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Innovation in Beekeeping: A Literature Review under Brazilian Background

Isabella Mendes da Silva
Civil and Environmental Engineering Department
University of Brasília.
Brasília, Brasil
isabelamendes10@gmail.com

Sanderson César Macêdo Barbalho
Professor, Industrial Engineering Department
University of Brasília
Brasília, Brasil
sandersoncesar@unb.br

Abstract

This article aims to identify the number of publications, authors of the most cited documents, and journals that published the most regarding innovation studies in beekeeping. Therefore, the study used 57 articles retrieved from the Scopus database by searching for the terms “beekeeping” and “innovation”. The results showed several research fields, mainly in tropical countries, highlighting articles from Spain, Mexico, and Brazil. Technological discussion is not the main research issue, but social, organizational, economic, and environmental issues. Innovation is the main discussion but is spread through various nuances, and technologies have not gained momentum. Thus, the research provided a solid basis for future studies and highlighted the importance of international collaboration in research related to the topic. However, it is necessary to develop more in-depth and empirical studies for a broader and more precise understanding of the complex synergies in applying innovation in agriculture and beekeeping as an economical and ecological-friendly activity.

Keywords
Bibliometric analysis, innovation, beekeeping, technology.

1. Introduction

Innovation is one of the most important factors for any organization's long-term success or a country's economic development. Based on the findings of MOORE, J. F. (1993), the systemic view of innovation gained prominence, and with this, new terms emerged: business ecosystem, innovation ecosystem, and entrepreneurship ecosystem. This presupposes the need to build or strengthen a network (ecosystem) for disseminating knowledge that emerges as innovation.

Innovation is also a central issue in the rural environment and necessary to promote sustainable rural development. The exchange of knowledge and practices based on interactions in networks of farmers, communities, rural assistance, and other social institutions strengthens cooperation and favors the environment for innovation.

For a broader study base, it is necessary to prioritize specific approaches, research, or methods to delve deeper into issues important to a research group. Thus, a bibliometric analysis was carried out using overview research relating to innovation and beekeeping to qualify a set of ongoing research focusing on boosting innovation in beekeeping in the

Federal District and surrounding areas. Parallel to a more classic literature analysis, it was the first step to propose innovative new products for beekeepers in the region.

Bibliometric analysis is one of the research techniques that focuses on measuring, in a quantitative way, the scientific publications of an author, Higher Education Institution (HEI), or field of research in academic journals with arbitrated selection (SOUSA; RIBEIRO, 2013). In this sense, this work aimed to carry out a bibliometric analysis of innovation and beekeeping to observe better and understand the field of research related to the topic and analyze its importance for ongoing research.

In the next section, we discuss the theoretical basis for the study. Next, we present the methods used and follow the results of our systematic literature analysis. Some discussions and conclusions are presented in the end.

2. Theoretical basis

2.1 Beekeeping

Beekeeping is an ancient economic practice of raising bees (Apis mellifera: Hymenoptera: Apidae: Apini). Honey is the best-known product of the activity, but wax, propolis extract, pollen, royal jelly, and derivatives are also produced and sold; all these products contemplate the principles of sustainable development, which encompasses the economic, social, and ecological (de Oliveira Silva, 2023). Brazilian honey production is currently in 11th place globally, with approximately 51 thousand tons. Still, given the existing floristic diversity, the country has the potential for growth to 150 thousand tons of top-quality honey per year, accepted by the most demanding international markets (Nichele, 2018).

The beekeeping market in Brazil is mainly made up of small beekeepers, and half of them produce around 17% of all national honey. As beekeeping requires greater care, many beekeepers have found this activity an alternative source of income. However, to be successful, it is necessary to have the following understanding: beekeeping productivity is based on the quality of local floristics, directly influenced by the duration and periodicity of flowering, the technological level adopted, and the management conditions adopted by beekeepers (Trevisol et al., 2022).

Brazil is a country that offers beekeeping favorable conditions for its growth and development, given its extensive territory and vegetational and climatic diversity, and also has the characteristics needed to produce and offer the best products to the market (Barbosa & Cardoso, 2020). Based on this principle, a simple type of zootechnical activity does not require sophistication or much initial financial investment compared to others. Bee farming can occur in any natural space as long as the location has beekeeping pasture, natural water, and a favorable climate; its productivity is highly correlated to adequate management, climatic conditions, safety criteria, the beekeeping flora existing in the region, and the employability of new techniques and marketing efficiency (Souza et al., 2014).

