Second-generation biodiesel in Brazil: an analysis of research on animal fats through social and complex networks

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Abstract

The production of second-generation biodiesel is seen as more sustainable than first-generation biodiesel as it is produced from residues such as animal fats, a by-product of the meat industry. In Brazil, the biodiesel sector has become the main market for animal fats, absorbing around 712 thousand tons in 2018, equivalent to 38% of the fat produced. In order to reach this level, research and development were carried out supported by the Brazilian government through the Brazilian Biodiesel Technology and Innovation Network. The objective of this study is to map the scientific networks formed by Brazilian organizations that have collaborated to solve research problems regarding animal fats for biodiesel production through Social Networks Analysis and The Theory of Complex Networks. An exploratory-descriptive study was conducted in the main collection of Web of Science (WoS). It was observed that research started in 2008 and involved more than 80 institutions. The institutional network formed was of a small-world type, composed of 20 clusters. The research was indexed in 19 knowledge areas, with an emphasis on Chemistry, Energy and Fuels, and Engineering and 70% of them received some type of funding to conduct the research.

Keywords: Biodiesel; RenovaBio; Animal Fat; Complex Networks; Social Network Analysis.

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1. Introduction

Brazil agreed to reduce greenhouse gas (GHG) emissions by 37% by 2025 and by 43% by 2030, with the year 2005 as a reference, as a signatory to the Paris agreement independently (Brasil, 2015).

Among the commitments made in the energy area that directly affect the transport sub-sector, the Brazilian government plans to increase the participation of biofuels in the energy matrix to approximately 18% by 2030 (de Souza et al., 2017).

The Brazilian government launched the RenovaBio Program, a state policy, whose objectives are to boost biofuel production, encourage private investments, and provide advances in the production of second and third-generation biofuels (Brasil, 2017b). All of this is based on environmental, economic, and social sustainability, and predictability of the national biofuels market (Denny, 2020).

RenovaBio is also expected to achieve an 18% share of biofuels in the Brazilian energy matrix by 2030, contributing to the decarbonization of the transportation matrix (Brasil, 2017b; Denny, 2020).

Biodiesel has a crucial role to play here to help in the mitigation of emissions from the transport sector, especially in road transport of freight. This is a segment which is highly dependent on diesel oil and accounts for 80% of diesel oil demand. It is also responsible for 49% of emissions from the transport sector (EPL, 2018).

Other important contributions of biodiesel use include (i) air quality improvement in the large urban centers of the country, reducing respiratory diseases due to the inhalation of particulate materials, hydrocarbons and carbon monoxide released by diesel engines; (ii) social and economic benefits related to job and income generation throughout biofuel production chain, and; (iii) reduction in the consumption of imported diesel (FGV & Ubrabio, 2010; Rico & Sauer, 2015), which reached 22% of 57,179 10^3 m^3 consumed in Brazil in 2019, resulting in a trade deficit of approximately US$ 13 million (EPE, 2020).

However, technological and market challenges will have to be faced to guarantee an increase in the percentage of biodiesel in diesel blends in the coming years. Investment in research, development, innovation (RD&I), and technology transfer will be necessary if biodiesel production is to go from 5.9 billion liters in 2019 to around 18 billion liters by 2030 (de Souza et al., 2017).

Some of these challenges have been listed by the Brazilian Union of Biodiesel and Bioquerosene (Ubrabio) and include: (i) diversification of sources of raw materials; (ii) optimization of biodiesel production technologies to take advantage of low-quality and lower-cost fatty materials; (iii) improvement in transport and storage of biodiesel; (iv) simplification of quality control processes, and; (v) adding value to co-products generated in biodiesel production (Embrapa, 2020).

In order to overcome these challenges and guarantee percentage increases in the mixture of biodiesel with diesel oil in a sustainable man-

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ner, the Ministry of Science, Technology and Innovations (MCTIC), through the Science, Technology and Innovation Plan for Renewable Energies and Biofuels, has encouraged the institutional articulation of different agents involved in biodiesel production chain, and has reinforced the importance of the Brazilian Biodiesel Technology and Innovation Network (RBTB) (MCTIC, 2018).

Created in 2004, RBTB involves an extensive RD&I infrastructure with 37 laboratories. It brings together hundreds of Brazilian researchers affiliated with universities, science and technology institutions and private companies (Rodrigues, 2011) .

RBTB has become one of the rare examples of successful structuring of a scientific-technological base to support a government program (Rocha, Quintella, Torres, & Silva, 2015; Rocha, Silva, Quintela, & Torres, 2013). An additional 180 million reais have been invested in specific projects for biodiesel production chain, enabling technological mastery, production scale, and logistics of different sources of raw materials (MCTIC, 2016), such as soy and beef tallow.

In the case of beef tallow and other animal fats, the biodiesel sector has become the main consumer market, absorbing about 712 thousand tons of animal fat (37.47%) out of the 1.9 million tons produced in the country in 2018 (ABRA, 2020).

Animal fat as an input represented 27% of Brazilian biodiesel production in 2019 (ANP, 2020) and demand for this input is increasing since biodiesel produced from these fats is considered second-generation. which leads to RenovaBio's environmental certification system (Batista, 2020).

