Technological trends in vegetable oil extraction for biodiesel: A patent-based analysis with emphasis on native and unconventional oilseed feedstocks.

Sofia Laura Valverde Alves de Meneses [1*], Solciaray Cardoso Soares Estefan de Paula [2], Agnes Sophia Braga Alves [1], Thalia Catherine Sacramento Ferreira [1], Marcos Vinicius Lima dos Santos [1], André Feitosa Brito [1], Thâmilla Thalline Batista de Oliveira [1]

[1] *SENAI CIMATEC, Department Microbiologia Industrial, Salvador, Bahia, Brazil*; sofia.alves@fbter.org.br; agnes.alves@fbter.org.br; thalia.ferreira@fbter.org.br; marcos.lima@fbter.org.br; andre.feitosa@fbter.org.br; thamilla.oliveira@fieb.org.br
[2] *SENAI CIMATEC, Department Agroindústria, Salvador, Bahia, Brazil;* solciaray@fieb.org.br
**Corresponding author: SENAI CIMATEC; addresses;* sofia.alves@fbter.org.br

Abstract: The growing global demand for renewable energy and the urgency to reduce greenhouse gas emissions have positioned biodiesel as a key element in the energy transition. Its production from vegetable oils depends on feedstock selection and the extraction and conversion technologies applied. This study presents a technological prospection based on an international patent analysis, focusing on vegetable oil extraction and biodiesel production, with special attention to native and unconventional species from the Atlantic Forest. A systematic search was conducted using the Derwent Innovations Index, employing the IPC code C10L and relevant keywords. A total of 121 active patent families were analyzed. Results indicate a concentration of technological activity in Asia, especially India, China, and Japan, and highlight Brazil's strategic role. Technological routes include physical, chemical, thermochemical, enzymatic, and hybrid methods, with increasing emphasis on green solvents, energy integration, and biotechnological innovations. Feedstock analysis revealed strong interest in first-generation crops (soybean, canola, palm), but also growing focus on second- and third-generation species, such as *Jatropha curcas*, *Camelina sativa*, *Acrocomia aculeata*, and microalgae. Despite advances, gaps remain regarding integration with agroforestry systems and the commercial scale-up of sustainable technologies. This work provides insights into innovation trends and identifies opportunities for the development of cleaner and more efficient biodiesel technologies.
Keywords: Biodiesel production chain. Oil extraction methods. Oilseed crops. Patent landscape.

1. Introduction

The growing demand for renewable energy and the imperative to reduce greenhouse gas emissions have propelled biodiesel as a strategic alternative to the energy transition. Produced from renewable oilseed feedstocks, biodiesel substitutes fossil diesel in combustion engines while fostering agricultural diversification and strengthening local supply chains [1-2].

Production viability depends on feedstock selection and the technologies applied in extraction and conversion. Technological routes include physical (pressing), chemical (transesterification), thermochemical (cracking, hydrotreatment), and biotechnological methods; the latter is valued for higher efficiency and lower environmental impact [3-4]. Feedstock choice significantly influences yield and sustainability. First-generation oilseeds—soybean (*Glycine max)*, canola (*Brassica napus*), and oil palm (*Elaeis guineensis*)—are widely used but compete with food production and demand high natural resource inputs [1]. Second- and third-generation oilseeds—such as *Jatropha curcas*, *Camelina sativa, Acrocomia aculeata*, and microalgae—offer advantages in adaptability, oil content, and reduced socio-environmental impacts [5-6]. Despite progress, further efforts are necessary to better understand global technological trends, particularly innovations in oil extraction and conversion processes. Patent-based technology prospecting serves as a strategic tool to identify trends, uncover gaps, and guide R&D initiatives.

This article analyzes technological evidence on vegetable oil extraction and conversion into biodiesel based on an international patent survey. It discusses key technological routes, prominent oilseed species, and innovation trends, with emphasis on promising native and unconventional feedstocks for the bioenergy sector.

2. Material and Methods

This study conducted a technological prospection based on patent analysis related to the extraction of vegetable oils for biodiesel production, with a focus on species from the Atlantic Forest. The methodology followed a systematic approach (Table 1).