Cerqueira & Figueiredo (2017) highlight that 84.6% of beekeepers entered the activity at the encouragement of family members; they acquire experience in their youth and seek new knowledge in the field so that they can maintain the activity as a supplement to their income or as a full-time profession, in this case. , there is a greater dedication of time depending on the number of hives and their management.

2.2 Technology and Beekeeping production

The management of beekeeping production cannot be considered well-structured in Brazil, with long, medium, short, and very short-term production plans, as advocated by advanced practices in the area (Pinto, 2016; Lima, 2013). The work generally shows a very informal management profile, almost configuring an extractive activity, according to Pinto (2016).

On the other hand, Underwood et al. (2023) point to bee management practices to avoid losses in beekeeping, especially colony losses and bee deaths. Agrebi et al. (2021) present good managing practices in Belgium, Underwood et al. (2019) in the United States, and Claing et al. (2021) in southwestern Quebec. Gebreyohans and Gebremariam (2017) present the practices most Ethiopian beekeepers use and their relationship with honey productivity and colony loss. Sperandio et al. (2019) characterize the main European “Beekeeping Practices” as chemical control, replacement of supers with each litter, replacement of honeycombs produced by alternative feed sources, complementary feeding, and change in the number of worker bees. According to the author, the category and experience of the beekeeper are the main drivers for honey productivity. The study especially related these practices to the eventual development of

models for honeybee health indices and models of their population dynamics. In their report, Underwood et al. (2023) further demonstrate that organic management of apiaries results in greater colony health and productivity. The study is conducted with beekeepers from Pennsylvania and West Virginia, defines organic beekeeping as based on intervention only when necessary, and excludes applying synthetic chemicals or antibiotics to colonies. This management system is common among small and medium-sized beekeepers. It is based on an integrated pest management approach that combines cultural practices with approved organic chemicals (e.g., formic acid, oxalic acid, thymol) for pest control. Researchers are interested in ecosystems for organic food production, where honeybees play a crucial role (FERRARI et al., 2023).

Mining international studies in the area of beekeeping using technologies from the so-called industry 4.0, we see in Gavina et al. (2014) a mathematical model to optimize the location of apiaries based on (i) beekeeper preference in a fuzzy model; (ii) number of available colonies; (iii) strength of colonies with a certain degree of uncertainty; (iv) probabilistic foraging capacity of certain plant clusters; and (v) spatial orientation of the apiary.

Precision beekeeping systems and services, technologies from the so-called Industry 4.0 applied to beekeeping, have recently emerged in international literature. In Hadjur et al. (2022), for example, it is suggested to monitor temperature, humidity, and colony weight conditions, as well as CO2 and rainfall levels in the region to predict beekeeping productivity.

The European Horizon 2020 program promotes the development of the Smart Apiculture Management Service, presented by Wakjira et al. (2021), where applications in Ethiopia and Indonesia are presented. The system is based on three pillars: (i) the development of modern and modular hives adapted to the local context, equipped with a remote measurement system for bee behavior, productivity, and health; (ii) the development of a cloud-based Decision Support System (DSS) to implement a management application for beekeepers; and (iii) development of adapted bee management guidelines on seasonal changes, available forage plants and an ICT data-based model for bee management. Finally, the technology is open, based on an MIT standard license, available on GitHub (https://github.com/sams-project).

Catania and Vellone (2019) present an Arduino-based precision beekeeping system tested on French honeysuckle blooms in Italy. Through temperature and humidity monitoring, the system could correlate temperature and humidity conditions with the start and stop moments in honey production and swarming conditions. The authors suggest sensing rainfall, wind speed, and noise as additional ways to support beekeeping management.

Liu et al. (2021) developed an information system for the beekeeping production chain. The system monitors the production area's atmosphere, water quality, light, temperature, and humidity. The system also allows 24-hour monitoring, historical playback and remote control, and real-time monitoring of apiary safety and hive status. The authors suggest that not needing to open the hive to carry out monitoring implies greater productivity, as it does not generate disturbances in the daily lives of the colonies. The project envisages the use of automated boxes that not only monitor the colonies but also feed the bees when necessary and automatic cooling. Ultimately, the system allows integrated management of the entire bee product chain, generating traceability information valued at points of sale.