Therefore, understanding and analyzing the research networks working on animal fat for biodiesel production is crucial. This research can lead to the diversification of raw materials for this biofuel production, demonstrate advantages of this input over vegetable oils[1], and help to reduce environmental impacts, and avoid improper disposal of unprocessed and incorrectly discarded waste.

The objective of this work is to map the networks formed by Brazilian organizations within the scope of the Web of Science, which have collaborated to solve research problems concerning animal fat and biodiesel through Social Network Analysis (SNA) and Complex Network Theory (CNT).

The mapping of these co-authorship networks enables an understanding of different relationships established between organizations dedicated to this theme, revealing the process of scientific cooperation and its dynamics for knowledge dissemination among its members, which is not accessible through traditional research methods.

2. Biodiesel generations

Biodiesel is a consolidated term and widely used in the industry to refer to a synthetic and biodegradable fuel equivalent to petrodiesel. Although derived from biological sources, biodiesel mixed with diesel can be easily used in compression ignition engines without the need for modifications (Ambat, Srivastava, & Sillanpää, 2018).

Chemically, biodiesel is categorized as a combination of long chain mono-alkyl esters (carbon = C14 to C22) extracted from vegetable oils, recycled cooking oils or animal fat, through different processes such as cracking, esterification and transesterification (Pinto et al., 2005).

The transesterification reaction is the most used method to produce biodiesel and consists of a chemical reaction of oils or fats with alcohol (methanol or ethanol), stimulated by a catalyst, which results in biodiesel and glycerin (Rezende et al., 2021). It is the most economically viable process used on an industrial scale to produce biodiesel (Gebremariam & Marchetti, 2018)

With a consolidated production technology and environmentally friendly, biodiesel has become one of the main biofuels for the transport sector, especially road transport, which accounts for about 75% of global energy use in the sector (Gebremariam & Marchetti, 2018; International Energy Agency, 2011).

Biodiesel has been categorized into generations, taking into account the raw material used in its production (S. P. Souza, Seabra, & Nogueira, 2018). First-generation biodiesel is mainly made from food crops, while second-generation biodiesel is produced from non-edible vegetable and animal waste, while third-generation biodiesel uses macro and microalgae oils as raw material (Singh et al., 2020). This third generation uses a promising feedstock for biodiesel production due to its high oil content. However, its commercial exploitation is still in pilot or demonstration phase (Faruque, Razzak, & Hossain, 2020; Medeiros, Sales, & Kiperstok, 2015).

Currently, the sustainability of biodiesel produced from conventional agricultural crops (e.g. soy and palm) has been criticized, due to its competition with food production, water usage, land use change and biodiversity loss (Kargbo, Harris, & Phan, 2021). Because of this, attention has turned to the production of second-generation biodiesel, as it uses waste that does not compete with food crops or lead to deforestation. Furthermore, second-generation biodiesel is cheaper in terms of the cost of the raw material required, which can reach 80% of total production cost of biodiesel (Bhuiya et al., 2014). As a result, R&DI efforts are being directed towards the development of technologies capable of using low-cost, non-edible raw materials that help mitigate environmental damage, such as the use of animal fat residues from the meat industry (Toldrá, Mora, & Reig, 2016).

The fats are obtained through a process known as rendering, in which parts of the slaughtered animals that do not go for human consumption (e.g. viscera, bones, animal tissue, fat scraps and other inedible parts) pass through a high temperature and pressure system that converts these animal wastes into a variety of usable products such as fertilizers, soap, pet food, feedstuff and biodiesel (Mekonnen, Mussone, & Bressler, 2016; Woodard & Curran, Inc., 2006).

[1] Higher cetane and oxidation stability levels and lower iodine levels, for example. Authors' note.

Currently, the main animal fats used in biodiesel production are beef tallow, lard, and white fat from poultry fat and swine processing (Adewale, Dumont, & Ngadi, 2015; Feddern et al., 2011). Fats and oils generated by a fish processing plant and meat residues from leather industry are also considered viable raw materials for biodiesel production (Lazaroiu et al., 2017).

Despite the advantages presented, animal fats have a high level of free fatty acids and require more complex production techniques, which can lead to a lower physical-chemical quality of biodiesel (Ambat et al., 2018). Furthermore, biodiesel made from animal fat is less resistant to cold which can limit its use to tropical regions, especially when it is used in its pure form (S. P. Souza et al., 2018; Toldrá-Reig, Mora, & Toldrá, 2020).

Animal Recycling Industry in Brazil

The animal slaughter industry in Brazil produced 14 million tons of slaughter byproducts in 2020, making the country one of the world's largest producers of animal rendering byproducts (ABRA, 2021).

Table 1: Representation of animal recycling in Brazil (Values in tons 2020)

Species	Live Animal Weight (ton)	Recycling (%)	Recycled raw material (ton)	Fats, Oils and Grease (Ton)
Ruminants	18,813,230	38%	7,174,049	1,358,017
Poultry	17,597,327	28%	4,866,152	519,747
Swine	5,298,507	20%	1,038,507	146.027
Fish	459,136	45%	206,611	14.463

Source: (ABRA, 2020, 2021)

A large amount of slaughtered animal waste is transformed into inputs for industries of feed and pet food, hygiene and cleaning, cosmetics, paints, energy, and other industries, by companies linked to the animal products recycling sector (Bueno, Freitas, & Nachiluk, 2012).

