Magna Scientia Advanced Research and Reviews

eISSN: 2582-9394

Cross Ref DOI: 10.30574/msarr

Journal homepage: https://magnascientiapub.com/journals/msarr/

Magna Scientia
Open access publication

(Review Article)

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Industrial *Cannabis sativa*: Hemp oil for biodiesel production

Ravindra B. Malabadi [1, *], Kiran P. Kolkar [2] and Raju K. Chalannavar [1]

[1] *Department of Applied Botany, Mangalore University, Mangalagangotri-574199, Mangalore, Karnataka State, India.*
[2] *Department of Botany, Karnatak Science College, Dharwad-580003, Karnataka State, India.*

Magna Scientia Advanced Research and Reviews, 2023, 09(02), 022–035

Publication history: Received on 11 September 2023; revised on 02 November 2023; accepted on 05 November 2023

Article DOI: https://doi.org/10.30574/msarr.2023.9.2.0145

Abstract

This review paper highlights the production of biodiesel from hemp seed oil via transesterification reaction. Hemp seeds present a viable feedstock option for biodiesel production. This is demonstrated by the plants high yield, ability to grow on infertile soil, resilience to disease and bugs. Hemp biodiesel performs well in biodiesel blends. Hemp biodiesel yield was calculated at 207 gallons/ha. This is higher than the yield of biodiesel from rapeseed and soybeans oils but lower than that of palm oil. Hemp biodiesel can meet ASTM D6751 and EN 14214 requirements. Hemp biodiesel exhibit poor kinematic viscosity and oxidation stability. However, this can easily be improved with the use of additives. Dilution/blending, micro-emulsification, pyrolysis, and trans-esterification are the four techniques applied to solve the problems encountered with the high fuel viscosity. Hemp biodiesel provides substantial environmental benefits. The amount of emission reduction corresponds roughly to the biodiesel blend rating of the fuel. Hemp biodiesel may be used an alternative to the highly controversial biodiesel produced from palm oil. Hemp faces many perception and legal challenges that prevent wide-scale production of hemp seed oil. Hemp remains a niche crop in the food supply chains, rendering it prohibitively expensive as a feedstock in biodiesel production. Legalization and increased production of hemp oil may improve the cost of producing hemp oil and subsequently hemp biodiesel.

Keywords: Biodiesel; Biofuel; Blending; *Cannabis sativa*; Climate change; Greenhouse gas emission; Hemp; India; Transesterification; Vegetable oil

1. Introduction

Cannabis sativa is a flowering plant from the *Cannabaceae* family and genus *Cannabis*. Cannabis is a plant notorious for its psychoactive effect, but when used correctly, it provides a plethora of medicinal benefits [1-29]. *Cannabis sativa* L., is classified into two types as Industrial *Cannabis sativa*, hemp or Medical *Cannabis sativa* L.(drug or marijuana) based on its THC content [1-25, 93]. Medical *Cannabis sativa* (drug or marijuana) contains a very high levels of THC (above 0.3 to 38% of dry weight) [1-23, 93]. On the other hand Industrial *Cannabis sativa* L. (Hemp) contains very low levels of THC (0 to 0.3% of dry weight) [1-29]. However, due to the presence of psychoactive molecules, Λ9-tetrahydrocannabinol (Λ9-THC) and Λ8-tetrahydrocannabinol (Λ8-THC), Cannabis cultivation and its use is restricted/regulated in many countries [1-29]. Hemp is cultivated to produce a vast variety of products such as hemp seeds, hemp oil, clothing, rope, paper, insulation, cosmetics, biodegradable plastics, construction material (such as hempcrete), resin, pulp, animal bedding and fuel [1-29]. Biodiesel, biochar, bioplastics, biofuels, and biopesticides are some of the innovative applications of the hemp plant, which are subjects of research and debate at present time [1-29, 31-57]. The stalks, seeds, and leaves are converted into various construction materials, textiles, paper, food, furniture, cosmetics, and healthcare product [1-29, 31-57]. Hemp oil is widely used in the manufacturing of food and beverages on account of its high nutritional content, including fatty acids, proteins, and several other ingredients [1-29, 31-57]. Hemp oil has also shown antiviral properties [1-29]. In addition to fibre and essential oils, the hemp plant produces hundreds of secondary metabolites including flavonoids, diterpenes, triterpenes, and Cannabinoids [1-29].