Despite recent developments in the international context, the work found is still frugal, and analyzing the literature that relates beekeeping to the use of RGB, multispectral or thermal image processing, no methodologies, tools, methods, or production planning systems were found, or management of beekeeping operations. Despite IoT, cloud technology, and data analytics suggestions, there are no reports regarding this broad utilization, only technical proposals. We also don´t find works using augmented reality or artificial intelligence to help beekeepers increase their productivity and provide comfort to beehives.

3. Methodology

The reported research Project started with close cooperation among the University of Brasília and the Brazilian Ministry for Regional Development. The main background contributed to boosting organic production in general, and organic honey was identified as a potential development area and higher incomes for small farm holders in the region of Goiás and the Federal District.

Some proposals for new technologies were suggested for a stricter partnership with these actors involving new kinds of automatically monitored beehives and artificial intelligence for organic honey production planning. These proposals

allowed the researchers to know more about the Brazilian honey business and the environmental issues regarding beekeeping.

The researchers decided to take a step back and apply a more scientific problem-solving method to identify and work on technology development for beekeeping. A more general literature analysis was started, focusing on the international state-of-the-art in beekeeping, and research for Brazilian-based literature began. A third step was a more general systematic literature analysis reported here.

For the bibliometric analysis, a search was carried out associating keywords related to the topic using the Scopus tool in January 2024. Therefore, the following combination was "TITLE-ABS-KEY (beekeeping AND innovation)". Thus, it was possible to obtain a set of different articles/books that used the combined words, presenting their interconnections based on the assigned relevance parameters, such as the area of activity for which the document was intended, themes, etc.

A network was created using the VosViewer tool, in which, in addition to associating pre-defined parameters, it is possible to observe groupings defined in different colors, separated by their characteristics and interaction levels (FARIAS and BARBALHO, 2023).

From the networks created, it was possible to analyze graphs that relate the researched documents based on parameters such as co-citation between authors, bibliography, and co-occurrence of keywords, among other data (FARIAS and BARBALHO, 2023).

4. Results

As a result, from the combination of the terms "beekeeping" and "innovation" as search keywords, which formed the Boolean combination "TITLE-ABS-KEY (beekeeping AND innovation)", 57 documents were obtained.

Of the 57 documents found, the ten most cited articles were selected, corresponding to 17.5% of the sample.

Table 1 presents these documents based on the author, title, and place where it was published.

Table 1. 10 most cited documents in the sample. Source: From the author.

Author	Title	Publication
GIL-LEBRERO, S. et al. (2017)	Honey bee colonies' remote monitoring system	Sensors
WAKJIRA, K. et al. (2021)	Smart apiculture management services for developing countries—the case of the SAMS project in Ethiopia and Indonesia	PeerJ Computer Science
RIVERA-GOMIS, J. et al. (2019)	Good farming practices in apiculture	Revue Scientifique et Technique
FEDORIAK, M. et al. (2021)	Stakeholders' views on sustaining honeybee health and beekeeping: the roles of ecological and social system drivers	Landscape Ecology
KHAN, A. S. et al. (2009)	Desempenho da apicultura no estado do Ceará: Competitividade, nível tecnológico e fatores condicionantes	Revista de Economia e Sociologia Rural
CONTRERAS-ESCARENO, F. et al. (2013)	Present situation and characteristics of beekeepers in the South and Southeastern regions of the State of Jalisco, Mexico |	Revista Mexicana de Ciências Pecuárias

	Características y situación actual de la apicultura en las regiones Sur y Sureste de Jalisco, Mexico	
IZQUIERDO, A. V. et al. (2016)	Typology and characterization of beekeepers in the State of Morelos, Mexico | Tipología y caracterización de apicultores del estado de Morelos, México	Revista Mexicana de Ciências Pecuárias
SARI, F. et al. (2020)	Integration of NDVI imagery and crop coverage registration system for apiary schedule	Journal of Apicultural Science
BORLINGHAUS, P. et al. (2022)	Honey bee counter evaluation – Introducing a novel protocol for measuring daily loss accuracy	Computers and Electronics in Agriculture
MIHAILOVIC, B. et al. (2020)	Farm differentiation strategies and sustainable regional development	Sustainability

It stands out among the most cited articles that there is no predominant scientific communication vehicle, except the Revista Mexicana de Ciências Pecuárias, which had two publications related to beekeeping.

