Biodiesel from Castor Oil

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An attractive alternative to the use of fossil fuels is biodiesel, which can be obtained from a variety of feedstock through different transesterification systems such as ultrasound, microwave, biological, chemical, among others. The efficient and cost-effective biodiesel production depends on several parameters such as free fatty acid content in the feedstock, transesterification reaction efficiency, alcohol: oil ratio, catalysts type, and several parameters during the production process. However, biodiesel production from vegetable oils is under development, causing the final price of biodiesel to be higher than diesel derived from petroleum. An alternative to decrease the production costs will be the use of economical feedstocks and simple production processes. Castor oil is an excellent raw material in terms of price and quality, but especially this non-edible vegetable oil does not have any issues or compromise food security. Recently, the use of castor oil has attracted attention for producing and optimizing biodiesel production, due to the high content of ricinoleic fatty acid and the possibility to esterify with only methanol, which assures low production costs. Additionally, biodiesel from castor oil has different advantages over conventional diesel. Some of them are biodegradable, non-toxic, renewable, they can be used alone, low greenhouse gas emission, among others. This review discusses and analyzes different transesterification processes, technologies, as well as different technical aspects during biodiesel production using castor oil as a feedstock.

Keywords: Biodiesel ; Castor oil ; Ricinus communis

1. Vegetable Oils to Produce Biodiesel

During biodiesel production it is necessary to consider the ecological and economic benefits during its production and its use as a biofuel. The biodiesel production cost depends greatly on the feedstock price. It is advisable to produce biodiesel in the same regions where the feedstock is located to decrease costs and environmental footprint related to feedstock transport [1].

The primary feedstock to produce biodiesel is raw vegetable oils and used cooking oils, as well as different animal grease. To produce biodiesel, several vegetable oils can be used such as rapeseed, soybean, cotton, peanut, corn, olive, sesame, safflower, and sunflower [2]. Some examples of tropical oily crops containing good quality oil that can be transesterified are *Raphanus sativus* (radish), *Jatropha curcas* (physic nut), *Cyperus esculentus* (tiger nut), *Simmondsia chinensis* (jojoba), *Gratissima persea* (avocado), *Lupinus albus* (white lupin), *Caryocar brasiliense* (pequi), the palm species *Acrocomia aculeata*, *Mauritia flexuosa*, *Elaeis oleifera*, *Syagrus coronata, Attalea speciose,* and *R. communis* (castor seeds) [3]. Table 1 shows some raw materials used in biodiesel production. However, the most common feedstock is raw vegetable oils extracted from energy and non-energy crops such as soybean, rapeseed, sunflower, coconut, and palm oil, which are cultivated around the world [4].

Table 1. Examples of oil-feedstock used in biodiesel production.

Feedstock Source (Oil Content, %)	Characteristics	Advantages	Disadvantages	Ref.
Castor beans (46–55)	**Liquid at room temperature, light yellow color, and slightly pungent *US$824/tonne of oil**	**Transesterification can be performed at room temperature Miscible in alcohol Non-edible Low acid value High flashpoint**	**Generation of toxic solid waste High viscosity Decrease fuel atomization**	[5][6]

Feedstock Source (Oil Content, %)	Characteristics	Advantages	Disadvantages	Ref.
Jatropha (34–60)	**Colorless after extraction (fresh) and pale yellow after standing time, liquid at room temperature **US$250/tonne of oil**	**Biodiesel obtained is stable during storage Non-edible High cetane number, good oxidation stability, low viscosity**	**Engine corrosion due to free fatty acids Generation of toxic solid waste High cloud point Not suitable at low temperature High acid value**	[7][8]
Soybean (12–22)	**Fresh has a pale light color, and dark after storage, liquid at room temperature ***US$746/tonne of oil**	**The yield of 98% crude biodiesel in refined oils High thermal stability Low viscosity**	**The high cost of production Biodiesel production in long-term is unsustainable Edible High acid value**	[9] [10]
Sunflower (38–50)	**Refined has a clear and vaguely yellowish-brown color Liquid at room temperature ***US$689/tonne of oil**	**Low viscosity**	**Used to produce food and fiber Biodiesel production in long-term is unsustainable Edible High acid value**	[10] [11]
Palm (18–40)	**Semi-solid at room temperature, reddish and clear color, depending on extraction source (pulp or kernel) ***US$535/tonne of oil**	**96% yield of crude biodiesel in refined oils Cheap feedstock Good oxidation stability Acceptable ratio of saponification High flashpoint**	**High cloud point Conversion to biodiesel may not be sustainable long term Edible**	[9] [12]
Used cooking oil	**Depends on the cooking process can vary yellow to dark brown, liquid at room temperature ****US$500/tonne of oil**	**Low cloud point Environmentally friendly Low price of feedstock Non-edible High thermal stability**	**High ratio of acid esterification High ratio of saponification High acid value**	[11] [13]

Reported price from [14] (refined oil); ** Reported price from [15]; *** Reported price from [16]; **** Reported price from [17].