* Corresponding author: Ravindra B. Malabadi

Industrial *Cannabis sativa*, hemp is an eco-friendly and worthwhile crop that complements a sustainable growth system [1-29, 31-57]. Industrial hemp farming has the potential to dramatically minimize the amount of carbon impact on the environment and can be cultivated with a little or no usage of chemical pesticides or fertilizers [1-29, 31-57]. Increasing climate change concerns along with efforts to reduce greenhouse gas emissions has demanded bio-based energy to substitute fossil fuel consumption [31-104]. Bioethanol and biodiesel are two major biofuels used in the transportation sector [31-104]. The majority of global energy use is based on fossil fuels, which are non-renewable or finite have been depleted [31-104]. According to the literature, fossil-fuel reservoirs will diminish by 2060 [31-104]. Therefore, scientists worldwide are searching for alternative energy sources to replace fossil fuels [99-104]. The world's scientific community is actively strengthening and enhancing the techniques used to generate renewable and green energy from resources such as hydro, ocean tides, sun and wind, etc [99-104]. However, none of these resources currently meet the requirements to replace petrol and diesel fuels [99-104]. Biodiesel is one of the current renewable and environmentally friendly energy sources capable of meeting energy demands [99-104]. Additionally, the burning of fossil fuel is responsible for the current climate change, as a result of produced greenhouse gas emissions [31-98]. Biological conversions of industrial hemp into bioethanol and other biochemicals have been introduced to address the a forementioned energy and environmental challenges [1-29, 31-57]. Its high cellulose content and the increased production because of the demand for Cannabidiol oil and hempseed products make it a promising future bioenergy and biochemical source [1-29, 31-57]. Research on hemp biomass for bioenergy production has been promising [1-29,31-57]. Hemp biomass was used for energy purposes for centuries [1-31-57]. However, energy use of hemp traditionally was limited to the use of oil pressed from hemp seed for e.g. lighting purposes [1-29, 31-57]. Hemp has been evaluated as a feedstock for liquid biofuel, biogas, bioethanol, and combustion [1-29, 31-57]. In general, biodiesel feedstock can be categorized into three groups: vegetable oils (edible or non-edible oils), animal fats, and used waste cooking oil including triglycerides [30-104].

Biodiesel is promoted because of having low carbon contents compared to fossil fuels, thus reducing the emission of greenhouse gasses from automobiles [99-104]. Biodiesel is an alcoholic ester of various fatty acids, also known as FAMEs (Fatty acid Methyl Esters) [99-104]. Biodiesel is synthesized from plant oil, lipids of microalgae, animal fat, and sewage sludge via the transesterifcation process [99-104]. The triglyceride is composed of a glycerol molecule which is attached to three fatty acids of long carbon chains. The chemical and physical characteristics of oil depend on the nature of fatty acids attached to the glycerol molecule [99-104]. Thus, the characteristics of biodiesel depend on the feedstock properties [99]. Animal fats, hemp oil, castor oil, jatropha oil, microalgal lipids of Oedogonium, Oscillatoria, Ulothrix, Chlorella, Cladophora, Spirogyra [103], neem plant oil, palm oil, pongamia plant oil, sewage sludge, soybean, sunflower waste cooking oils (WCOs), and yellow oleander are currently utilized as feedstocks for biodiesel [99-104]. Some microalgae contain up to 70% lipids, compared to 20–40% for typical oilseeds [103]. The extracted lipids are converted into biodiesel by trans-esterification [103-104]. Lipid extraction is the major step in biodiesel production [103-104], but it is subject to many challenges related to energy conversion and conservation and the optimal use of energy resources due to the structure of the algal cell wall [103-104]. Lipid conversion to biodiesel from algal feedstocks depends upon an effective biomass disruption method to improve oil recovery and optimization of the energy processes [103-104]. However, because of food security concerns, the use of edible oil in biodiesel production is criticized globally [99-104]. Furthermore, the greenhouse gas emission will increase through the direct and indirect land-use change from the production of biodiesel feedstocks and the risks of soil and water degradation resources and ecosystems [99-104]. Non-edible plant oils, waste cooking oils, and edible oil industry byproducts are suggested as effective biodiesel feedstocks because nonedible feedstock does not compete with food from human consumption [99-104]. Several non-edible plant oils, such as castor oil, jatropha oil, mahua oil, neem plant oil, eucalyptus oil, pongamia oil, and yellow oleander oil, are currently used as feedstocks for biodiesel production [99-104]. Moreover, biodiesel has high combustion efficiency and a reduced ignition delay time [99-104]. It can be used directly or blended with fossil diesel with minimal engine modifcation [99-104]. Due to these qualities, biodiesel has attracted the attention of the global scientific community, and numerous researchers are pursuing its development [99-104].

Biodiesel is a notable alternative to the widely used petroleum-derived diesel fuel since it can be generated by domestic natural sources such as soybeans, rapeseeds, coconuts, and even recycled cooking oil, and thus reduces dependence on diminishing petroleum fuel from foreign sources [30-104]. The injection and atomization characteristics of the vegetable oils are significantly different than those of petroleum-derived diesel fuels, mainly as the result of their high viscosities [30-104]. Modern diesel engines have fuel-injection system that is sensitive to viscosity change [30-104]. One way to avoid these problems is to reduce fuel viscosity of vegetable oil in order to improve its performance [30-104]. The conversion of vegetable oils into biodiesel is an effective way to overcome all the problems associated with the vegetable oils [30-104]. Dilution, micro-emulsification, pyrolysis, and transesterification are the four techniques applied to solve the problems encountered with the high fuel viscosity [30-104]. Transesterification is the most common method and leads to monoalkyl esters of vegetable oils and fats, now called biodiesel when used for fuel purposes [30-104]. The methyl ester produced by transesterification of vegetable oil has a high cetane number, low viscosity and improved heating value compared to those of pure vegetable oil which results in shorter ignition delay and longer combustion duration and hence low particulate emissions [30-104]. In the following section, the biodiesel production from hemp oil has been discussed and updated.

