Scientometric Analysis: Technological Development in Coffee Production*

Análisis Cienciométrico: Desarrollo tecnológico en la producción de café.

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Abstract

In recent years, technology applied to coffee cultivation has begun to play a more prominent role in the academic sphere, becoming a subject of growing interest for researchers from various regions. This scientometric review focused on examining 291 studies published between 2004 and 2024, sourced from the Scopus and Web of Science databases, with the aim of understanding how scientific knowledge has evolved regarding the incorporation of technology into coffee farming. One of the most notable findings is the dominance of Brazil, both in terms of publication volume and its impact as reflected in citations. In contrast, Colombia—despite its strong coffee-growing tradition—shows very limited scientific participation. The study also identifies a rise in academic output starting in 2019, which appears to coincide with the adoption of tools such as remote sensing, regenerative agriculture, and various IoT-based solutions. Rather than offering a purely quantitative view, this work brings attention to the need for broader perspectives, interdisciplinary integration, and stronger representation of certain countries in the scientific dialogue surrounding the technological transformation of coffee production

Keywords: Agricultural technification, Coffee production, Scientometrics, Sustainable agriculture, IoT in agriculture, Scientific databases (Scopus, Web of Science), Technological innovation, Bibliometric analysis, Coffee cultivation.

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Resumen

En años recientes, la tecnología aplicada al cultivo del café ha comenzado a tener un papel más destacado en el ámbito académico, transformándose en un asunto de interés creciente para investigadores de diversas regiones. Esta revisión cienciométrica se concentró en examinar 291 estudios publicados entre 2004 y 2024, tomados de las bases Scopus y Web of Science, con la finalidad de entender cómo ha progresado el saber científico respecto a la incorporación de tecnologías en la caficultura. Uno de los descubrimientos más destacados es la preponderancia de Brasil, tanto en términos de cantidad de publicaciones como por el efecto manifestado en las citas. En contraste, Colombia —a pesar de su historia cafetera— presenta una participación científica muy limitada . El estudio también identifica un repunte en la producción académica a partir de 2019, lo cual parece coincidir con la implementación de herramientas como los sensores remotos, la agricultura regenerativa y diversas soluciones basadas en (IoT). Más que ofrecer una mirada meramente cuantitativa, este trabajo pone sobre la mesa la necesidad de ampliar las perspectivas, integrar disciplinas y reforzar la presencia de ciertos países en el debate científico sobre la transformación tecnológica del café.

Palabras claves: Tecnificación agrícola, Producción de café, Cienciometría, Agricultura sostenible, IoT en agricultura, Bases de datos científicas (Scopus, Web of Science), Innovación tecnológica, Análisis bibliométrico, Cultivo de café

1. Introdución

Coffee is one of the most traded commodities globally, ranking just below oil and second only to water as the most consumed beverage. Global coffee production for the 2022/23 period reached 107.07 million bags. In recent years, the technological advancement of coffee cultivation has led to an optimization of production processes, making them more efficient, for instance, in pest control, soil management, and water resource conservation [1]. The introduction of new technologies is transforming how processes can be streamlined, enabling countries to remain competitive in the global coffee market. However, the coffee sector also faced a deficit of 3.16 million bags, despite a recovery in the Brazilian market.

Declines were recorded in Colombia and Vietnam, with decreases of 6.7% and 3.4%, respectively. In Colombia's case, this translates to a loss of 6.07 million bags. Coffee production for the 2023/2024 period is projected to grow by 4.8%, with global consumption expected to reach approximately 172.49 million bags [2]. The drop in Colombian coffee production is mainly attributed to unfavorable climate conditions and, additionally, to a presumed low level of technological advancement in cultivation [3 [3]]. This is largely due to the traditional methods used by most Colombian coffee growers, which are passed down from generation to generation.

Following this line of thought, new technologies have emerged to enhance the sustainability and profitability of coffee production globally. For instance, the implementation of regenerative agriculture, which focuses on restoring, renewing, and improving soil quality, has gained traction. Similarly, the use of renewable energy sources, such as solar panels for electricity generation, is being adopted [4]. Additionally, the Coffee Institute of Costa Rica (ICAFE) has promoted the development of technologies aimed at improving sustainability and the production of high-quality coffee. In this context, remote sensing tools, such as multispectral cameras and LiDAR, stand out as complementary tools to traditional practices [5].

IoT technologies have gained significant traction in the agricultural field, as they allow real-time monitoring of soil conditions, plant health, and pest control [6] . This contributes to greater sustainability and supports a safe transition from traditional farming models to more technologically advanced systems.