The preferred characteristics of oily raw materials to produce biodiesel are crop adaptability to grow under local conditions (precipitation, soil, latitude, temperature, etc.), availability, high oil content, appropriate composition, high adaptability with agricultural infrastructure, access to agricultural supplies (water, fertilizers, pesticides), potential to commercialize the different agricultural co-products generated as well as to obtain crops from marginal land [18]. *R. communis* meets most of the properties considered desirable to produce useful feedstocks in biodiesel production, except the high viscosity of oil that may limit its use. They are composed mainly of triglycerides and slight amounts of free fatty acids. Table 2 shows the most abundant fatty acids in vegetable oils (palmitic, oleic, and linoleic acids) from several sources. As mentioned above, castor oil, unlike other vegetable oils, has little variability in fatty acid content as compared to other species. In addition to ricinoleic acid, depending on its origin, *R. communis* may contain small quantities of oleic, linoleic, palmitic, stearic, and linolenic acids [19].

Table 2. Main fatty acids in vegetable oils used as feedstock in biodiesel production.

Oil	Fatty Acid Composition (wt%)								Ref.
	Saturated			Monounsaturated		Polyunsaturated			
	C14:0	C16:0	C18:0	C18:1 cis-9	C18:1*	C18:2	C18:3	Others	
Castor	**-**	**1.1**	**1.0**	**3.3**	**87.7**	**4.7**	**0.7**	**1.5**	[20]
Jatropha	**-**	**12.80**	**6.20**	**39.94**	**-**	**45.40**	**-**	**<1.0**	[8]
Soybean	**-**	**11.46**	**3.08**	**23.30**	**-**	**53.32**	**0.31**	**8.53**	[20][21]
Sunflower	**0.08**	**8.03**	**3.26**	**29.27**	**-**	**59.32**	**-**	**0.04**	[23]
Palm	**0**	**46.8**	**3.80**	**37.60**	**-**	**10.50**	**-**	**1.3**	[24]

Oil	Fatty Acid Composition (wt%)								Ref.
	Saturated			Monounsaturated		Polyunsaturated			
Canola	-	3.90	1.10	64.40	-	20.4	9.60	0.6	[25]

Vegetable oils as a feedstock for biodiesel production is a promising source. However, most of them are used for food purposes and their use is restricted for this activity. Hence, castor oil for biofuel production shows several advantages over conventional edible oils. Due to its non-edible oil and its main fatty acid (ricinoleic acid) with hydroxyl groups that have a higher solubility in alcohol, it represents a great advantage to obtain methyl esters at low temperatures.

2. Castor Oil Biodiesel Production and Features

Castor oil is a light yellow and slightly pungent liquid, that is used in several industries around the world. Some of these industries are pharmaceutical, cosmetic, chemical, among others. However, in recent years this non-edible vegetable oil has been investigated to produce biofuels, specifically biodiesel. The above is due to the physicochemical, chemical, and physical characteristics of castor oil (Table 3) give to biodiesel when this is used as a feedstock.

Table 3. Main characteristics of raw castor oil.

Parameter	Zhang et al. [26]	Molefe et al. [27]	Kaur and Bhaskar [28]
Acid value /(mg.g^{-1})	1	2.07	<4
Saponification value /(mg.g^{-1})	180	175	178
Iodine value (g/100 g)	86	84	85
Refractive index (n20 D)	1.48	1.48	1.47
Relative density (g/cm^3)	0.956	0.961	0.965
Flashpoint (℃)	322	145	229
Specific heat (kJ/kg/K)	nd	0.089	0.089
Ricinic acid (%wt)	88	89.5	87-90
Oleic acid (%wt)	7	3	2-7
Linoleic acid (%wt)	5	4	1-5
Linolenic acid (%wt)	1	0.3	nd

nd: not determined

The process to produce biodiesel from oilseeds usually starts with oil extraction using a mechanical press or solvents. Figure 1 shows a general scheme for castor oil extraction. To perform mechanical oil extraction from castor beans it is necessary to consider the high oil viscosity. On the contrary, this is not necessary if the oil is extracted with solvents, but an evaporation step would be needed to recover the solvent. After extraction, different refining steps such as filtration, centrifugation, deodorization, discoloration, or winterization would be necessary to improve biodiesel quality.