Regarding co-authorship by countries, it was possible to identify 34 countries, which, when using as a parameter, at least three documents per country, ten different countries were found, presented in Table 2. In these 10, there are at least 35 documents related to searched words, and the same document may be associated with searches carried out by more than one country.

Table 2. Documents found by country based on Co-authorship. Source: Scopus, January 2024.

Country	Documents	Citation
Spain	3	74
Mexico	5	31
Brazil	4	21
Ethiopia	3	20
Germany	3	20
Indonesia	3	16
Turkey	3	8
Romania	3	3
Italy	3	2
United States	5	2

Of the 35 documents, ten originated in either Mexico or the United States, which proved to be the countries with the most research in terms of the terms researched. Furthermore, Mexico was the second largest in terms of citations, with 31 citations in the area, while Spain had 74 citations related to the topic.

These countries, therefore, represent the countries with the highest production in terms of the quantity of documents on beekeeping and innovation in the research carried out. It is worth highlighting the presence of tropical countries in the research, particularly Mexico, Brazil, and Indonesia, which ranked 2nd, 3rd, and 6th in citations.

The fact that there is more research and citations in tropical countries is directly related to the importance of beekeeping in the economy and subsistence in tropical regions, where climatic conditions are favorable to produce honey and other beekeeping products. Furthermore, the biodiversity present in these countries can offer unique opportunities for research and development of new techniques and products related to beekeeping. Various plants and flowers can influence the quality and diversity of the honey produced, encouraging studies and research in these

countries and the need to face specific challenges related to climate, diseases, and pests that affect hives in these regions. (LEVEN, L. V. et al., 2006).

Regarding the documents, GIL-LEBRERO, S. et al. (2017), of Spanish origin, similarly to previously identified research already presented, addressed in their research a remote monitoring system to obtain information about the conditions of hives called WBee, which uses wireless sensor networks. WBee is a low-cost and easily scalable system that monitors hives' temperature, relative humidity, and weight in real time. Furthermore, the system allows data to be stored at different levels, ensuring its availability even during communication failures. Researchers and beekeepers can access the data through a cloud server, which makes it possible to monitor the condition of the hives in real time. Finally, the author concludes that this system is a non-intrusive and valuable solution for monitoring hives, contributing to the preservation of bees and the understanding of producers and researchers.

In turn, of Mexican origin, CONTRERAS-ESCARENO, F. et al. (2013) aimed to diagnose the current situation and characteristics of beekeepers in the South and Southeast regions of the State of Jalisco. To this end, a survey was carried out with 183 beekeepers distributed in 5 extracts according to the number of hives owned: 1-25, 25-50, 50-100, 100-500, and >500. The authors concluded that beekeeping is the main economic activity for beekeepers with more than 100 hives in contrast to those with less than 25 hives who dedicate themselves to other economic activities. Furthermore, honey production per hive is greater in beekeepers who have less than 50 hives. As the incorporation of new beekeeping technologies is still nascent in the region, there is an important potential for generating new production models.

Of Brazilian origin, the article published by KHAN, A. S. et al. (2009) aimed to study technological and competitive aspects of beekeeping in Ceará. As a methodology, cross-sectional data was used, and an index based on innovation technologies was created to measure the technological level. The main results showed that beekeepers use 60.13% of the recommended technologies, with harvesting technology being the one that contributed most to developing the technological index. In contrast, management technology had the smallest participation. The authors concluded that the technical level is an important factor in determining competitiveness, and technological innovation is essential for the competitiveness of this sector.

Regarding the keywords within the sample, 357 were found, and based on a parameter of at least two keyword occurrence numbers, it was possible to obtain 44 terms (Figure 1), which formed 6 clusters: blue, red, green, yellow, light green, and purple.

These 44 terms indicate keywords that are directly related to the combination used in the bibliometric analysis, where despite not being in the research, terms such as adaptation and economy were directly linked to the approach to innovation in beekeeping.