The scientometric analysis presented in this article is of vital importance, as it enables us to assess the extent to which research is being conducted globally on improving coffee production. The study is based on searches conducted in the Scopus and Web of Science (WoS) databases. Based on this approach, the article aims to break down information regarding authorship, the number of articles published each year, scientific collaboration, and other scientometric methodologies [7] .

The purpose of this article is to review the literature on the optimization of coffee cultivation, focusing on key aspects such as soil quality, air quality, water sources, pest control, bean size, and the integration of new technologies such as IoT to enhance coffee production [8] .

To achieve this goal, a systematic search was conducted in the Scopus and WoS databases using keywords such as “coffee production,” “IoT agriculture,” and “sustainable coffee farming.” The results were then exported and processed for the analysis of scientific collaboration networks, annual scientific output, international and author-level collaborations, citation counts, and the identification of key terms and high-impact articles. This visualization enables a better understanding of the evolution of knowledge related to the technification and sustainability of coffee cultivation, as well as the identification of leading research streams and emerging trends [9] .

2. Methodology

This article is based on a scientometric review that analyzes the scientific output related to the optimization and technification of coffee cultivation worldwide. For this purpose, the Scopus and Web of Science (WoS) databases were used as information sources, both of which are recognized for their broad and reliable academic coverage [10].

A systematic search was conducted using key terms such as: “Technification,” “Coffee cultivation,” “Coffee,” and “Crop technification.” The search was limited to documents published between 2004 and 2024, including articles, reviews, book chapters, conference papers, and other relevant academic publications. Table I presents the search parameters used in both databases [2].

Table I. Search parameters used in SCOPUS and Web of Science

Parameter	Web of Science	Scopus
Range	2004 -2024	
Date	March 16, 2025	
Document types	Article, Review, Book Chapter, Conference Paper, Book, Early access, proceedings paper, conference review, editorial, book chapter.	
Keywords	"Tecnificación" OR "Cultivos de café" OR "Café" OR "Tecnificación de cultivos"	
Results	239	70
Total (woS + Scopus)	291	

Once the information was collected, an exploratory analysis of the retrieved documents was conducted, taking into account the number of publications per year, the collaboration network among authors and institutions, and the most frequently addressed topics. This review allowed for the identification of the most innovative approaches to the technification of coffee cultivation and provided a general overview of current trends in this field of study.

Figure 1 presents the methodological flowchart applied in the scientometric analysis of technification in coffee production. In the identification phase, a total of 309 records were collected from the WoS and Scopus databases, of which 124 were removed due to duplication, resulting in 291 unique records. Subsequently, during the preprocessing stage, text mining and web scraping techniques were applied, organizing the collected information into an Excel file consisting of 22 sheets. Based on this data, a scientometric analysis was conducted focusing on three key dimensions: scientific production by country, analysis of scientific journals, and analysis of authors. This process enabled the systematic structuring of relevant information to assess the current scientific landscape regarding coffee crop technification [11] .