2. Biodiesel Production

India is one of the fastest growing economies in the world and energy security is critical for its socio-economic development [30]. India relies heavily on crude oil imports, and this trend will continue due to the rapid growth of its economy and over crowded population [30-104]. In order to foster energy security, India's strategy is to focus efforts toward energy self-reliance and developing renewable energy options [30-97]. In this context, India proposed an indicative biofuel blending target of 20 percent for both bioethanol and biodiesel by 2030 (Extended B20 target) [30-98]. Biofuels are environment friendly fuels and their utilization would address global concerns about containment of carbon emissions [30-104]. Use of biofuels has, therefore, become compelling in view of the tightening automotive vehicle emission standards to curb air pollution [30-98]. Overall, the choice of the vehicle used on Indian roads directly affects fuel consumption and thus the environmental impact caused during the fuel production [30-57]. India's energy security would remain vulnerable until alternative fuels to substitute/supplement petro-based fuels are developed based on indigenously produced renewable feed stocks [30-81]. Most of the worlds ethanol production is obtained from two major crops: corn and sugarcane [30-57]. Studies showed that plants grown for biofuel purposes have the potential to reduce the net greenhouse gas emissions [30]. Currently, about 2.5% of the world's transportation fuels are produced from the crop plants including maize, sugarcane, and vegetable oils [30-104]. In addition to the agricultural waste, several grasses like switch grass, *Miscanthus,* and foxtail millet have been identified as candidate bio-energy feedstock [30-104]. Considerable efforts have been made to develop vegetable oil derivatives that approximate the properties and performance of the hydrocarbon-based diesel fuels [30-104]. The problems with substituting triglycerides for diesel fuels are mostly associated with their high viscosities, low volatilities and polyunsaturated character [30-104].

Biodiesel is primarily produced from seed-oils that are rich in triglycerides by transesterification to fatty acid methyl esters [30-104]. Mechanical pressing is traditionally used to extract the oil. However, newer extraction techniques, such as supercritical carbon dioxide extraction, have also been used [30-104]. There are multiple transesterification reaction options including alkaline, acid, or enzyme-catalyzed reaction mechanisms [30-104]. Impurities from contaminated raw oils can impact fuel properties, such as turbidity, cloud point, and color [30-104]. Methods to remove impurities before or after transesterification include wet washing to remove water-soluble compounds, dry washing with specific adsorbent materials, filtration, and ion-exchange [30-104]. Hemp seed is comprised of 25%–35% oil that is high in fatty acids [30-104]. The oil is traditionally used in foods. Investigations are ongoing into the optimum conditions for hemp-based biodiesel [30-104].

Biodiesel is a clean-burning, oxygenated mono-alkyl ester fuel manufactured from natural, renewable sources like new or used vegetable oils and animal fats [30-104]. There is commercial production of biodiesel from soybean oil in the USA, rapeseed oil in Europe and palm tree oil, and *Jatropha curcas* oil in Asia [30-98]. In Asia, India, Singapore, Indonesia, Malaysia and China, as well as Latin America such as in Colombia, Argentina and Brazil, biodiesel production was quickly rising [30-104]. Indonesia expects to grow biodiesel production by 23% by 2030, while biodiesel usage is expected to rise by 7% over the next decade [30-104]. Greenhouse gases and other forms of air pollutants are emitted by fossil fuels, which negatively influence the environment [30-104]. One of the most major sources of pollution in the environment is pollutants created by the burning of fossil diesel fuel [30-104]. Diesel engine pollutants have a substantial impact on both the environment and human health [30-104]. However, including worldwide environmental concerns, growing petroleum costs, and the expected depletion of fossil diesel fuel are some of the problems [30-104]. It was also noted that biodiesel is becoming more widely accessible for the transportation sector by mixing with traditional diesel fuel [30-104]. Growing environmental concerns, dwindling petroleum reserves, and world agriculture based economy are all driving reasons behind the promotion of biodiesel to be sustainable transportation fuel [30-104]. Biodiesel fuels are being researched as a possible replacement for diesel due to the predicted future depletion of fossil fuel sources and the present rising cost of such fuels [30-104]. Biodiesel has a higher cetane index and emits less carbon dioxide emissions, among other advantages [30-104].

Hemp seed oil can be used to produce biodiesel though the process of transesterification [30-104]. Oil from hemp seeds presents a viable feedstock option for biodiesel production [99]. Hemp provides a competitively high yield compared to similar crops. Biodiesel from hemp seed oil exhibits superior fuel quality with the exception of the kinetic viscosity and oxidation stability parameters, which can be improved with the introduction of chemical additives [30-104].

Previously, homogenous catalysts were utilized in the transesterifcation process, but they are corrosive, non-recyclable, and generate substantial amounts of waste [99-104]. Furthermore, they produce more soap; besides, their catalytic activity is diminished when the water content exceeds 0.3% by weight [99-104]. Therefore, they required refined feedstock raw materials for biodiesel synthesis [99]. To address this issue, scientists initiated the synthesis of heterogeneous catalysts, which are recyclable and remain active even at high levels of water and FFAs [99-104]. In addition, the nanocatalysts are more effective due to their ultra-small size (10–80 nm) and high surface area-to-volume ratio [99-104]. This shift from homogenous catalysts to heterogeneous catalysts for biodiesel production is the major break through in reducing the product cost [99-104].The catalytic efficacy and reusability are the properties which make the heterogeneous catalysts desirable in terms of product quality and cost [99-104].

