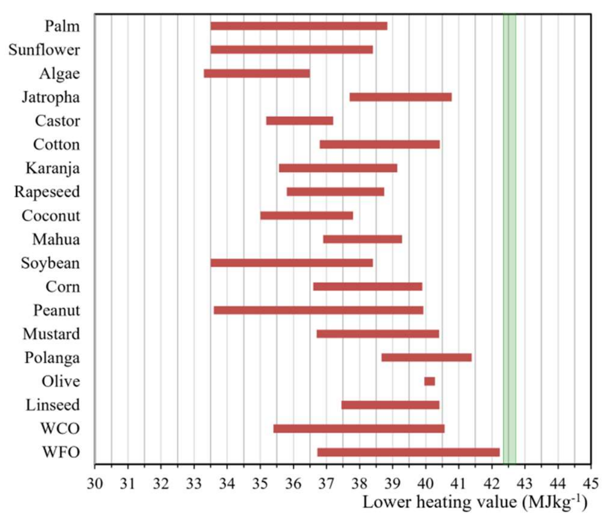

Figure 7. Lower heating value of biodiesels and diesel

The lower heating value of biodiesel should be considered in conjunction with the oxygen content of biodiesel, which is higher compared to diesel fuel. Overall, this has the implication of slightly lower power and torque values, mainly at higher operating modes. However, attention should be paid to this parameter, especially if the intention is to use biodiesel with a low net calorific value. It is better to mix such biodiesels with biodiesels that have a higher calorific value to preserve the desired operating parameters of the diesel engine.

5. Conclusions

Biodiesel production from vegetable oils depends on a range of factors. Whatever raw material it is produced from, the use of biodiesel depends primarily on the quality of the obtained fuel, as well as its compatibility with diesel engines and its environmental impact, which makes it a confirmed and still promising alternative to traditional fossil diesel fuel.

In 2022, over 1.2 billion hectares of land were used for crop cultivation, with only 6% dedicated to biofuel production. Countries with a surplus of raw materials benefit from converting oilseeds and other suitable crops into biofuels, which helps regulate market prices and reduces reliance on fossil fuels. Especially important is the social and state system organization in the collection of WCO and its processing into biofuels, which has multiple significance.

The paper presents data on the yield and oil content of fifteen vegetable oil feedstocks from which biodiesel is obtained through further processing. Some of the most important characteristics of nineteen biodiesels produced from different feedstocks are presented. Biodiesel is mainly produced worldwide from palm (36%), soybean (23%) and rapeseed oil (14%). In addition, biodiesel is produced in a respectable amount from WCO (14%) and then from animal fats and fats from meat processing (6%). Although the highest percentage of biodiesel (73%) is obtained from three types of vegetable oils (palm, soybean and rapeseed), the potential and importance of other vegetable raw materials for the biodiesel production should not be neglected. Some are of greater potential (for example, algae, Jatropha, Mahua, Pongamia, etc.) and some of less, but both groups can significantly contribute to the development of local communities, not only in terms of conventional diesel fuel replacing and reducing the overall toxicity of exhaust gases, but also economically, through the development of new jobs from cultivation to production to distribution of biodiesel. Also, the global positive impact on the reduction of total CO_2 emissions in the entire life cycle of the mentioned plant crops should be considered.

This paper presents the value ranges for some important characteristics of biodiesels (produced from nineteen different raw materials), including density, viscosity, flash point, CFPP (cold filter plugging point), CP (cloud point), cetane number, iodine number, oxidation stability and heating value. Grouping the data in this manner facilitates a clear and straightforward analysis, aiding in the selection of raw materials for biodiesel production as well as the choice of biodiesel for mixtures. The data on biodiesel characteristics provide valuable insights into potential challenges or advancements in the technological processes involved in biodiesel production. The literature indicates significant variability in the values of the presented parameters of biodiesel from different feedstocks, even within biodiesel made from the same feedstock. This could be a cause for concern. Whether these differences are related to the chemical composition of the biodiesel or are a consequence of the purity of the biodiesel, production processes, transportation or storage, it is particularly important that the characteristics of the biodiesel (or blend) used in diesel engines comply with the standards. Otherwise, diesel engine performance and emissions may be impaired.

In recent years, there has been a trend of mixing biodiesel obtained from different raw materials. This should not be viewed only through an economic framework, but also through the fact that the addition of biodiesel from some raw materials that are not of high production (e.g., coconut) can improve the emission characteristics when used in diesel engines.

Further research, which is ongoing, is aimed at analysing data on the characteristics of different biodiesel feedstocks (density, viscosity, flash point, cetane number, iodine number, cloud point, etc.) with the aim of presenting a database that researchers can use in comparison and selection of raw materials for biodiesel production, for direct production or mixing several different ones to obtain biodiesel with optimal properties. Also, some of the multi-criteria decision analyses and optimization methods will be presented as ways of selecting biodiesel feedstocks for direct biodiesel production, blending different feedstocks, or blending different biodiesels.

Acknowledgment

This research was financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract No. 451-451-03-65/2024-03).

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Paper submitted: 05.02.2025
Paper revised: 10.03.2025
Paper accepted: 17.03.2025