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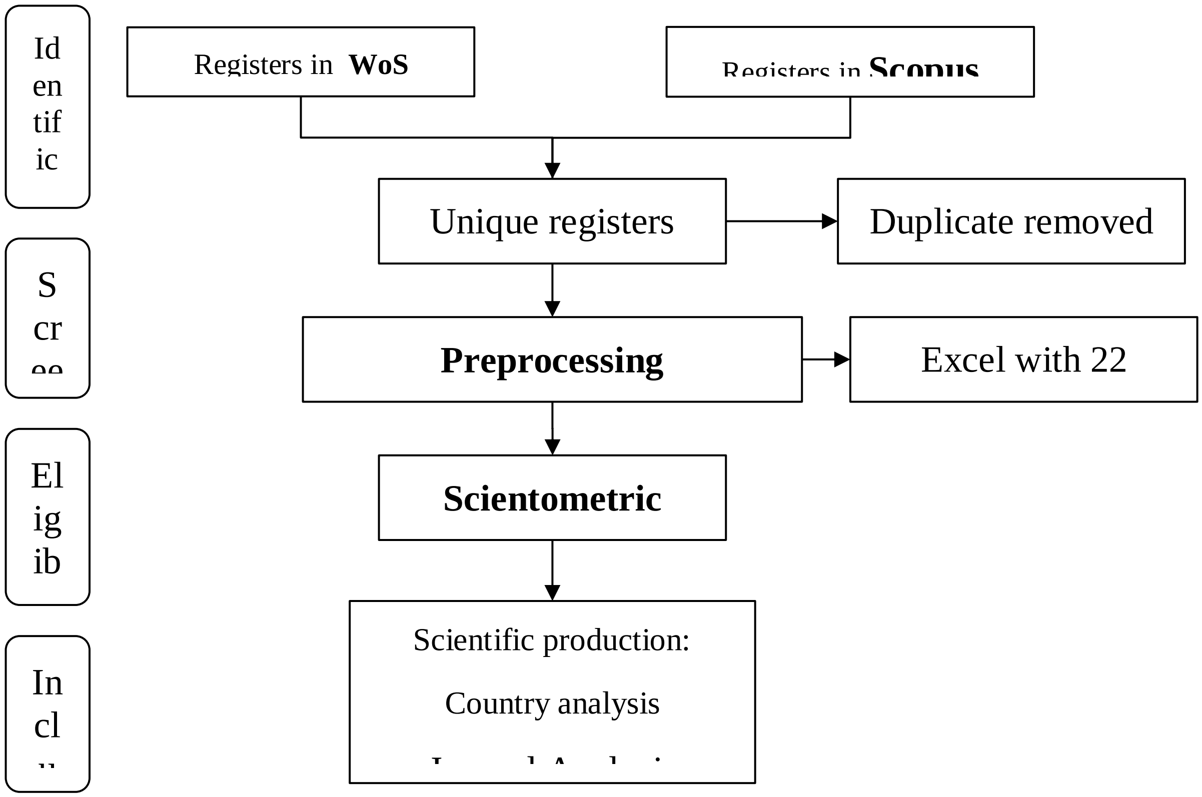

Figure 1. Methodological flowchart of the scientometric analysis

3. Results

The main findings of the scientometric analysis on technification in coffee production are presented below. This analysis made it possible to identify patterns in the evolution of scientific output, countries with the greatest impact, specialized journals, and influential authors in the field. The results are summarized in tables that highlight the distribution of publications by country, the impact of scientific journals, and the productivity of researchers, providing a comprehensive view of academic development in this area. Table II presents the key results of this scientometric review [12].

Table II. Results

Indicator	Key Result
Total documents analyzed	291 documents (WoS + Scopus)
Years analyzed	2004 - 2024
Period with highest growth	2019 - 2024, with a growth rate of 21.67%
Country with most publications	Brazil (214 publications; 54.45%)
Country with most citations	Brazil (3895), followed by USA (1557)
Highest number of citations in one year	2023 (1226 citations)
Journal with most publications	Sustainability (10 articles, Q1)
Journal with highest H-Index	Remote Sensing (H-Index 371, SJR 3.972, Q1)
Most productive author	Ferraz G (16 articles, 129 citations)
Most cited author	Damatta F (402 citations, H-Index 8)
Key scientific communities	3 communities: Production/Agricultural Technology, Socioeconomic, Biotechnology
Prominent collaboration network	Brazil, Belgium, France, and Germany with highest connectivity
Presence of Colombia	14 publications (3.56%) and low citation count (83), notable in biotechnology and natural compounds

Scientometric Analysis

Scientific production

The analysis of annual scientific production allows us to examine the progress made over time by the research community regarding the development of technification in coffee cultivation. It also helps highlight the impact and relevance of new technologies, providing key information to guide public policy, investments in science and technology, and the allocation of resources. Figure 1 shows the number of articles published over a 20-year period, revealing that WoS has maintained a higher level of scientific output compared to Scopus. However, Scopus has shown a slight increase in the number of articles starting in 2022. The total publication rate from 2003 to 2024 stands at 22.60% [13] .