3. Biodiesel: Transesterification Reaction

Biodiesel is a sustainable liquid bio-energy resource that might be used to replace diesel fuel. It has the potential to reduce pollutant emissions and may be used without modification in compression ignition engines [30-104]. As an alternative fuel, biodiesel possesses qualities that are comparable to diesel fuel [30-104]. Transesterification is the process of turning large, branching triglycerides into smaller, straight-chain methyl esters in the presence of a solvent, employing an alkali, acid, or enzyme as a catalyst [30-104]. The transesterification process aids in the reduction of oil viscosity [30-104]. In the presence of homogeneous catalysts such as sodium hydroxide (NaOH), potassium hydroxide (KOH), and sulphuric acid, the method works effectively [30-104]. Methanol and ethanol are the most often used solvents, with methanol being favoured due to their inexpensive cost and physical and chemical properties [30-104]. They efficiently break down sodium hydroxide in these alcohols and react swiftly with triglycerides. Transesterification requires a 3:1 stoichiometric molar ratio of alcohol to triglycerides [30-98]. To push the equilibrium to a maximum ester yield, the ratio must be greater in reality [30-104].

Conventional transesterification processes are time-consuming and costly. New methods, such as non-thermal plasma technology, reduce the reaction time and temperature [104]. Therefore, this study evaluated the use of a combined plasma jet–hydrodynamic reactor for transesterification [104]. The plasma jet used in this research comprised a ceramic tube with a central high-voltage electrode and a ring outer electrode, into which argon gas was fed [104].

4. Biodiesel from Plant seed oil

Recent concerns regarding climate change and rising energy costs have dramatically increased interest in using alternative energies, especially biomass energy which is carbon neutral [30-104]. Hemp is among the fastest growing plants with unique fibre characteristics [30-98]. The first generation of biodiesel feed stocks is edible oils [30-81-104]. Edible oils have been used to make biodiesel in the United States and Europe because they are readily accessible, have a high biodiesel production rate, and are simple to process owing to their low free fatty acid content [30-81-104]. However, the cost of the production of biodiesel from edible oils is very expensive particularly in developing countries [30-104]. The first generation biofuel is unsustainable since it competes with edible vegetable oils for food and biodiesel production [30-104]. Exploration of innovative low-cost agricultural non-edible crops and the use of by-products in biodiesel production might significantly reduce biodiesel costs, especially in developing countries where edible oils are prohibitively costly [30-104].

Biodiesel contains no sulphur, aromatic hydrocarbons, metals, or crude oil leftovers, biodiesel is an alternative and clean fuel that emits less greenhouse gas emissions [30-104]. It has the key benefits: 1) biodiesel may be combined with diesel fuel in any quantity, 2) biodiesel can be used in a diesel engine without modification, 3) biodiesel contains no toxic ingredients, and 4) biodiesel emits less harmful pollutants into the environment [30-104]. Consequently, much effort is being invested into developing biodiesels from non-edible and edible vegetable oils such as *Jatropha curcas, Madhuca indica, Calophyllum inophyllum, Ceiba pentandra, Sapium sebiferum, Euphorbia lathyris, Reutealis trisperma,* hemp seed oil, papaya and watermelon seed oil, cottonseed oil, flax seed oil, vegetable oil, karanja biodiesel, orange peel oil, safflower seed oil, lemongrass oil, sunflower oil, juliflora and *Pongamia pinnata* oils [30-104]. Biodiesel is produced commercially from a variety of crops, mainly from soybean oil in the United States, palm oil in Southeast and East Asia and rapeseed oil in Europe [30-97]. The quality of fuel depends on a range of characteristics such as heat value, specific gravity, flash point, sulphur content, viscosity, cloud point, pour point, oxidization stability, etc. ASTM standard in the USA and Canada and EN 14214 in the EU defines minimum and maximum limits for these parameters [30-104].

Asokan et al., 2018 [88] reported biodiesel from papaya and watermelon seed oil by trans-esterification process using methanol and KOH as catalyst [88-104]. A new biodiesel i.e. WP is produced which is a mixture of papaya seed oil based biodiesel and watermelon seed oil biodiesel in a 1:1 ratio is prepared [88-104]. The blends (B0, B20, B30, B40, and B100) of WP with diesel and watermelon 100% and papaya 100% are used for further testing [88]. The performance, combustion and emission test were conducted on single cylinder 4-stroke diesel engine using different blends of these biodiesels and the results showed that B20 is superior blend among other biodiesel blends [88-104]. Further, the performance and combustion characteristics of B20 is very close to diesel while the emission characteristics of B20 is better than that of diesel as the emission of CO, HC and smoke is 27.27%, 23.8%, 8.3% less for B20 than diesel respectively [88-104]. Thus this study concluded that B20 is the most suitable blend of WP for substitute of diesel which will reduce diesel consumption by 20% [88-104].

Another work investigates the flaxseed oil biodiesel (FB) production and tested in a single cylinder DI diesel engine to analyse the emission as well as performance parameters [89-104]. H_2SO_4 and methanol with KOH were used for *trans*-esterification process and gives 90% yield [89-104]. The BTE of B20 is 33.05% which comparable to diesel (33.43%) at higher loads [89]. Considerable reduction of emission (CO, HC, NOx and smoke) were absorbed for FB blends compared to diesel fuel throughout the test [89-98]. Overall, from this experiment B20 gives best performance and least emission compared to other FB blends. Therefore flaxseed oil biodiesel as a good source of fuel for diesel engine [89-104].