Data collection was carried out in April and May 2025 using the international Derwent patent database (Table 1). Keywords were selected based on prior literature identifying conventional oilseed species for biodiesel production and potential species from the Atlantic Forest. These terms were combined with "extraction" to capture patents related to vegetable oil processing for biodiesel. IPC code C10L was used as a key filter, targeting “Fuels not otherwise provided for; Fuel additives; Combustion carbon.”

Patents were included if they mentioned at least one target species (*Glycine max*, *Elaeis*, *Arachis hypogaea*, *Jatropha*, *Acrocomia aculeata*, *Euterpe*, *Ricinus communis*, *Mauritia flexuosa*, *Copernicia prunifera*, *Lecythis pisonis*, *Camelina sativa*, *Brassica*, *Carapa guianensis*), even when combined with other feedstocks, as long as they addressed oil extraction followed by biodiesel conversion under IPC C10L. Only active patent families (DWPI) were considered to ensure technological and commercial relevance. Patents lacking the conversion step or focusing on unrelated raw materials (e.g., used cooking oil, animal fats, or microalgae) were excluded, as were those outside the biodiesel technological scope, such as lubricants and unrelated additives.

3. Results and Discussion

A total of 128 patents were initially identified. After applying inclusion and exclusion criteria, 121 patent documents were retained. None of the patents analyzed showed integration with agroforestry systems (AFS).

The geographical distribution of patents reveals trends in technological development and intellectual property strategies in the biodiesel sector (Figure 2). The data show a significant concentration in Asian countries, with India leading (22 patents), followed by China (17) and Japan (11). This dominance reflects these countries' investments in renewable energy and their roles as major agricultural producers of biofuel feedstocks. Brazil stands out with 13 patents, highlighting its role as a key player in the development of biodiesel technologies suited to tropical conditions. In North America, the United

States holds only 4 patents, while Mexico shows surprisingly strong activity with 5 filings. European patents (EP) total 4, with smaller contributions from countries such as France (3) and Finland (2).

An important aspect is the presence of 6 WO (PCT) patents, representing international applications under the Patent Cooperation Treaty. These filings indicate technologies with potential for protection in multiple countries, reflecting inventions with broader market ambitions. EP patents, on the other hand, indicate regional protection within European space. The presence of filings in Canada (1), Australia (3), and Russia (2) demonstrates targeted expansion strategies into specific markets.

The analysis also reveals unexplored opportunities, particularly in Africa, which are entirely absent from the records. The disparity between Asian leaders and other regions suggests varying policies and investment levels in biofuel innovation. This geographical distribution reflects both the origins of technological innovation and the target markets for commercialization of oilseed-based biodiesel technologies.

The temporal distribution of patents shows a gradual increase starting in 2005 (1 patent), reaching a peak in 2014 (14 patents), followed by relative stabilization between 2015 and 2018, with an average of 9–11 patents per year (Figure 2). Patent ES2192978B1 (2005) describes a pioneering process for biodiesel production from *Brassica carinata* (erucic acid-free) via KOH/methanol transesterification and water purification, developed by the Universities of Jaén and Córdoba. The resulting biodiesel featured low CO_2 emissions, anticipating future environmental demands.

The temporal pattern suggests a technological maturation cycle in this field, with the peak of development occurring between 2010 and 2018—likely driven by biofuel incentive policies—followed by a phase of consolidation or redirection of research efforts in more recent years.

Since 2019, a progressive decline has been observed, with only 3 to 7 patent filings per year. Recent data show 3 patents in 2024 and 2 in 2025. These figures should be interpreted cautiously due to the patent confidentiality period, which typically lasts 18 months from the date of filing. As such, many recent innovations may not yet be publicly available. Therefore, the numbers for 2024 and 2025 likely underestimate the actual level of innovation, reflecting only patents that have surpassed the confidentiality period or were published early.

Patent ES2818054T3, published in 2021 by QS Biodiesel Ltd, discloses a method for producing biodiesel through the transesterification of vegetable oil (e.g., sunflower oil) with a short-chain alcohol. In the process, the solvent used for vegetable oil extraction is introduced as a cosolvent in the transesterification step, allowing process integration and lowering overall energy demand.