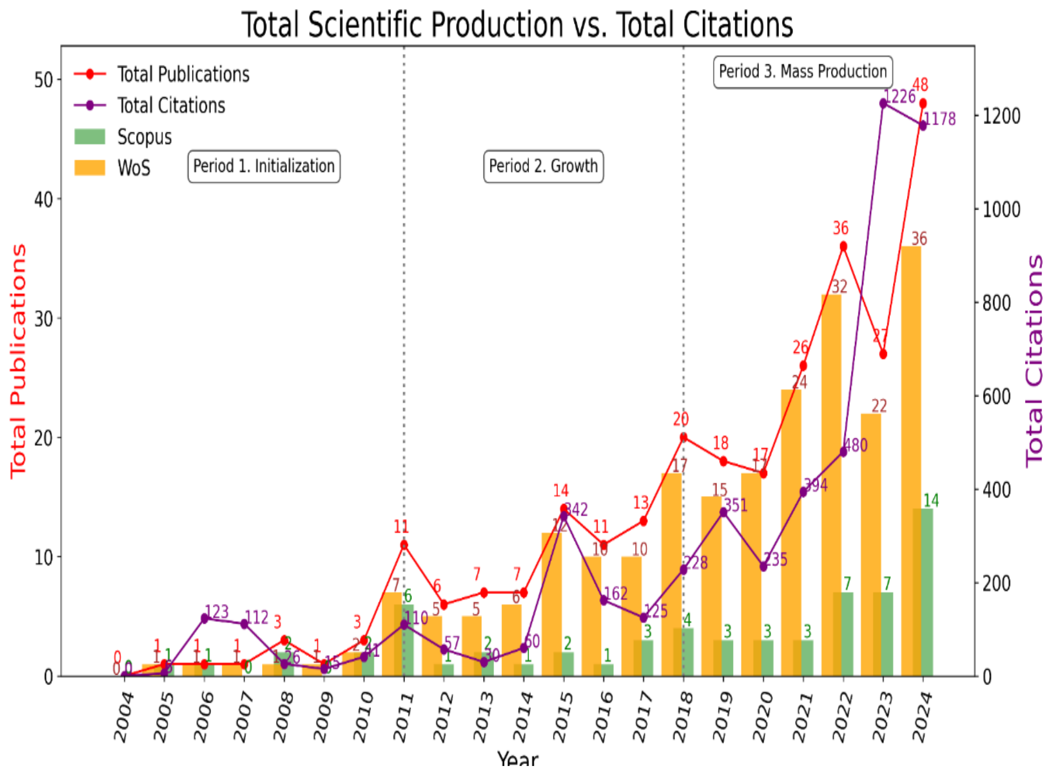

Figure 2. Scientific Annual Production

Period 1. Initialization (2004–2011):

During this time period, scientific production reached a rate of 24.27%. The number of publications in WoS and Scopus was very similar. From 2005 to 2006, each database reported one publication per year. In 2007, Scopus did not report any articles, and it was only in 2008 that Scopus surpassed WoS with a ratio of 2 to 1. In 2009, Scopus again showed no scientific output [14] .

Period 2. Growth (2012–2018):

Scientific production during this time interval accounted for 8.92%. Here, we can observe a slight increase in the relevance of scientific publications related to the technification of coffee cultivation. WoS continued to produce significantly more publications than Scopus; however, Scopus began to generate slightly more articles than during the initialization period, with 2018 being the year with the highest number of publications for Scopus. For WoS, the year with the most publications was also 2018, with 17 articles. Additionally, the number of citations increased notably, with 110, 342, and 228 citations recorded in 2011, 2015, and 2018, respectively—making 2015 the year with the highest citation count [15] .

Period 3. Mass Production (2019–2024):

The publication rate during this period was 21.67%. The number of publications in WoS continued to show an upward trend, with 2024 being the peak year, accounting for 36 published articles. Similarly, Scopus also demonstrated an increasing trend, with its highest number of publications also occurring in 2024. However, Scopus still lags behind WoS in terms of overall article output. Additionally, citation counts increased during this period, with 2023 registering the highest number of citations—totaling 1,226 [4].

Country Analysis

The technification of coffee represents a key process in the modernization of the production chain, spanning from cultivation to commercialization. This process involves the incorporation of agricultural technologies, processing systems, quality control, traceability, and environmental sustainability. For example, [16] demonstrated that drones are useful for monitoring crops. Similarly, [17] showed the potential of *Crotalaria juncea* L. to remediate soils contaminated by herbicide use, promoting healthier soil conditions. In recent years, the scientific community has identified countries leading in this field, producing research that addresses technical, economic, and socio-environmental projects—such as X-ray fluorescence spectrometry, which allows for rapid detection of micronutrients like manganese in plants, optimizing fertilization processes [18].

In terms of mechanization, [19] demonstrated that mechanized harvesting in circular coffee systems is more efficient and causes less damage to the plants. Lastly, salinity remains a challenge, but there are suitable ways to manage its negative effects on crops. [20] presents initiatives that represent progress toward a more sustainable and technologically integrated agriculture in the region.The following table presents the main countries that have contributed to scientific research on the technification of coffee, including data on the number of publications, citations, percentages, and quartile distribution.

Table III: Contribution by countries to coffee technification research: production, citations, and quartile distribution.