Hemp seed oil has a clear advantage over palm seed oil as a source of biodiesel fuel [30- 104]. Palm oil is one of the most commonly produced types of biodiesel, primarily in Southeast Asia [30-104]. The expanding production of palm oil has a tremendous negative impact on the environment. It is facing increasing scrutiny worldwide for its destruction of the rain forest and wildlife, including the displacement of animal and human populations, and the resulting carbon dioxide emissions. Therefore, crop selection is very important when combating climate change [30- 104].

Another investigation on biodiesel produced from juliflora seeds using the 2-stage acid transesterification process followed by alkali transesterification process producing 80% yield of Juliflra Oil Methyl Ester has been reported [30-104]. Experiments were conducted on single cylinder diesel engine using juliflora biodiesel and its diesel blends[30-95]. The experimental results of fuel blends (B20, B30, B40, and B100) were compared with those from diesel (D100) [30-95]. The results indicated the performance and combustion characteristics of B20 as almost in line with those of diesel fuel trend [30-95]. Brake Specific Fuel Consumption (BSFC) for blends B20 and B30 (0.27kg/KWh) at full load was closer to diesel (0.26 kg/KWh) [30-104]. The BTE for Juliflora Biodiesel B100 is 31.11% and it was closer to diesel (32.05%) at full load [95]. However, the emission characteristics of CO, HC and smoke for biodiesel and its blends were smaller or equal compared to diesel throughout the experiment [30-95]. At full load, the NOx for biodiesel B100 was 1832 ppm which was a little higher than diesel fuel (1821 ppm) [30-95]. This led to the conclusion of B20 being most suitable blend of other blends and it is substitute of diesel which will reduce diesel consumption by 20% [30-104].

The enzymatic production of biodiesel by transesterification of cottonseed oil was studied using low cost crude pancreatic lipase as catalyst in a batch system [30-96]. The effects of the critical process parameters including water percentage, methanol:oil ratio, enzyme concentration, buffer pH and reaction temperature were determined [96]. Maximum conversion of 75–80% was achieved after 4 h at 37 °C, pH 7.0 and with 1:15 M ratio of oil to methanol, 0.5% (wt of oil) enzyme and water concentration of 5% (wt of oil) [96]. Various organic solvents were tested among which a partially polar solvent (*t*-butanol) was found to be suitable for the reaction [96]. The major fuel characteristics like specific gravity, kinematic viscosity, flash point and calorific value of the 20:80 blends (B20) of the fatty acid methyl esters with petroleum diesel conformed very closely to those of American Society for Testing Materials (ASTM) standards [96].

One of the recent study in 2023 [99] synthesized biodiesel from the widely available non-edible seed oil of *Sisymbrium irio* L. (a member of the Brassicaceae family) via a transesterifcation procedure over a homemade TiO_2 catalyst [99-104]. At 1:16 oil to methanol ratio, 93% biodiesel yield was obtained over 20 mg catalyst at 60 °C and 60 min [99-104]. The ASTM methods were used to analyze the fuel properties [99]. The quantitative and qualitative analysis was performed by FT-IR, GC-MS, and NMR spectroscopy[99]. GC-MS study confirmed 16 different types of fatty acids of methyl esters [99]. FT-IR analysis showed important peaks that confirmed the successful occurrence of biodiesel [99-104]. ^{1}H-NMR and ^{13}C-NMR showed important peaks for converting triglycerides into corresponding FAMEs [99-104]. The acid value (0.42 mg KOH/mg/kg), fash point (106 °C), and water content (0.034) of biodiesel are below the specifed limit of ASTM D6751 whereas kinetic viscosity (3.72 mm2 /s), density (0.874 kg/L), cloud point (− 4.3 °C) and pour point (−9.6 °C) and high heating value (41.62 MJ/kg) fall within the specifed range of ASTM D6751 test limit [99-104]. The unsaturation degree and oxidative stability of biodiesel are above ASTM D6751 test limit [99]. The physic-chemical properties of the SIB confirmed that it is eco-friendly fuel and a competitive source for manufacturing biodiesel on a commercial scale. Furthermore, the SIB is engine friendly and has good fuel efficacy [99-104].

4.1. Hemp seed oil Extraction

Hemp seed oil may be extracted from whole or dehulled hemp seed. Conventional processing techniques are primarily aimed at extracting oil efficiently and to obtain an oil of good quality [30-89]. Pressing is one of the oldest methods used for extraction of hemp oil, with seed pre-treatment and processing variables affecting the efficiency of oil extraction and quality of the oil [30-89]. Opportunities for improvements in processing for hemp seed and production of fractions from hemp seed oil will be similar to that for the processing of more established oil seeds such as soybean, rapeseed/canola seed, sunflower seed, safflower seeds, flax seeds and palm kernels [30-89]. The various methods for the extraction of oil from oilseeds that have been applied to hemp seed include mechanical pressing, solvent extraction, use of supercritical CO_2, and microwave or ultrasound assisted processing [30-91].