Brazil has a waste processing structure to ensure that animal waste is correctly disposed of, avoiding disposal in landfills, and environmental and sanitary problems (Feddern et al., 2011). Much of this waste is processed in slaughtering plants themselves. Another part is collected from small slaughterhouses, butchers and supermarkets, and processed by rendering plants, known as 'graxarias' in Portuguese. These two models are called by Brazilian legislation: Dependencies Attached to Industrial Slaughter Plants and Processing Unit of Inedible Products (Brasil, 2017a).

Currently, there are 319 companies registered with the Federal Inspection Service (SIF), a control system of the Ministry of Agriculture, Livestock and Supply (MAPA) in Brazil, which assesses the production quality of edible or inedible animal origin food throughout the five Brazilian regions (ABRA, 2020).

The use of animal fat as an energy input is a solution from the point of view of supply stability. The country is highly dependent on soy to produce biodiesel and the rapid adherence of animal fat producing companies to the Biodiesel Production and Use Program (PNPB) has changed this market. Animal fat has ceased to be a devalued or even an unwanted input (Mekonnen et al., 2016).

The first plant dedicated to biodiesel production in Brazil from beef tallow was set up in 2008. The use of this raw material for biodiesel production has become increasingly significant, boosting a diversity of scientific studies in the country since then (Fernandes et al., 2021; Mekonnen et al., 2016).

About 32% of the 2,038,254 tons of animal fat produced in the country in 2020 was destined for biodiesel industry. Beef tallow ranks third among the raw materials used in this biofuel production with 8.7% share in 2020. Poultry fat (0.63%) and pork fat (2,01) had a low share in the same period, while fish oil is not yet being used on an industrial scale for biodiesel production (ABRA, 2021; Brasil, 2021).

3. Brief introduction to network theory

The Theory of Networks has its origin in the 18th century with the problem resolution of the Bridges of Königsberg by Leonhard Euler, who founded what is now known as Theory of Graphs, enabling the mathematical representation of networks (Heitor et al., 2014; Barabási & Pósfai, 2016; Newman, 2018). A network is a graph, an abstraction that allows connecting relationships between pairs of objects, represented by $G = \{V, E\}$, where (V) is a discrete (finite and enumerable) set of Nodes or Vertices and (E) are the Edges, a set of lines that represent any type of connection between the set elements (V) (Bloch, Jackson, & Tebaldi, 2021).

Two other historical milestones for the Theory of Networks are: the development of the Social Network Analysis (SNA) and the Theory of Complex Networks. At first, SNA was linked to Sociometry, an analytical tool used to describe social relationships through a graphic representation known as a sociogram, developed by Jacob Moreno in the 1930s (Scott, 2017). Sociometry has decisively contributed to SNA consolidating itself as one of the study approaches of social groups by enabling a systematic analysis of these groups from their respective structures and using particular measures (Recuero, 2017; Wasserman & Faust, 1994).

Social Network Analysis (SNA) is an approach focused on the study of human relationships and, unlike traditional methods of research centered on attributes, it focuses on connections among individuals and exchange of information resulting from these relationships (Borgatti, Everett & Johnson, 2013; Freeman, 2021; Fuentes-Solís, Soto-Caro & Paredes, 2019; Wasserman & Faust, 1994).

In SNA language, vertices are called actors to represent people or groups, and edges are called loops or connections. A set of indices can be used to measure actors' importance in a network (Bloch et al., 2021), with centrality indices being the most used:

- Degree centrality: used to find nodes with the highest number of connections to other nodes in the network.

- Betweenness centrality: identifies nodes that act as a kind of bridge between other nodes, forming the shortest paths of information flow within the network.

- Closeness centrality: identifies nodes closest to other nodes in a network. The central node is the one that has the greatest possibility to interact quickly with all nodes.

Other concepts involving SNA and a detailed explanation of the aforementioned indices, and others, can be found in (Scott & Carrington, 2011; Tabassum, Pereira, Fernandes, & Gama, 2018; Wasserman & Faust, 1994).

In SNA, a network can be analyzed in three ways: individually, where each author is analyzed by group, where subgroup formations are analyzed, and the network as a whole, enabling the identification of several aspects, among which: (i) relationship patterns among actors of a network; (ii) connectivity between these authors; (iii) formation of clusters; (iv) network evolution over time; and (v) flow of communication, information and knowledge within a network (Bordin, Gonçalves, & Todesco, 2014).

The Theory of Complex Networks (TCN) appeared in different knowledge areas at the end of the 20th century, due to rapid computational evolution that allowed the gathering of large volumes of data, allowing analysis of networks with non-trivial topological properties, such as information, technological, biological and social networks. Currently, it is widely applied in characterization and mathematical modeling of complex systems, and the most widespread network models: random networks, free-scale networks, and small-world networks (Newman, 2018).