The two most recent publications in 2025 refer to WO2025051706A1, filed by BASF SE. This patent describes an innovative process for producing renewable hydrocarbons (diesel and aviation kerosene) from biomass, including palm, soybean, canola, *Jatropha*, and *macaúba*. The method combines mechanical pressing or hydrothermal liquefaction with hydrotreatment and features integration with anaerobic digestion of residues for energy optimization. The second patent, US12247137B2, filed by Neste Oyj, discloses a renewable isoparaffinic distillate for use as a solvent, derived from vegetable oils and fats through hydrotreatment and isomerization. Although its main applications are non-fuel (e.g., paints, cosmetics), the patent reinforces the versatility of renewable feedstocks.

3.1 Extraction And Conversion Technologies For Biodiesel Production

Patent surveys reveal a wide range of extraction and conversion technologies for biodiesel production, including physical, chemical, enzymatic, and biotechnological methods. Key processes are identified. Physical and mechanical methods used for oil recovery and processing include cold or hot pressing for initial oil extraction, reactive milling (which combines mechanical force with solvents or alcohols), high-pressure processing (ranging from 100 to 1000 MPa), and hydrodynamic cavitation. Additionally, centrifugation is applied for separation following hydrolysis or emulsification.

Among the chemical and thermochemical methods, transesterification stands out, which can be catalyzed by alkaline, acid, or enzymatic agents (such as KOH or NaOH). Thermal or catalytic cracking, performed at temperatures between 100 and 800°C, allows for direct hydrocarbon conversion. Other approaches include hydrotreatment and isomerization, used to produce renewable diesel and aviation kerosene, as well as solvent extraction using hexane, methanol, or supercritical CO_2 under various temperature and pressure conditions.

Enzymatic and biotechnological methods involve enzymatic hydrolysis and transesterification using lipases and phospholipases, plant cell cultures (in suspension or immersion) for direct lipid production, and genetic modification strategies (e.g., enhancing lipid yield through MGAT genes). Fermentation or anaerobic digestion of residues, integrated with extraction processes, is also commonly employed.

Finally, recent innovations include hybrid processes that combine physical extraction with chemical or enzymatic conversion (such as pressing followed by microwave-assisted transesterification), sustainable technologies utilizing green solvents (like subcritical CO_2 or ethyl acetate) or solvent-free methods (such as water or acid fractionation), and energy integration strategies involving hydrothermal pyrolysis, residue gasification, and waste heat recovery.

Dominant trends include green chemistry replacing toxic solvents like hexane with safer alternatives (alcohols, CO_2), energy efficiency via hydrothermal liquefaction and hydrotreatment for advanced biofuels, and biotechnology applying genetic engineering to increase oil yields in species such as Brassica and Jatropha. Challenges remain in enzymatic method scalability and high costs of advanced catalysts like ruthenium in metathesis reactions.

3.2 Main Oilseed Crops

To visualize and analyze the diversity of oilseed species used as biodiesel feedstock, a word cloud was generated based on species name frequency across studies (Figure 3). This technique highlights the most recurrent and relevant species, with *Jatropha curcas*, soybean, canola, palm, and various microalgae standing out, reflecting scientific and technological interest in these sources. Based on the compiled oilseed species, their use in biodiesel production can be contextualized according to technological generations classified in scientific literature. Biodiesel generations (1st to 4th) relate to feedstock origin, socio-environmental impact, advanced technologies, and food production competition [1].

The 1st generation mainly comprises edible vegetable oils from conventional crops such as soybean (*Glycine max*), canola (*Brassica napus*), oil palm (*Elaeis guineensis*), corn (*Zea mays*), sunflower (*Helianthus annuus*), and peanut (*Arachis hypogaea*). These oilseeds are widely cultivated, have established supply chains, and well-developed extraction technologies. However, their main limitation is direct competition with food production and intensive use of fertile land and water resources, raising environmental and ethical concerns, especially in food-insecure regions. Although technically viable, large-scale biodiesel production from these sources is considered unsustainable, research is driving these impacts toward alternatives that reduce these impacts. The 2nd generation includes non-edible oilseeds and alternative sources often grown on marginal lands. The most cited example is *Jatropha curcas*, recognized as a promising feedstock due to its non-competition with food crops. It has high oil content (27–40%) and adapts to low-fertility environments. However, commercial experiences in countries like India and Mozambique revealed productivity challenges due to genetic variability and irrigation needs in semi-arid areas. Other relevant 2nd-generation species include *Camelina sativa, Brassica carinata*, castor bean (*Ricinus communis*), *Pongamia pinnata* (karanja), and macaúba (*Acrocomia aculeata*), all noted for lower environmental impact and integration potential in sustainable production systems.