Plant seed oil is stored in the seeds as triacylglycerol (TAG) and to liberate these lipids, the cell wall must be weakened or disrupted [30-104]. Lipid recovery from various organic sources may be accomplished using a variety of lipid extraction techniques [30-81]. The type and oil content of lipid components varies [30-81]. Many approaches are being used in order to improve the process by extracting the highest amount of oil from the hemp seed at the lowest possible cost [30-81]. Mechanical extraction (cold press technique and expeller-pressed method) and solvent-based extraction were utilised in many developing nations to extract the oil content from the seeds (Soxhlet extraction method) [30-104]. Due to technological improvements in recent years, a few new technologies in oil extraction have been established, including supercritical fluid extraction, ultrasound-assisted extraction, and microwave-assisted extraction [30-104]. Oil extraction techniques are intended to deliver high extraction yields and create high value meals by obtaining high-quality oil with minimum unwanted components [30-81].

5. Biodiesel from Hemp seed oil

One of the study reported the conversion of hemp seed oil to biodiesel through base-catalyzed transesterification [60, 61-81-104]. The conversion is greater than 99.5% while the product yield is 97% [30-57, 60-81-98]. Several ASTM tests for biodiesel quality were implemented on the biodiesel product, including acid number, sulphur content, flash point, kinematic viscosity, free and total glycerin content [60]. In addition, the biodiesel has a low cloud point (-5^o C) and kinematic viscosity (3.48 mm2/s) [60]. This may be attributed to the high content of poly-unsaturated fatty acid of hemp seed oil and its unique 3:1 ratio of linoleic to a-linolenic acid [30-89].

According to this study, fully refined hemp seed oil was converted to biodiesel through a typical two-step base-catalyzed transesterification reaction [30-81-104]. On the basis of the this study, methoxide solution was first prepared by dissolving 4.5 g potassium hydroxide (KOH) into 120 mL methanol [30-81-86]. This methoxide solution was then mixed with 450 g hemp seed oil in a three-neck flask so that the oil:methanol molar ratio was 1:6 with the presence of 1 wt.% (relative to oil) KOH catalyst [30-81-98]. The mixture was heated and stirred at 50^o C for 20 min and then allowed to settle until the completion of phase separation [60]. The bottom layer containing byproduct glycerol and unreacted methanol was drawn out of the three-neck flask [60-98]. Another 50 mL methoxide solution containing 2.3 g KOH was then added and the stirrer started to permit a second transesterification reaction to take place for 10 min at 50^o C [60-102]. After the completion of the two-step base-catalyzed transesterification reaction, excess reactants, catalysts and the byproduct in the fuel product were removed by gently rinsing with distilled water [60-104]. The moisturized fuel product was dried by air bubbling [60-98]. The dried fuel product was then tested. The free and total glycerin content, acid number, sulphur content, flash point, and kinematic viscosity were determined by the American Society for Testing and Materials (ASTM) Methods (ASTM D6751-09) [60]. The density of hemp oil and biodiesel were tested by a pycnometer at 15^o C [60-89]. The cloud point of the hemp oil and biodiesel were tested by differential scanning calorimetry (DSC) [60-90]. The cloud point was also tested by a polarized light microscope (PLM) [60]. Industrial hemp seeds with high seed yield and high oil content makes it a potentially new crop source for biodiesel production [60-90]. It has been shown that hemp virgin oil can be converted into hemp biodiesel with a high product yield [60]. Furthermore, hemp biodiesel meets the standards for biodiesel fuel set by ASTM 6751-09 [60-104]. The distinct properties of hemp biodiesel are its low cloud point and low kinematic viscosity [60]. These promising cold flow properties make hemp biodiesel attractive and competitive. [30-60-89]. Because fossil fuel (coal, oil, and gas) reserves are fast depleting, it is predicted that hemp-based biodiesel will be a viable for long-term alternative [60-81]. Because these fossil fuel resources are limited, if they are used over an extended period of time, global resources will ultimately run out [30-60-81]. To summarise, the hemp seed oil is differentiated by the many ecological, energy, and economic advantages connected with its commercial usage, and increased use of this plant is helpful to the environment and food production [60-104]. Therefore, this study showed that the use of hemp oil based biodiesel generally reduces the global warming potential and the non renewable energy demand as compared to fossil diesel [30-60-104].

Another experimental study, updated the economics of producing biofuels from an industrial hemp *(Cannabis sativa)* 23 genotype – 19m96136 was investigated [69-98]. This study reported the utilization of Industrial hemp biomass variety 19m for the production of biodiesel [69-89]. Between 3.95 and 19.91 million gallons of biodiesel can be produced when lipid content in the biomass ranged between 2 and 10% [69-104]. At least 42.59 gallon of bioethanol was produced with 2% lipid-containing hemp, which decreased by 9% to 33.96 million gallons upon, increasing the lipid content up to 10% [58-63-89]. The UPC of biodiesel, produced from 19m industrial hemp plant biomass with 10% lipids 449 was at $4.31/gal, which is in the range of soybean biodiesel cost ($4.15/gal) [69-104]. Additionally, a 450 hectare of 19 hemp (10% lipids) can produce nearly 67 gallons more biodiesel than soybean [58-89]. Comparing the two 10% lipid-containing biomass i.e., 19m hemp and lipid-cane, if 19m hemp can be produced at $50/MT, hemp biodiesel will be cheaper than lipid-cane biodiesel[58-98]. The economic benefits of producing hemp biodiesel highlights the importance of understanding the lipid metabolism in plant cells [69-81]. Furthermore, this study demonstrated the critical research need, to focus on improving lipid accumulation in vegetative tissue [58-81]. Overall, the technoeconomic study showed that hemp can be a promising bioenergy crop, producing biodiesel at a lower price than soybean in addition to ethanol production [58-63-89].