Country	Publications	% Publications	Citations	% Citations	Q1	Q2	Q3	Q4
Brasil	214	54.45%	3895	21.39%	97	60	9	1
USA	31	7.89%	1557	8.55%	17	1	1	1
México	15	3.82%	714	3.92%	5	0	0	0
Colombia	14	3.56%	83	0.46%	4	5	0	0
Italia	11	2.80%	717	3.94%	4	0	0	0
India	8	2.04%	47	0.26%	2	0	0	0
Portugal	8	2.04%	894	4.91%	7	0	0	0
España	8	2.04%	857	4.71%	4	0	0	0
Reino Unido	7	1.78%	831	4.56%	2	2	0	0
Francia	6	1.53%	126	0.69%	1	2	0	0

Brazil is by far the leader in research on coffee technification, accounting for 54.4% of publications and also holding the highest number of citations—reflecting both the volume and high academic impact of its research. Regarding soil, [21] demonstrated how intensive management negatively affects soil physical quality in tropical regions, while [22] highlighted the importance of soil quality indicators in Brazilian coffee systems.

The United States ranks second, with fewer publications but also showing a high academic impact, reflecting a quality-over-quantity approach. In the field of genetics, [23] identified useful QTL loci to improve disease resistance and productivity in crops—an important contribution for breeding programs in developing countries. Meanwhile, [24] emphasized the relevance of organic matter in the formation of soil aggregates, reinforcing its role in fertility and structure.

Mexico and Colombia, as major coffee producers, hold a relevant presence, although Colombia shows a low academic impact with fewer citations. Portugal and Spain have fewer publications but achieve notable recognition due to their contributions being published in high-quartile journals. In Mexico, key aspects of soil management and genetic improvement in agricultural contexts have been addressed. For example, [24] characterized the physical and chemical quality of coffee with designation of origin, finding that altitude influences antioxidant compounds—highlighting the value of local conditions.

Lastly, Italy, India, the UK, and France contribute moderately, standing out more in terms of quality than quantity. In conclusion, Brazil's leadership is evident, while other countries show potential to strengthen their visibility and scientific impact in this field.

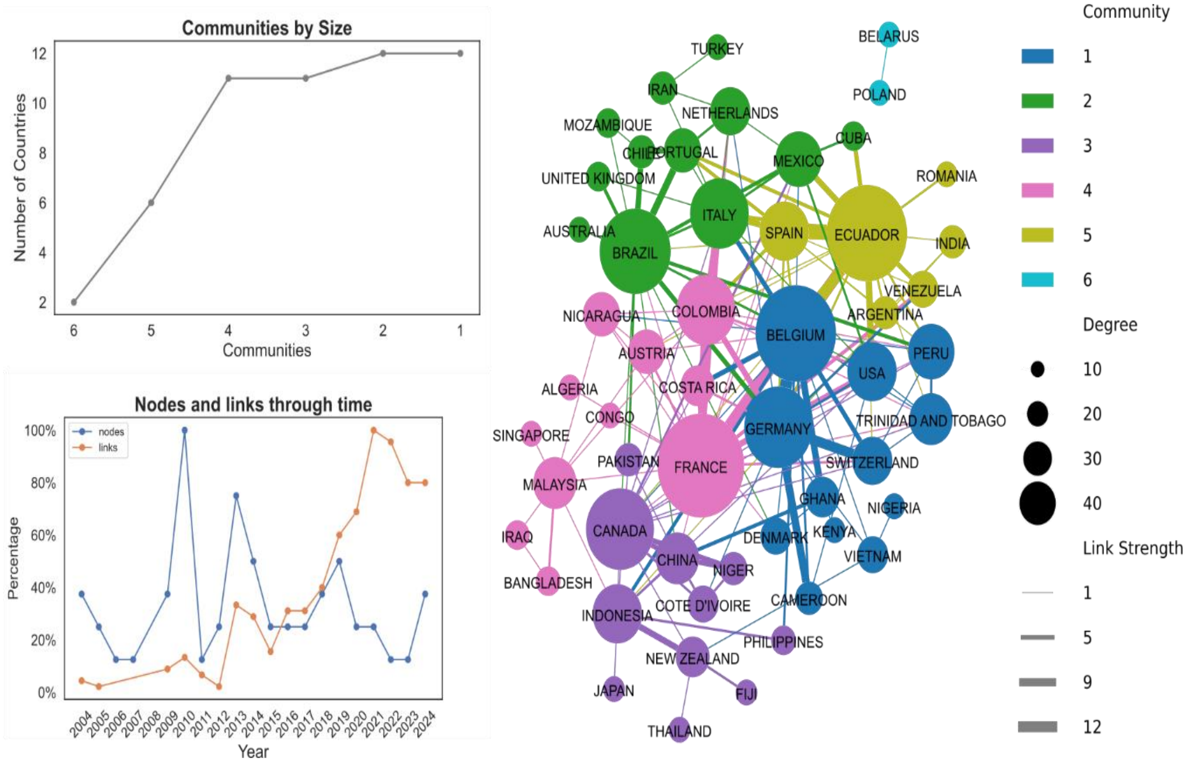

Figure 3: Global network of coffee technification by communities and connectivity.