The classification is made based on different indexes, and the most used are: average minimum path, agglomeration coefficient and degree distribution. The mathematical formulation and explanation of these and other indexes can be found in (Barabási & Pósfai, 2016).

4. Methodology

This work can be characterized as an exploratory-descriptive study of a quantitative nature. The technical procedures adopted are related to metric studies of information for measuring scientific knowledge, especially scientometric indicators for use in the analysis of information flows of scientific and technological literature in order to measure development and dissemination of scientific knowledge, to evaluate research activities at different levels, and to assist in management and decision making.

In this article, these indicators were applied to research on the use of animal fat for biodiesel carried out by researchers affiliated with Brazilian organizations and search, selection and analysis protocols were adopted.

The search was carried out on Clarivate Analytics' ISI Web of Science (WoS) database. This brings together a complete set of academic publications in all sciences, in addition to having the Journal Citation Reports (JCR), the most prestigious report on metrics and analysis of the world's journals, by area of knowledge. The friendly interface for data downloading was taken into account as well as the best compatibility with the software used.

A search combining labels of country/region and topic fields was carried out in the Main Collection of the WoS on 02/04/2020, and updated on 06/22/2020. The search terms were obtained through an initial bibliographic search (Leoci, 2014). The advanced search was used because it allows the use of Boolean operators to form and combine search results with no specific period. The following string was used:

CU=(Brazil) AND TS=(("animal fat$" OR "animal oil$" OR "animal grease$" OR "waste animal fat$" OR tallow OR lard OR "poultry fat" OR "chicken fat" OR "beef fat" OR "bovine fat" OR "pig fat" OR "pork fat" OR "swine fat") AND (biodiesel* OR "bio-diesel*"))

This was limited to articles and reviews until December 31, 2019 and 180 documents were recovered, out of which 85 were selected after an analysis to verify the occurrence of terms in the titles, keywords and adherence of the general objective of each document.

A .CSV file with a complete record and cited references from the 85 documents was generated and exported to *Microsoft Excel* for the creation of bibliometric indicators of production, institutional co-authorship and research funding. The following free pieces of software were used to build the networks: VOSviewer, Gephi and Pajek.

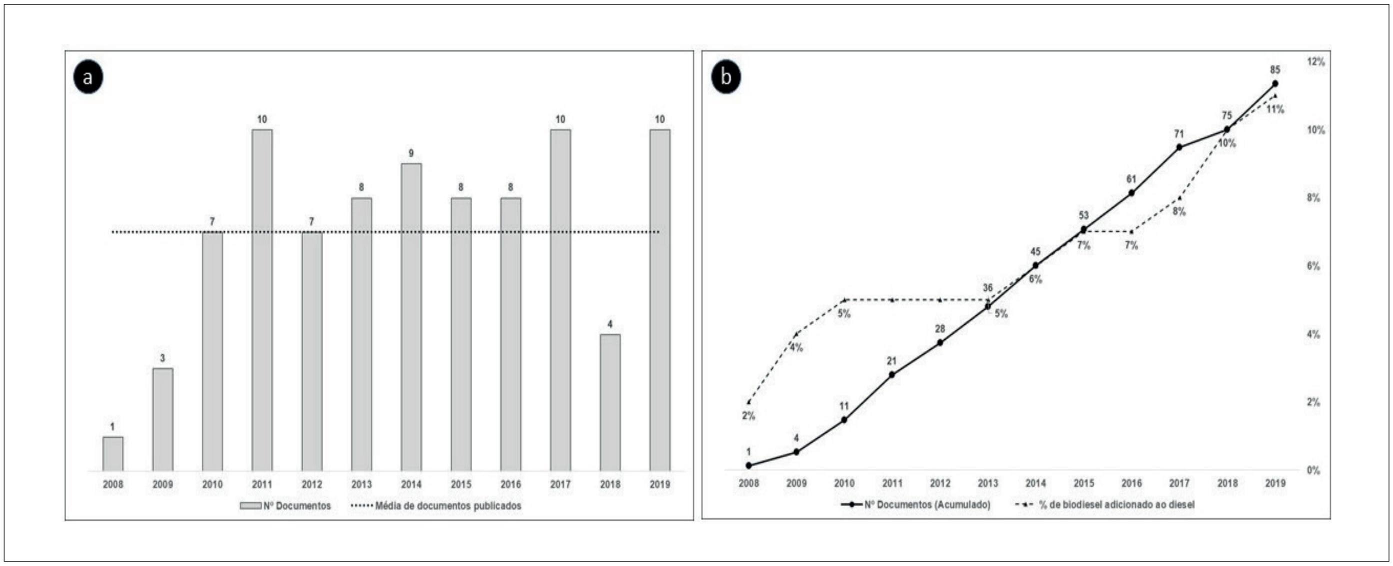
It is important to note that WoS takes into account the author's affiliation, regardless of their position in the list of authors, which can cause an overlap in number of publications attributed to each institution, country or most active author.

5. Results and discussion

The research corpus consisted of 85 documents, 82 articles, 2 conference articles and 1 review article, and their annual distribution can be seen in Figure 1a.