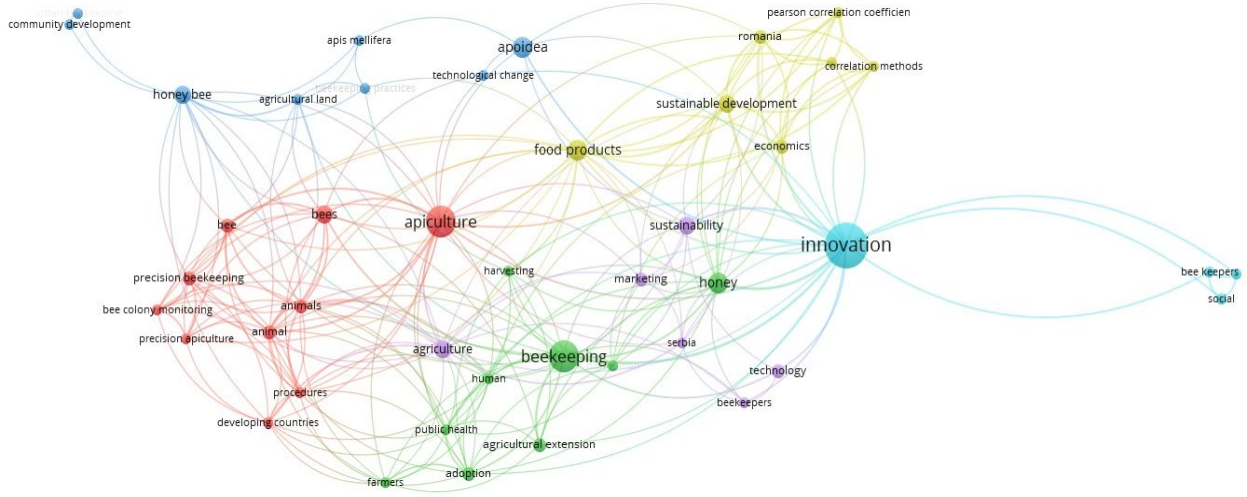

Figure 1. Co-occurrences of keywords.

The red one is the most condensed from the higher to lower keyword clusters. It highlights the word Apiculture and presents precision beekeeping as a procedure for honeybee management, especially in developing countries. The green cluster is dominated by the word Beekeeping and relates to honey as important to public health. It also highlights beekeeping as having adoption barriers for farmers who need support from agriculture extension to be effectively and healthily implemented. The yellow cluster emphasizes the food products based on beekeeping and their correlations to sustainable development and the economy. Purple cluster tied sustainability and agriculture as the main words, suggesting beekeeping effectively balances these issues. It also highlights marketing and technology as the main issues to address. The blue cluster is dominated by the word Honeybee and highlights technological change and community development to agricultural lands. Effectively, working with bees demands a change in the occupational reasoning of land once they impact the neighborhood, and better community organization is necessary in rural areas. Finally, the light blue cluster is dominated by Innovation, that is spite of being the most present keyword with associations with all other clusters, has social and beekeeper as its main influenced words, suggesting the demands for innovative products, services, and organizations for both the beekeeper and the social perception in regards to honeybees.

Regarding the bibliographic coupling of documents, of the 57 documents found, three links were obtained from a minimum of 6 citations per author, as shown in Figure 2. It was possible to observe the formation of 3 Clusters: blue, red, and green.

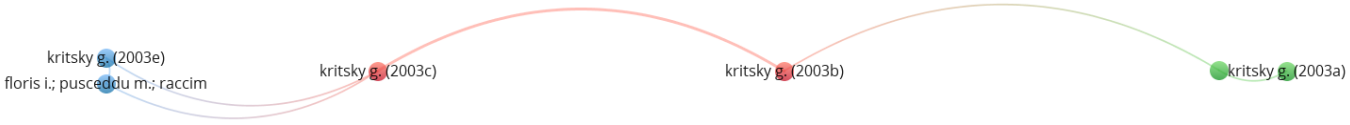

Figure 2. Author bibliographic coupling graph.

FLORIS, I. et al. (2020), of Italian origin, focused on using cork in the thermoregulation of the hive as an innovative attempt to value non-wood products and beekeeping in Mediterranean forests. For this purpose, a comparison was made between experimental hives made with cork as a thermal insulator and conventional hives made entirely with fir wood to evaluate their effects on the thermoregulation of Apis mellifera colonies in Northwestern Sardinia (Italy). As a result, the daily temperature pattern of cork-modified hives was more regular than that of control hives. In addition, bees had more efficient winter thermoregulation in cork-modified hives.

As for co-citations, 3,469 authors were obtained. By inserting eight citations per author as a minimum parameter, 13 results were obtained, shown in Figure 3, in which around 3 Clusters can also be observed.