The figure highlights the collaboration network, identifying six communities, with the largest grouping more than ten countries, reflecting active and broad participation in technification processes. The network shows larger nodes such as Brazil, Belgium, France, and Germany, which stand out for their high connectivity, indicating their important role in the dissemination of technology and knowledge about coffee. Although Colombia has limited visibility in the network, it plays a strategic role by integrating into networks with countries such as Spain, France, and Portugal.

Its participation reflects key research on natural compounds with agricultural applications, strengthening its position in coffee technification through international cooperation and developing innovative research in biotechnology and natural compounds.

Journal Analysis

The present analysis aims to compare and evaluate the list of scientific journals related to agriculture, environment, and similar fields (Table IV). The table shows a considerable proportion of journals classified in the highest quartile (Q1), indicating their high quality and scientific impact. Regarding the number of registered publications, the journal *Sustainability* stands out with 10 records in WoS, followed by *Agronomy-Basel* and *Engenharia Agrícola*, suggesting significant scientific output within the coffee research field . Additionally, the journal with the highest H-Index is *Remote Sensing*, meaning that 371 of its articles have been cited, demonstrating strong academic influence. Furthermore, the SJR, which assesses the quality of citations and the reputation of journals, highlights *Remote Sensing* with a high index, positioning it as the most influential journal in the table. Other well-performing journals include *Agriculture, Ecosystems & Environment* and *Environmental and Experimental Botany* Overall, the table allows for the identification of relevant journals with high scientometric impact, serving as key tools for researchers seeking works with high visibility and international recognition.

Table IV: Leading scientific journals by impact and academic productivity.

JOURNAL	SN	WOS	SCOPUS	TOTAL	SJR	H-INDEX	QUARTILE
Sustainability	20711050	10	0	10	688	207	Q1
Agronomy-Basel	2073.4395	9	0	9	688	91	Q2
Engenharia Agrícola	14154366, 18071929	9	0	9	403	44	Q2
Revista Brasileira De Ciência Do Solo	1000683	7	0	7	486	62	Q2
Industrial Crops And Products	9266690	6	0	6	974	186	Q1
Remote Sensing	344257	6	0	6	3.972	371	Q1
Plants-Basel		6	0	5			
Bioscience Journal	13474421, 13891723	3	1	4	630	131	Q2
Environmental And Experimental Botany	988472	4	0	4	1.147	175	Q1
Agriculture Ecosystems & Environment	1678809	4	0	4	1.946	224	Q1

Figure 3 presents a co-citation analysis of scientific journals related to the technification of coffee. The first cluster, composed of journals such as *Genome*, *Annals of Botany*, *Plant Cell Reports*, and *Molecular Ecology*, focuses on genetics and adaptation to environmental conditions. In this regard, recent studies such as [25], which examines gene expression in coffee under different cultivation conditions, and [26], which explores the effect of elevated CO_2 on coffee physiology, represent key research contributions.

Figure 4: Community analysis network of scientific journals on coffee technification.

The second cluster centers on journals such as *Frontiers in Sustainable Food Systems*, *Food Chemistry*, and *Biomolecules*, focusing on product quality, sustainability, and nutrition. Within this axis are studies such as [27], which analyzes bioactive compounds in coffee based on processing and origin, as well as [28], on volatile compounds affecting pest attraction, which also impacts coffee quality.

The third cluster, led by the *International Journal of Molecular Sciences*, followed by *BioEssays*, *Biotechnology Advances*, and *BMC Biotechnology*, focuses on broader research in molecular biology and general biotechnology. Notable studies include [29], which examines disease management in coffee plants through different agronomic practices—demonstrating how molecular tools and integrated management are applied to cultivation. Finally, research such as [30] on the climatic impact on the distribution of *Coffea canephora*, and studies on the socioeconomic use of coffee waste such as [31], reinforce the interdisciplinary nature of the field.

In summary, this analysis highlights that the technification of coffee is an increasingly broad and interdisciplinary field, with stronger connections among areas such as biotechnology, food sustainability, and product quality—reinforcing the importance of integrating applied science in improving the coffee production chain.