The 3rd generation encompasses microalgae, oleaginous yeasts, waste oils (vegetable or animal), and lignocellulosic biomass. The identification of microalgae species such as *Chlorella, Nannochloropsis, Dunaliella tertiolecta, and Prototheca* highlights the growing scientific interest in the identification of microalgae species. Microalgae offer high lipid productivity (up to 70% dry weight), rapid growth, and cultivation in closed systems without arable land. They can use wastewater and capture CO_2, directly contributing to greenhouse gas mitigation. Despite these advantages, commercial scalability is limited by high cultivation, harvesting, and oil extraction costs.

The 4th generation focuses on genetically modified organisms and synthetic biology approaches to enhance productivity, stress tolerance, and photosynthetic efficiency. Genetically engineered microalgae such as *Chlamydomonas, Phaeodactylum*, and modified *Nannochloropsis* strains exemplify this generation. Still experimental, this approach promises direct conversion of CO_2 into lipids or hydrocarbons with greater genetic and biochemical control. Progress depends on biosafety, regulatory frameworks, and industrial infrastructure investment.

In summary, the data reveal a broad diversity of species reflecting research trends toward more sustainable and technologically advanced feedstocks. Oilseeds like *Jatropha*, *Camelina*, microalgae, and alternatives such as *Pongamia* and macaúba represent the future of biodiesel production, meeting increasing demands for energy efficiency, environmental sustainability, and economic viability. Scientific literature supports this gradual transition from 1st generation sources to more resilient and sustainable models in subsequent generations.

4. Conclusion

The patent analysis reveals a dynamic and evolving landscape of biodiesel technologies, with increasing interest in sustainable extraction methods and alternative feedstocks. However, further efforts are needed to integrate these innovations into scalable and ecologically sound production systems, particularly within the context of native biodiversity and agroforestry potential.

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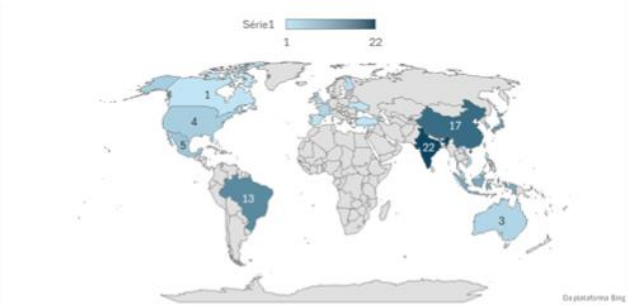
Table 1. Criteria used in scientific and technological surveys.

Database	Type	Keywords	Field	Filters
Derwent	Paten t	(Glycine max OR Elaeis OR	Title, Abstra	IPC: C10L

	document	Arachis hypogaea OR Jatropha OR Gossypium OR Acrocomia aculeata OR Euterpe OR Ricinus communis OR Mauritia flexuosa OR Copernicia prunifera OR Lecythis pisonis OR Camelina sativa OR Brassica OR Carapa guianensis) AND Extraction	ct and Climas	DWPI Families

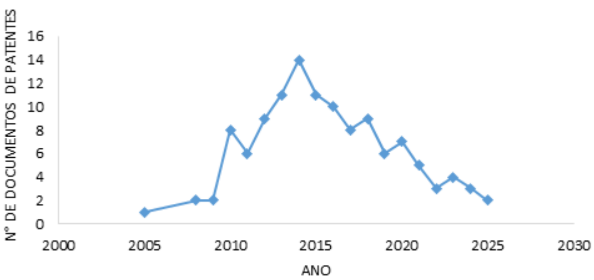
Source: Developed by the author.

Figure 2. Geographical coverage of patents on oilseed extraction for biofuels.



Source: Developed by the author.

Figure 3. Timeline of patent filings.



Source: Developed by the author.

Figure 4. Word cloud showing principal oilseed species identified.

Source: Developed by the author.

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