English was the most used language in the documents (n=72; 84.71%), followed by Portuguese (n=13; 15.29%). The records were published in 50 journals (average ≅ 2 documents/ journal), showing the dispersion in communication of the research produced. In total, 28 articles (33%) were published in 15 open access journals, a national preference making Brazil a world leader in this publication type (SCIENCE-METRIX, 2018).

Figure 1.a and 1.b: Time evolution of publications on animal fat and biodiesel, and blending percentage of biodiesel to diesel from 2008 to 2019.



Source: Prepared by the authors with data collected from WoS Main Collection (2020)

The beginning of Brazilian research on animal fat in WoS scope dates back to 2008, with the work on evaluating the properties of biodiesel from bovine tallow (Moraes et al., 2008).

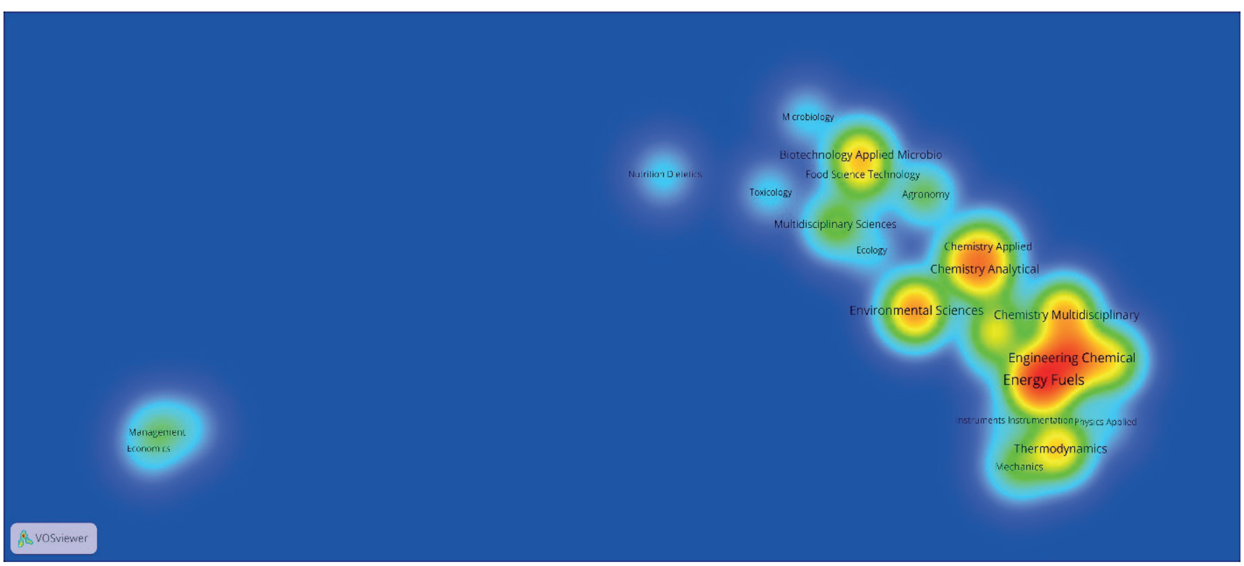
Since then, researchers affiliated with Brazilian organizations have been continuously producing scientific papers on the subject. However, the increase in the number of publications is not directly linked to the increase in blending percentage of biodiesel to diesel in Brazil (Figure 1.b), as shown by a regression (R^2=0.279).

However, it is important to note that two factors positively influenced research growth: the mandatory introduction of biodiesel in the Brazilian energy matrix through the National Plan for Production and Use of Biodiesel, and the creation of the RBTB that financed research that enabled technological mastery, scale production and logistics of different sources of raw materials, such as beef tallow.

The documents were indexed in 19 knowledge areas, mostly Chemistry (38.82%), Energy and Fuels (31.76%), and Engineering (30.59%).

From the analysis of WoS subject categories, it was possible to identify the interaction patterns among these areas (Figure 2).

Figure 2: WoS subject categories where the research corpus was indexed (2008 – 2019)



Source: Prepared by the authors with data collected from WoS Main Collection (2020)

The red areas indicate a scientific proximity between areas (centralities and influence), while green and blue colors show unrelated areas. Energy and fuels, and chemical engineering categories are the most strongly related.

Scientific Cooperation and Institutional Co-Authoring Networks

All 85 documents were written by more than one author, which is common in life sciences and engineering. In total, 397 authors were identified (4.67 authors/article) and the most common co-authorship level were groups of 6 authors. Based on these data, it was possible to calculate the collaboration coefficient (Ajiferuke, Burell, & Tague, 1988), which resulted in 0.83, a high value.

Concerning international cooperation, 7 documents (8.25%) were identified with collaborative links between Brazilian institutions and German, Portuguese, Colombian and American institutions. Although small, Brazilian research with international collaboration was diversified, and included: a study of potential environmental impacts and barriers to environmental sustainability of biodiesel produced from soy and beef tallow; engine performance and power generation tests using tallow biodiesel blends; animal fat biodiesel production without the addition of chemical or biochemical catalysts; aa evaluation of tallow biodiesel by-products, and; activation energy determination for thermal decomposition of crude glycerin and bovine tallow.