Author Analysis

Author analysis makes it possible to identify the most influential researchers within the study area. In this case, ten authors were evaluated based on their publications, citations, H-Index, Effective Size, Constraint, and CDI, as shown in Table 4. The scientometric analysis of the most relevant authors in coffee technification shows that Ferraz G. is the most productive, with the highest number of publications listed. Following closely, with the same number of publications, are Pereira L. and Santana L.

However, Damatta F. stands out with the highest number of citations and the highest H-Index, indicating the high quality and recognition of his research in the field. For example, [32] evaluated different sources (MOP KCl, K_2SO_4) and doses of potassium in Arabica coffee in Brazil. The study demonstrated that all sources improved yield and nutrition. In terms of collaboration networks, authors Pereira L. and Silva M. have the highest Effective Size values, reflecting a more diverse research collaboration. These results help identify key references and potential strategic partners for future research in the field.

Table V: Main authors in coffee technification, according to their productivity, impact, and collaboration.

Author	Papers Total	Total Citations	H-Index	Effective Size	Constraint	CDI
FERRAZ G	16	129	6	81.50	0.04	0.09
PEREIRA L	10	101	6	229.19	0.02	0.04
SANTANA L	10	78	5	21.18	0.12	0.08
BENTO N	9	38	4	11.78	0.17	0.08
BARATA R	8	66	5	11.52	0.17	0.08
DAMATTA F	8	402	8	142.87	0.03	0.07
POZZA E	8	89	5	103.98	0.03	0.11
SILVA M	8	19	3	212.81	0.02	0.08
SILVA C	7	207	4	142.64	0.02	0.16
CONTI L	6	61	4	30.86	0.10	0.08

Figure 5 represents an analysis of a diverse collaborative structure, with authors organized into communities specialized in different dimensions of coffee technification—whether in fields such as agronomy, processing, technological innovation, sustainability, and more. For example, [33] highlights that the coffee berry borer is the main pest damaging coffee crops. This study underscores advances in integrated pest management methods, emphasizing sustainable certifications to enhance the effectiveness and sustainability of pest control.

Other notable studies include the use of TCS3200 sensors to quantify color in coffee grading systems [34], and research on rehabilitating degraded soils through the use of organic residues to improve soil aggregation and the distribution of C and N, which supports the recovery of soil quality for coffee cultivation [35].

Ferraz G. appears as one of the most central authors in the network, positioning himself as an influential figure with high productivity across communities. He has addressed key topics on crop protection and biological control. For instance, [36] reports a study conducted on farms in Brazil, which revealed that *Coffea arabica* acts as a significant reservoir for fruit flies, showing much higher infestation levels than *C. canephora*, highlighting the need to include coffee in integrated pest management strategies in agricultural systems.