Figure 1. General scheme to produce biodiesel from castor oil (adapted from [29][30]).

Once the biodiesel is obtained, this can be used directly in a neat form (100%) or blended with petrodiesel (25%, 50%, and 75%, commonly). However, to ensure that the biodiesel or the blend does not represent a potential risk to the vehicle engine, biodiesel needs to conform to specific parameters established by different entities such as Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels (ASTM D 6751–06a) or European Committee for Standardization for biodiesel (EN 14214). Table 4 shows key parameters for biodiesel from castor oil and its comparison with the two standards mentioned above, as well as with petrodiesel characteristics. Castor oil biodiesel has different advantages in comparison with fossil diesel, the most significant are biodegradable, non-toxic, renewable, it can be used alone, low greenhouse gas emission (80% less carbon dioxide emissions and not sulfur content), and during combustion, it decreases the unburned and aromatic hydrocarbons. Nevertheless, one of the main disadvantages that castor oil biodiesel has is related to its high viscosity, as compression ignition is difficult, especially at low temperatures, which causes a decrease of volatility and as a consequence of burning ratio, without a complete burn provoking deposit. The above facts harm the injection system, as well as blocking the fuel filter [31]. Likewise, high values of density can cause some problems in the injection system as well as in the fuel pump.

Table 4. Main characteristics of biodiesel produced using castor oil as a feedstock.

Product	**Kinematic Viscosity (mm^2/s at 40 °C)**	**Density (kg/m^3)**	**Acid Value (mgKOH/g)**	**Flash Point (°C)**	**Water Content (%)**	**Calorific Value (MJ/kg)**	**Cetane Number**	**Cloud Point (°C)**	**Pour Point (°C)**	**Iodine Value (gI_2/100 g)**	**Ref.**
*Biodiesel from castor oil	23	960	13.12	262	nd	30.18	nd	3	−13	nd	[32]
	14	926	nd	164	nd	37.90	nd	−23	nd	nd	[33]
	15	946	0.63	194	0.15	38.34	43	nd	−30	nd	[34]
	26	961	1.19	nd	0.31	nd	nd	nd	nd	80.5	[28]
	18	920	0.25	170	0.006	39.5	nd	nd	nd	nd	[35]
	14	923	nd	273.1	nd	37.34	50	nd	nd	83.40	[36]

**Biodiesel according ASTM D 6751–06a	1.9–6.0	860–900	≤0.50	≥130	≤0.50	nd	≥47	−3–−12	−15-10	nd	[37]
**Biodiesel according EN 14214	3.5–5.0	860–900	≤0.50	≥101	≤0.50	nd	≥51	nd	nd	nd	[37]
***Fossil Diesel	2.5–4.5	820–860	nd	68–80	nd	≥45.56	≥46	−15–5	−35–15	nd	[38]

*Without blend (B100)

** Limit values

***According to ASTM D975 for diesel grade LS#1 and LS#2

nd: not determined

ASTM D 6751–06a: Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels.

EN 14214: European Committee for Standardization for biodiesel.

Biodiesel production around the world is produced from different feedstocks and specifically vegetable oils. Moreover, a wide variety of methods to obtain this biofuel exist, however, the most common is through transesterification. Biodiesel from castor oil offers environmental and technical benefits, therefore, it can be considered as a viable alternative in the present and future to other forms of biodiesel. *R. communis* plants have a strong adaptation to different weather, and one of the main characteristics of these plants is being able to grow in marginal soils. This characteristic contributes directly to decrease land use for biofuel production and preserve it to cultivate products used for human consumption. Moreover, non-edible vegetable oil from castor bean seeds is a suitable feedstock to replace 40%–50% of edible oil currently used in biodiesel production. Furthermore, the ricinoleic fatty acid offers advantages to the transesterification process such as high miscibility in alcohol, low reaction temperature, low iodine content, and low freezing point. Biodiesel from castor oil offers a wide range of benefits, among them, is that it is biodegradable, non-toxic, renewable, and safe handling, it can be used alone, and it presents low greenhouse gas emission, high flash point, and similar energetic content to fossil diesel. However, when castor biodiesel is used without blending (B100) some challenges are present, for example, the high viscosity and high density decrease its ignition and can be a potential risk for vehicle engines. Finally, it is necessary to improve the transesterification process to decrease the final price and can be competitive with petrodiesel cost.

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