In the organizational scope, 83 institutions engaged in research into animal fat and biodiesel were identified. They published at least one paper on this theme, demonstrating a strong interinstitutional interaction and confirming RBTB's commitment in training human resources, and the creation of scientific collaboration networks involved in solving problems at different stages of the biodiesel production chain.

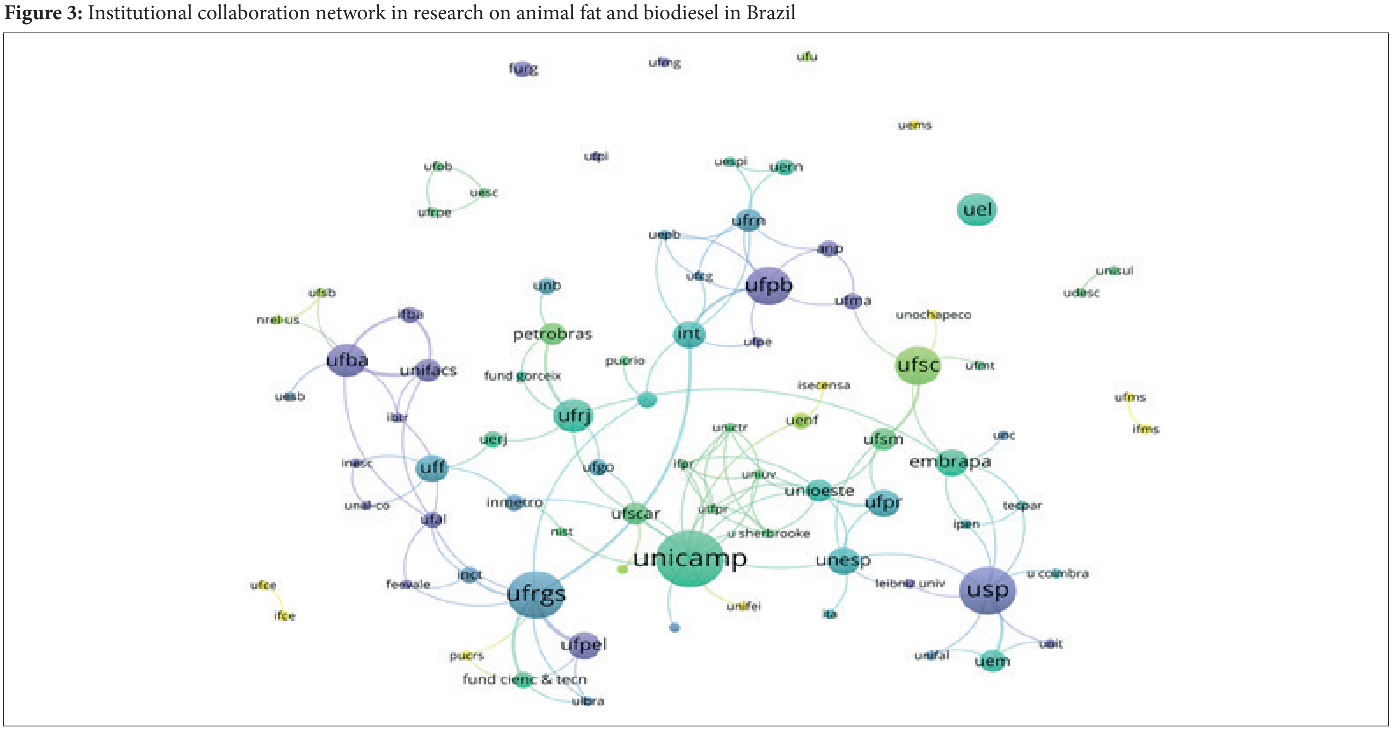
An institutional co-authorship network formed by 83 institutions that established 129 co-authorship bonds, distributed over 11 connected components can be seen in Figure 3. This network was structured based on the average number of publications. For example, publications from the Federal University of Bahia (UFBA) are older than publications from the Federal University of Mato Grosso do Sul (UFMS) on average. Thus, there is an idea of publications' temporality by institution.

The size of the nodes indicates the number of documents published by each institution, and the distance between them provides a proximity indication. On the other hand, the bonds represent co-authorship of articles, and their thickness indicates the relationship strength, that is, the wider, the stronger the relationship.

As for the formation of clusters, *VosViewer* uses its own calculation technique, which seeks to group institutions according to thematic affinity (Waltman, van Eck, & Noyons, 2010). Thus, all institutions formed 20 clusters in total, where the two largest clusters brought together ten institutions, with most institutions from the Northeast of Brazil.

Some of the Northeastern institutions have been pioneers in biodiesel research in Brazil since the mid-1970s. One is the Dendiesel project, led by chemical engineer Hernani Sá of the Executive Committee of the Lavaca Cacaueira Plan (Ceplac), which used palm oil as a fuel. Another is research on the transesterification of oils and fats from agricultural activity and the extractive sector of Professor Expedito Parente of the Federal University of Ceará (UFCE), leading him to claim the first worldwide patent for the biodiesel industrial process (PI 8004358-5).