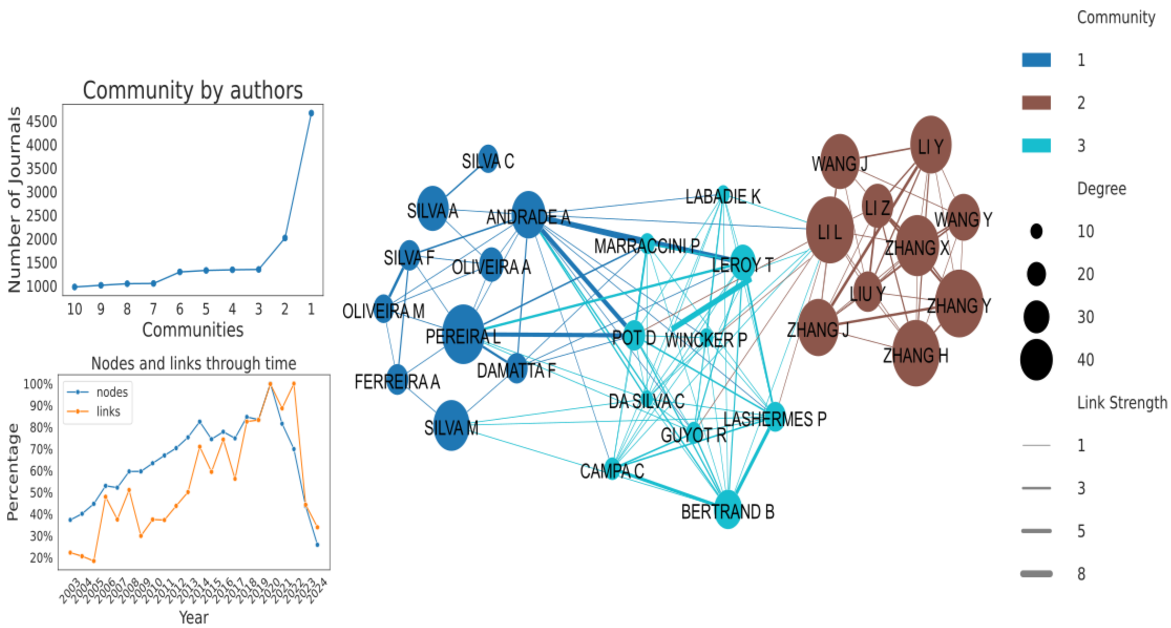

Figure 5: Scientific collaboration structure in coffee technification.

The three main communities identified in the network present different research approaches to coffee technification. **Community 1**, the largest, includes the majority of authors and covers core topics such as production, processing, and agricultural technology. This focus is exemplified in studies such as the one on coffee production in infertile soils through the combination of irrigation practices and fertilizers [37].

Community 2, although smaller, is well connected and relates to the socioeconomic aspects of coffee. For example, [38] analyzes the management of agricultural waste mixed with mineral soils. The study found that including soil during pyrolysis improves biochar yield, carbon retention, and specific surface area, making it more effective for agricultural applications and sustainability.

On the other hand, **Community 3** displays a dense and specialized network, emphasizing technological innovation and sustainability. This is evident in studies on precision agriculture and automation, including genotypic analysis of *Coffea canephora* to identify genotypes with genetic divergence and relevant sensory potential for improving product quality [39]. It also includes research on accessible new technologies such as multispectral cameras, which allow rapid detection of fruit ripeness—directly impacting cup quality and harvest efficiency [40]. The temporal analysis shows sustained growth in the number of authors and collaborations since 2000, with a peak observed between 2019 and 2021, indicating a consolidation of scientific interest in this field. The network reveals both specialization and interconnection among communities, highlighting key authors who act as bridges between research groups. This type of analysis is fundamental to understanding the evolution of scientific knowledge and identifying strategic actors in the academic production on coffee technification.

Conclusions

This scientometric review focused on identifying scientific production, analyzing countries, journals, and scientific collaboration among authors regarding technification in coffee production. Two queries were conducted, one in WoS and one in Scopus, which were merged using sophisticated data mining and web scraping algorithms. The final result was 291 documents used for this analysis. The results showed that this knowledge area is experiencing significant evolution.

Coffee technification showed interest over 20 years with a growth rate of 22.60%, identifying three important periods: initialization, increment, and mass production. Additionally, especially in recent years since 2019, the production of academic studies has experienced a remarkable increase, reaching its peak in 2024. This evidences how emerging technologies are gaining relevance in the coffee sector, as this increase in research does not seem to be a mere coincidence. A direct relationship was observed with the introduction of innovations such as regenerative agriculture, the use of clean energies, remote sensing, and real-time monitoring devices. These tools optimize fieldwork and are additionally changing how we understand and manage crops. Therefore, traditional practices, although valuable, are being left behind as they no longer suffice to meet current challenges.

One of the most notable aspects of the study was observing that Brazil leads in this area. It not only tops the list in terms of publications—representing 54.45% of the total—but is also the country with the most citations, demonstrating the weight and impact of its academic production. Following are the United States and Mexico, while Colombia, despite being a major coffee producer, accounts for only 3.56% of publications. Additionally, it has a very limited scientific impact, which is a call to attention since Colombia has a strong coffee tradition and clearly needs to enhance its involvement in the scientific and technological progress of the industry. Technology should not be seen as a threat to traditional knowledge but as a resource that can help preserve that heritage while simultaneously making it more robust, effective, and sustainable over time.

Regarding the journal analysis, SUSTAINABILITY is the journal with the highest number of publications (10 articles), ranked in the first quartile (Q1), and the researcher with the highest production is Dr. Ferraz, with 16 publications and an impact of 129 citations. In this sense, coffee technification is a novel area where an academic community is gradually consolidating.

Conducting scientometric reviews faces important challenges when consolidating databases such as Scopus and WoS, which have different data formats. Although this review overcomes this limitation, it is important to highlight the need to improve the algorithms that perform this process by enriching the data with more sources such as Open Alex. Although this is a scientometric study that objectively takes data and builds conclusions from the results, it is necessary to conduct qualitative research to deepen the findings. It is recommended that future research replicate the search with a qualitative and thematic approach to identify theoretical trends around the topic.

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