Present Green Cluster, FEDORIAK M. & ANGELSTAM P. (2021) researched stakeholders' views on maintaining bee health and beekeeping: the role of ecological and social system drivers. As a methodology, the steep gradient in NSE in the Ukrainian region of Chernivtsi was used as a case study with three strata: (i) traditional villages, (ii) intermediate, and (iii) intensive agriculture. The authors concluded that social system factors dominate over ecological factors and interact across scales, with beekeeping seen as a social innovation that improves stakeholders' navigation of social systems, thus supporting rural development in transition countries like Ukraine.

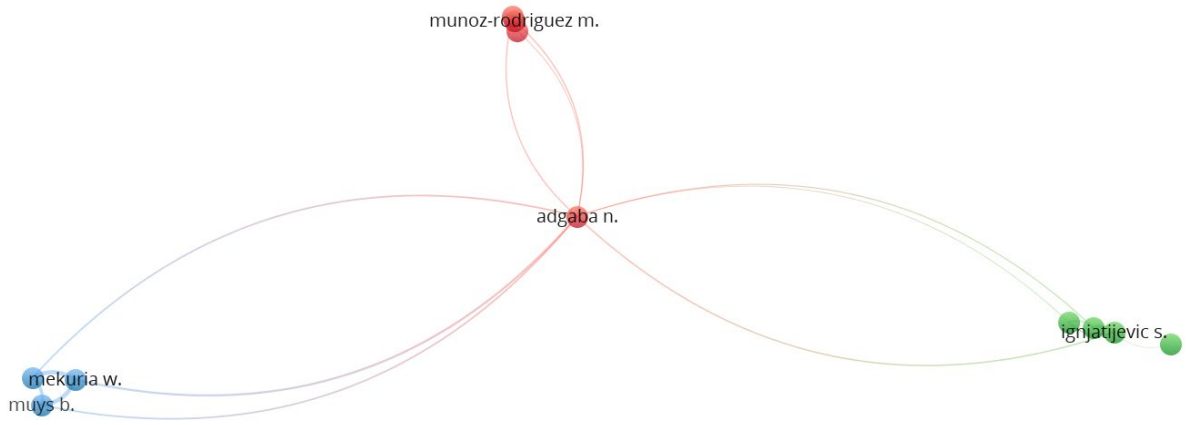

Figure 3. Author Co-citation Chart.

In the same cluster, CALVIN, M. & IGNJATIJEVIC S. (2023) researched the determination of factors that affect business performance in beekeeping production. For this purpose, the direct and indirect influence of the competitive environment (the opportunities of the business environment, threats, and relations with consumers) and innovative performance (in the fields of marketing, product design, product quality, distribution, manufacturing, and time to market) on the commercial performance of Serbian beekeepers were evaluated. The SEM method was used with the SmartPLS tool.

Some authors outside this co-citation and coupling clusters bring complementary insights. Using the terms "sustainability" and "technology" as keywords, GONZÁLEZ, M. A. P. & OCANA, A. B. (2023) addressed the importance of sustainability and innovation in beekeeping, aiming to identify the threats to sustainability faced by the sector through the analysis of its social, environmental, and economic dimensions and revealing the innovation and technological development efforts that are being carried out to neutralize the threats. As a methodology, digital network analysis tools (co-occurrence) based on studies published between 2014 and 2022 were integrated to identify the most relevant themes in scientific production, such as the methodology we used in the present article. Topics related to the loss of hives, bee mortality, diseases, and pests stand out among the main results associated with sustainability. About the technologies developed, terms such as monitoring, nutrition, improvement of sanitary conditions, and digital intermediaries are noticeable. Finally, the authors concluded that beekeeping presents several significant problems and challenges, with the study presenting multiple areas of activity for developing new research.

BORLINGHAUS et al. (2022) presented the term "precision agriculture" as a keyword, as their research was based on evaluating a bee counter, focusing on introducing a new method to measure the precision of daily loss. The authors introduced the advancement of automated bee counters; however, they highlighted that no method has been used for standardized validation of counting accuracy, and, therefore, there is no reliable data on daily bee losses or background mortality in colonies. Thus, combinations of existing approaches were made to form a new protocol that validates the counters, being viable enough to determine the measurement accuracy of a commercial counting system. Thus, the article concluded that by obtaining information on losses, the health of colonies, environmental impacts, and the effect of pesticides on bee colonies can be assessed. Furthermore, the protocol makes innovations in this field measurable and creates a basis for benchmarking different bee counting systems.