Figure 3: Institutional collaboration network in research on animal fat and biodiesel in Brazil



Source: Scopus data (2021)

Northeastern institutions also dominated the research scenario in the first quadrennium (2008-2011) with 25 organizations in total, with the Federal University of Paraíba (UFPB) being the most productive organization with 4 articles.

From the second quadrennium (2012-2015) on, there was an increase in the number of institutions in the South-Southeast regions, and the beginning of international collaborations. During this period, 43 institutions were identified, and the University of São Paulo (USP) was the most productive with 6 articles.

Finally, 49 institutions were identified in the third quadrennium (2016-2019), and the Federal University of Santa Catarina (UFSC) and the State University of Campinas (Unicamp) were the most productive with 5 articles each.

From the network's component, the main indexes related to SNA were calculated (Table 2), revealing their topological structure.

Table 2: Main TCN and SNA indexes of the giant component.

Indexes	**Real Network 2008 to 2019**
Number of components	1
Number of actors (institutions)	68
Number of co-authoring links	123
Average grade	3,618
Density	0,054
Average agglomeration coefficient	0,69
Diameter	12
Average minimum path	5,227

Source: Prepared by the authors.

Using the average agglomeration coefficient of Watts and Strogatz (Watts & Strogatz, 1998), it was observed that it was much higher (0.69) than the average agglomeration coefficient of a random network generated for comparison purposes. In addition, the average minimum path of the network (5,227) was also comparable with the average minimum path of that random network. This indicates that the institutional collaboration network in research on animal fat and biodiesel in Brazil is characterized as a small world network, that is, a network of greater articulation.

The high agglomeration coefficient indicates that there is a strong connection between the institutions, which facilitates information exchange and convergence of efforts in RD&I execution among researchers from these institutions. This demonstrates that the RBTB was successful in structuring a scientific-technological base to support and guide the Brazilian biodiesel program, at least regarding the raw material for the studied biodiesel production.

Other characteristics revealed in the network were degree distribution, closeness centrality, and betweenness centrality. The degree distribution shows the importance of the connections established by a network component: the greater the number of connections, the greater the vertex's importance.

The proximity centrality shows how close one vertex is to other network vertices. Therefore, the vertex of greater proximity centrality is the fastest when interacting with others.

On the other hand, the betweenness centrality indicates the information flow in a network. A vertex that has the greatest betweenness centrality acts as a bridge when connecting other vertices, giving it a greater control power, since other vertices depend on it to execute the interaction.

UNICAMP was the institution with the highest degree (13), while UFSC was the institution with the greatest proximity centrality (0.528) and betweenness centrality (0.280).

Table 3 shows the institutions with the highest degree, which established the largest number of collaborations in research on animal fat and biodiesel in Brazil. A considerable number of institutions (29) have a low degree and are connected to a few other institutions.

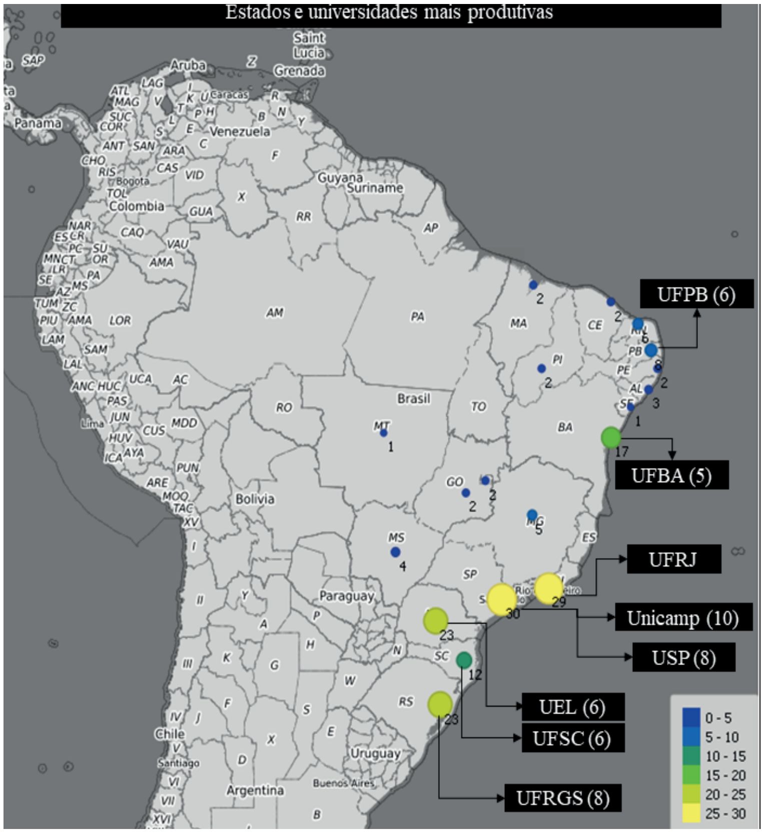
Table 3: Institutions with higher degree centrality.

Vertex (Institution)	**Degree centrality**
UNICAMP	**13**
UFRGS	9
UNIOESTE	9
USP	9
INT	7
UFBA	7
UFPB	7
UFRN	7
UNESP	7
EMBRAPA	6

Source: Prepared by the authors.