One of the recent study in 2023 confirmed that seven clones (KU03, KU18, KU27, KU45, KU49, RPF1, and RPF2) of four-month-old hemp (*Cannabis sativa*) were used for bioenergy production [63-86]. Physical properties, volatile content, fixed carbon, ash content, calorific value, chemical composition, ash composition, and metal element of the samples were investigated [63-104]. The results revealed that hemp stalk had desirable fuel characteristics with high volatile substance, high heating value, low ash content, very low nitrogen content, and non detectable sulphur [63-89]. Selecting well-adapted clones and appropriate technology which can convert the hemp stalks to suitable bioenergy forms are important aspects of bioresource management [63]. Based on findings, some selected hemp clone biomass possessed excellent characteristics and great potential to be used as raw material for bioenergy production [63-81-86].

As biodiesel use has become more widespread, engine manufacturers have expressed concerns with regards to biodiesels higher viscosity which could result in higher fuel injection pressure at low operating temperatures [81-104]. However, biodiesel fuels have demonstrated temperature dependent behaviour similar to that of common diesel fuels [81-86]. Sulphur content is an important parameter as burning fuels containing higher sulphur content releases sulphur oxide compounds which are major pollutants and a leading cause of acid rain [81-104]. Biofuels in general have negligible sulphur content [81-89]. Oxidation stability is an important indicator of long-term storage capability of the tested fuel [81-104]. Hemp is a cleaner fuel than soybean and rapeseed biodiesel fuels [81-89]. This is demonstrated by a significantly lower sulphur content [81-86]. It is also a safer fuel for handling, storage and transport due to its higher flash point [81-89]. However hemp biodiesel performs poorly when it comes to its kinematic viscosity which is slightly higher than the European EN 14214 max of 5 mm 2 /s but still lower the American ASTM D6751 maximum of 6mm2 /s (ASTM 2015) [81-89]. Furthermore, hemp biodiesel as well as other biodiesel exhibit poor oxidation stability compared to common diesel varieties and below the 6 and 8 hours specified by the ASTM D6751 and EN 14214 respectively [81-89]. These parameters can easily be improved with the chemical additives to satisfy testing specifications [81-89]. For example, antioxidants are often used to inhibit biodiesel oxidative degradation and increase the shelf life of the fuel [81-104]. Also, the higher viscosity of biodiesels can be improved by either blending it with petro-diesel or less saturated FAME, as well as the use of some additives [81-104]. Therefore, non-blended hemp biodiesel can provide a viable alternative to petro-diesel and a competitive biodiesel when compared to other crops [81-89].

Biodiesel can be blended with petroleum diesel at different percentages [81-86]. The “B” factor is universally used to designate the percentage of biodiesel in the mix [81-104]. The most common of these blends are B100, B20, B5 and B2 which contain 20%, 5% and 2% respectively [81-98]. B20 biodiesel blend is one of the most common blended fuels [81-86]. It is popular because it represents a good balance of improved performance, lower emissions, materials compatibility, cost and its ability to act as a solvent [81-104]. Additionally, biodiesel blends of 20% or lower do not require any modification to the diesel engine [81-98]. Biodiesel can also be used without blending (B100). However, certain modifications to the engine are required to avoid maintenance and performance issues [81-104]. B100 (Pure Biodiesel) contains 8% less energy content than its petroleum counterpart [81-104]. This represents about 1-2% overall difference [81-86]. However, biodiesel users report negligible difference in fuel economy or performance [81-104]. B100 blend (pure biodiesel) is the most common fuel available at the pump as it requires biodiesel compatible engine parts such as hoses and gaskets [81-86]. Therefore, it can be used on some engines built after 1994 with biodiesel compatibility [81-86]. On the other hand, biodiesel fuels exhibit superior engine cleaning effect since they act as solvents and can be used to clean the deposits accumulated in the engine due to petrol diesel use [81-98]. Hemp performs well in biodiesel blends [81-86]. In one of the comparative study, it is found that hemp B20 blend provides better thermal efficiency, lower specific fuel consumption, reduced CO and CO_2 emissions in comparison to pure diesel and Jatropha B20 blends [81-86]. However, the hemp blend has a higher NOx emission in the study [81-89].

Hemp biodiesel presents a carbon neutral replacement to diesel fuel [81-89]. During the three month life cycle of the plant, the Cannabis ingests carbon dioxide at a rapid rate much greater compared to that of trees, which makes hemp a very effective scrubber of carbon dioxide [1-29, 30-81-98]. Effectively, hemp could provide the means by which not introducing additional carbon into the environment [81-89]. The carbon dioxide emissions released to the atmosphere when burning biodiesel is reabsorbed through photosynthesis [81-86]. The short life cycle of hemp allows for crop rotation such as winter cereals which is beneficial to the soil and the yield of both types of crops [81-86]. As a rule of thumb, the emission benefits from using biodiesel fuels corresponds roughly to the blend rating of the fuel [81-86]. For example, a B20 blend use translates to 20% reduction in greenhouse gas emissions compared to petroleum diesel [81-104].