The results found from the model confirmed that a competitive environment and innovative performance have a direct and statistically significant positive impact on the commercial performance of Serbian beekeeping production. A weak indirect influence of a competitive environment on beekeepers' business performance was confirmed. Finally, the article concluded with recommendations for other authors on the innovative performance and business performance of Serbian beekeepers; these findings may be of special interest to authors and researchers, beekeeping organizations, and representatives of agricultural consultancy services.

5. Main Discussions and Conclusion

Considering the results obtained in the bibliometric analysis, it is possible to see the relevance of developing new studies and technologies aimed at innovation in the beekeeping sector. The results obtained throughout this study made it possible to identify 57 documents related to the terms under study.

Identifying the countries with the greatest scientific production in this field and analyzing the network of co-citations and authorship between authors and institutions helps to identify trends, gaps in the literature, and possibilities for collaboration in future research. The results made it possible to identify a predominance of publications in countries with a tropical climate, which is suggested to be related to the local climate and the difficulties they may face compared to other countries. In addition, the species' biodiversity in these countries' fauna and flora contribute to more research to take advantage of these factors for greater production in the beekeeping sector.

The results suggest that using bibliometric analysis to identify characteristics, patterns, and existing products is relevant when considering innovation and beekeeping. However, it should be noted that bibliometric analysis is insufficient to answer all questions related to the scientific understanding of a field of study, requiring systematic reviews to map themes, study methodologies, and emerging issues in each field.

Comparing the results of bibliometric analysis with the previous literature, in general, the literature allows us to validate the elements of economic growth, especially for developing countries, as well as the sustainability issues, demands for technology development, and a change perception need for boosting the apiculture practice on rural areas around the world. Technology issues, such as the main high-tech solutions offered for beekeepers, are not highlighted once the scientific discussion encompasses a whole view of the effective adoption of beekeeping in rural areas. Other products beyond honey, such as wax, propolis, or even organic honey or geographically originated honey, are not addressed, and even discussions regarding economic valuation for beekeeping activities are not well reported.

Production planning and control for beekeeping in other countries are not reported in the scientific literature analyzed, which can be understood as a validation for the Brazilian reports that suggested this economic occupation is weakly systematized, almost working on an extractivist basis. The demand for more innovation and technology for beekeeping is highlighted in the literature analyzed. We detected diverse proposals but no reports on the utilization and impact.

Empirical research is needed to gain a broader and deeper understanding of the complex synergies in any innovation-related environment. Therefore, it is important that there is more research on the topic and that they carry out a deeper analysis to improve the understanding of the role of innovation in promoting economic and sustainable development in beekeeping. Furthermore, the findings highlight the importance of international collaboration in research related to the topic once few coupling and co-citation networks exist.

As a limitation of the study, it is important to highlight that the analyses cannot be generalized, as the sample and search were based on one specific database. Additionally, only the most cited authors were analyzed, with prospects for future work with the systematic study of the entire database collected in the research.

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Biographies

Isabella Mendes da Silva is an undergraduate student of Environmental Engineering at the Department of Civil and Environmental Engineering at the University of Brasília, currently working in a private company in the environmental and sanitation infrastructure area, also working at the university, in laboratory projects for innovation ecosystems and agriculture, and, beekeeping 4.0.

Sanderson César Macêdo Barbalho has a degree in Electrical Engineering from the Federal University of Rio Grande do Norte (1993), a master's degree in Mechanical Engineering from the Federal University of Rio Grande do Norte (1997), and a doctorate in Mechanical Engineering from the University of São Paulo (2006), both master's and PhD, developed in the area of Production Engineering. He is a professional in project management with a PMP (Project Management Professional) certificate from the Project Management Institute (PMI). He is an Associate Professor in the Department of Production Engineering at the University of Brasília and Director of the Technological Development Center (CDT) at UnB. He worked between January 2003 and January 2008 as a senior development engineer and project manager and between January 2008 and August 2012 as Project Manager at OPTO ELETRÔNICA SA. He has experience in Electronic Engineering, Manufacturing Processes, Production Management, and Product Development. Professor Barbalho mainly works on the following topics: production management of ETO products, product innovation and development, project management, production planning and control, manufacturing processes, reliability analysis, failures and safety risks of electro-electronic equipment, mechatronics, engineering teaching, reference models and process improvement.