In general, the institutions listed in Chart 2 also have a considerable number of the 397 researchers identified. Finally, Figure 4 shows the main states and the most productive organizations and researchers.

Figure 4: Research distribution by federative unit and main organizations and authors.



Autores mais produtivos

1. Souza, Antonio G. (UFBP) = 6 documentos
2. Angilelli, Karina G. (UEL) = 5 documentos
3. Borsato, Dionisio (UEL) = 5 documentos
4. Santos, I. M. G. (UFPB) = 5 documentos
5. Coppo, Rodolfo Lopes (UEL) = 4 documentos
6. Da ros, Patricia C. M. (USP) = 4 documentos
7. De Castro, Heizir F. (USP) = 4 documentos
8. Galvan, Diego (UEL) = 4 documentos
9. Maia, A. S. (UFBP) = 4 documentos
10. Pereira, Roberto Guimaraes (UFF) = 4 documentos
11. Souza, A. L. (UFPB) = 4 documentos
12. Teixeira, Leonardo S. G. (UFBA) = 4 documentos
13. Bento, Fatima M. (UFRGS) = 3 documentos
14. Caramao, Elina B. (UFRGS) = 3 documentos
15. Cavalcanti, Eduardo H. S. (INT) = 3 documentos
16. Feddern, Vivian (Embrapa) = 3 documentos
17. Ferrao, Marco F. (UFRGS) = 3 documentos
18. Guimaraes, Paulo R. B. (Unifacs) = 3 documentos
19. Melegari de Souza, S. N. (Unioeste) = 3 documentos
20. Orives, Juliane R. (UEL) = 3 documentos
21. Pontes, Luiz A. M. (Unifacs) = 3 documentos
22. Ramalho, E. F. S. M. (UFBP) = 3 documentos

Source: Prepared by the authors based on data extracted from WoS (2020).

Finally, mentions of financial support received by the articles' authors were analyzed from the fields FU (Funding Acknowledgement) and FX (Funding Text) of the file's metadata extracted from WoS. This made it possible to establish a relationship among inputs' financing (scholarships, material and others) without the need to obtain direct information from each financier.

The data revealed that 65 documents (70.6%) received some type of funding from 26 identified institutions. Out of this total, 23 are public institutions, 3 private companies and 3 international institutions. This reflects what happens in Brazilian science in general as public institutions have assumed the leading role in the production of science and technology in Brazil (CAPES, 2018).

The most mentioned institutions were the National Council for Scientific and Technological Development - CNPq (46), the Coordination for the Improvement of Higher Education Personnel - CAPES (28), and the Research Support Foundations of several Brazilian states (23), with emphasis for the São Paulo State Research Support Foundation - FAPESP (9) and the Studies and Projects Funder - FINEP (12). All of these institutions are directly or indirectly linked to the ministries of Education or Science, Technology and Innovation. Among their objectives, they offer support in all stages and dimensions of scientific and technological development cycle, whether through scholarships, the purchase of inputs and others.

The support of international institutions came from the Foundation for Science and Technology of Portugal, the European Science Foundation and the National Renewable Energy Laboratory in the USA, all with one mention. The company that most supported research on animal fat for biodiesel was Petrobras with four mentions.

It is important to note that the number of documents financed in this study may be greater, since acknowledgment mentions for funding are processed by WoS if the document is written in English, however, 13 papers from this research corpus were published in Portuguese.

In addition, these mentions are voluntary and depend on the author's desire to publicize the support received. However, this is becoming mandatory in Brazil and CAPES has already established a mandatory standard for acknowledgment in publications that have been financed, in whole or in part by it (44).

6. Final considerations

This article has dealt with the study of research networks for the development of biodiesel from animal fat through Social Analysis Network and Theory of Complex Network. To this end, 85 documents produced by researchers affiliated with Brazilian institutions and published on the Web of Science were analyzed.

Production was uninterrupted in the analyzed period, with an approximate average number of publications of seven documents per year, and an average increase rate of 21.15%, making Brazil a country engaged in research on animal fat for biodiesel production within the WoS scope.

The requirement for a blending percentage of biodiesel to diesel and the setting up of the RBTB contributed significantly to leverage research on second-generation biodiesel in the country.

Scientific cooperation among teaching and research organizations proved to be small internationally, but nationally high. Overall, more than 80 institutions have mobilized to develop research on the use of animal fat in biodiesel, which has helped to overcome scientific and technological bottlenecks in biodiesel production from this input.

From SNA and TCN applications, it was possible to affirm that the institutional research network on animal fat and biodiesel in Brazil can be characterized as small-world. This favors the articulation between the components and facilitates the exchange of information. It demonstrates that the RBTB was successful in structuring a scientific-technological base to support and guide the Brazilian biodiesel program. However, some institutions are no longer working on research on the subject. This apparent drop may be due to several factors, such as successive cuts in science and technology budgets, which has prevented the continuity of research across the country.

However, the methodology applied in this research, which makes use of a consolidated database (WoS), open-source software and a reproducible procedure, can be useful for the analysis of other sectors, both in the energy field (research networks on green hydrogen, wind and solar energy, for example), as well as for different sectors, such as supply chain management and public policy management, among others.

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