Hemp seed oil is chosen as a feedstock for biodiesel production, methanol and KOH were used in the biodiesel production [87]. The chemical and physical properties of hemp oil biodiesel are measured to investigate the engine emission and performance characteristics of diesel engine [87-104]. From the results, B20 blend performance is best among other fuels tested [87-98]. Besides, the Brake Specific Fuel consumption (BSFC) at full load (0.3 kg/kW h) for B20 is slightly lesser than diesel fuel (0.32 kg/kW h) [87-98]. This indicated that the lower diesel/hemp seed oil biodiesel blends will increase the performance as well as decrease the fuel consumption [87-104]. Considering, the emissions from exhaust exhibited that Carbon Monoxide (CO), Hydrocarbon (HC) and Nitrox oxide (NOx) were lowered for all hemp seed oil biodiesel/diesel blends [87-102]. However, smoke emission increased slightly than diesel. In general, the results concluded that hemp oil biodiesel is a best alternative as well as good substitute fuel to diesel [87-104].

Hemp oil has a great potential to be used as a primary feedstock, or in combination with other types of oil, in the production of biodiesel fuel [81-86]. It has not yet been produced on a commercial scale despite numerous studies indicated its advantages [81-104]. The cultivation of hemp does not affect agricultural lands reserved for food crops as it has shown tremendous resilience to disease and ability to grow on infertile land with minimum use of pesticides [81-104]. Hemp can also be incorporated in other crop rotations in which both types of crops would benefit [81-86]. Since hemp seeds are used in biodiesel production, the discarded stems of the plant can provide substantial added economic value as it can be used in biomass ethanol production, or the fibre can be utilized in a variety of industrial processes [81-86]. When compared with similar crops that are used in large-scale commercial biodiesel production, hemp provides a substantially greater yield and has a higher oil content than that of rapeseed and soybean [81-86]. In addition, biodiesel made from hempseed can meet the ATSM D6751 and EN 14214 requirement for fuel quality and surpass that of conventional diesel except in the area of oxidation stability, as is the case with other biodiesel products [81-86]. However, the oxidation stability can be improved with the addition of antioxidants to the fuel prolonging its shelf life [81-86].

However, there are some problems remain in the way of commercial hempseed biodiesel production [81-86]. The fundamental fact is that the hemp seeds remain a “niche” crop in the food supply chain [81-86]. Farmers can gain high profits selling hemp seeds in the food supply chain as opposed to feedstock for biofuel [81-86]. The low hemp production does not match the high demand it garners in the health and food markets [81-86]. So unless hemp supply surpasses demand for hemp, it will remain prohibitively expensive to be utilized in biodiesel production [81-89]. However, the current worldwide production of hemp is very low with only few countries producing it as legal and perception barriers remain a big challenge [81-86]. Hemp still faces substantial legal hurdles to overcome in many jurisdictions around the globe [81-104].

6. Conclusion

Biodiesel can be primarily produced from seed oils in hemp. Hemp seed comprises 25%–35% oil high in fatty, the oil is usually used in foods and the composition makes it promising for biodiesel. Biofuels from hemp seed oil exhibit superior fuel quality because of low sulphur content and high flash point. Bioenergy is one of the sustainable resources available to meet the increasing energy demand and reduce the reliance on traditional fossil-based fuels. However, hemp biodiesel performs poorly regarding its kinematic viscosity and poor oxidation stability, which can be resolved by introducing chemical additives like antioxidants acids. Biodiesel is the group of monoalkyl esters of long chain fatty acids (called fatty acid alkyl esters) derived from renewable lipid feedstocks. It is a clean and renewable energy alternative to petroleum-based diesel fuel. Additionally, it can be used in conventional diesel engines as well as heating and power systems without modifications.

A transesterification reaction is used to produce biodiesel from the renewable lipid feedstock. This transesterification reaction is carried out by mixing with alcohol in the presence of a catalyst, during which the backbone of triglyceride is replaced with three alkyl groups of the alcohol. Catalysts for transesterification can be alkali, acid, enzyme, and heterogeneous catalysts. Since the base-catalyzed transesterification is rapid and easy to scale-up, it has been widely used in industry. Other important parameters for the transesterification reaction includes molar ratio of alcohol to oil, reaction temperature, catalyst concentration, agitation speed, and free fatty acid content. Noncatalytic transesterification through supercritical fluid technology is another promising way to produce biodiesel.

With recent increases in petroleum prices and uncertainties concerning petroleum availability, there is renewed interest in vegetable oil fuels for diesel engines. Vegetable oils have the potential to substitute a fraction of petroleum distillates and petroleum-based petrochemicals in the near future. Fundamentally, high viscosity appears to be a property at the root of many problems associated with direct use of vegetable oils as engine fuel.

Compliance with ethical standards

Acknowledgments

We would like to thank and acknowledge, Karen Viviana Castaño Coronado, Chief Communications Officer (CCO) and CO-Founder of LAIHA (Latin American Industrial Hemp Association), and CEO- CANNACONS, Bogota, D.C., Capital District, Colombia for thoughtful discussions, critical comments, supporting, promoting, encouraging and appreciating this research work.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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