

MICROBIAL FERMENTATION IN COFFEE PROCESSING: A COMPREHENSIVE BIBLIOMETRIC ANALYSIS REVEALING GLOBAL TRENDS, RESEARCH FRONTIERS, AND TECHNOLOGICAL DIRECTIONS (2020–2026)

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ABSTRACT

Microbial fermentation plays a critical role in shaping coffee quality through biochemical transformations during postharvest processing. This study aimed to analyze global research trends, key contributors, and emerging directions in microbial coffee fermentation using a bibliometric approach. Bibliographic data were retrieved from the Scopus database (2020–2026) and analyzed using the Bibliometrix package in R and VOSviewer to examine publication growth, influential authors, institutions, countries, collaboration networks, and thematic structures. A total of 237 publications involving 929 authors were identified, indicating a rapidly expanding and multidisciplinary research field. Results show a steady increase in scientific output, driven by growing interest in controlled fermentation, microbial starter cultures, and advanced analytical techniques. Highly cited studies emphasize the role of yeasts and lactic acid bacteria in metabolite production and flavor development, while emerging research highlights the shift toward process optimization and precision fermentation systems. Overall, the findings demonstrate that microbial coffee fermentation research is evolving from descriptive microbial studies toward integrated, technology-driven approaches. This study provides a comprehensive synthesis of research trends and highlights the importance of controlled fermentation strategies for improving coffee quality and supporting specialty coffee production.

KEYWORDS: coffee fermentation; microbial fermentation; bibliometric analysis; coffee quality; yeast; lactic acid bacteria

1. INTRODUCTION

Coffee is one of the most popular agricultural trade products in tropical and subtropical nations, and a major earner of millions of farmers. Apart from the economic value, coffee is appreciated for its sensory characteristics: aroma, flavour, acidity and body. Various factors such as variety and environmental conditions and post harvest treatment affect these characteristics. Among these, fermentation is especially important because of the biochemical alterations which it causes, and which impact coffee quality (Hali & Kang, 2019; Shen et al., 2024; de Souza Gomes et al., 2023).

During the fermenting process, the mucilage surround the beans is broken down by naturally occurring micro-organisms (yeasts, lactic acid bacteria, acetic acid bacteria). The organic acids, alcohols, esters, and other volatile compounds formed in this process may affect the flavor and aroma (Ferreira et al., 2023; de Melo Pereira et al., 2017). So, microbial fermentation is now recognised as one of the key points in the quality and specialty coffee production. The importance of microbial diversity, metabolic pathways and environmental factors on the sensory profile of coffee has been further highlighted by recent advances in microbiology and fermentation technologies (Shen et al., 2025). It is currently being studied whether the uniformity and flavour of the products can be improved by using controlled fermentation, microbial selected cultures (Bressani et al., 2021; Neyra-Vergara et al., 2025).

Furthermore, recent research published in Fermentation has indicated the increasing role of process control, such as application of starter cultures and anaerobic fermentation, in optimizing the microbial activity for flavor complexity (Bernardes et al., 2024) This research has been a step away from traditional spontaneous fermentation to more controlled and technology-driven approach. This has sparked recent research into the microbial flora, fermentation processes, and the impact of these on coffee quality, which has increased very quickly. Overall structure and research trends, however, in microbial coffee fermentation, are still not adequately synthesized.

Bibliometric studies can be used to identify the evolution of a research field based on publication trends, citation networks, and themes (Cruz-O'Byrne et al., 2020). The current study, therefore, engages a bibliometric analysis to trace the direction of the world's research on microbial fermentation and coffee quality with a view to highlighting the research direction and possible ways forward. The specific aim of this study is to analyze the trends in global research on microbial fermentation and coffee quality improvement through bibliometric analysis. It reviews and discusses the growth in publications between 2020 and early 2026, highlights the most productive authors, institutions, countries and journals, and analyses the most prominent studies and citation trends in the field. It also investigates collaboration networks to gain insights into the structure and development of research on microbial coffee fermentation. This study is a new contribution

because it combines the quantitative tools of bibliometric analysis with the specific fermentation context, thus connecting the dots between trends in the microbial world and the relevance in the context of improving coffee quality.

2. METHODS

2.1 Research Design

The study was carried out using a bibliometric research design, which has a quantitative approach that aimed to analyze the scientific publications related to microbial fermentation and the improvement of the quality of coffee. The publication trend, citation pattern, collaboration networks and thematic developments in the research field were analyzed using bibliometric analysis, which is broadly applied in mapping SSTs (Donthu et al., 2021).

2.2 Data Source and Search Strategy

Data of the bibliographic information used in this study were retrieved from the Scopus database (15 April 2026), considered one of the most complete databases of peer-reviewed literature covering multidisciplinary fields. Scopus covers a wide spectrum of agricultural sciences, food science, microbiology, and biotechnology making it a good source for bibliometric studies (Donthu et al., 2021). A structured search query was used in the Title, Abstract and Keyword field to identify relevant publications (Figure 1). The search was restricted for publications that appeared between January 2020 and February 2026, reflecting recent advances and new trends in the research on microbial coffee fermentation.

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TITLE-ABS-KEY (  
  (coffee OR "coffee beans" OR "arabica coffee" OR "coffea arabica")  
  AND  
  (fermentation OR "microbial fermentation" OR "anaerobic fermentation"  
   OR "controlled fermentation" OR "coffee fermentation")  
  AND  
  ("coffee quality" OR "cup quality" OR "sensory evaluation"  
   OR "sensory analysis" OR "flavor" OR "aroma")  
)  
AND (PUBYEAR > 2019 AND PUBYEAR < 2027)
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Figure 1. Scopus search string applied for the retrieval of publications on microbial fermentation and coffee quality enhancement (2020–2026).

2.3 Inclusion and Exclusion Criteria

The analysis included only articles published in peer-reviewed journals and review articles, which are usually subjected to a thorough academic scrutiny and present validated scientific results. The publications selected for this study were those that were written in English to enable uniformity in interpretation and analysis of the literature. In addition, the studies chosen should be specifically concerned with coffee fermentation, microbial activity in coffee fermentation and link the microbial activity to coffee quality parameters including flavor, aroma, coffee sensory profile, and coffee cup quality.

Conference abstracts, editorials, notes and book chapters were not included as they typically contain less information on methods and may not be subject to the same level of peer review as journal articles. Moreover, all the publications not directly related to coffee fermentation processes or microbial dynamics and those not related to coffee quality enhancement were excluded from the data set at the screening stage.

2.4 Data Extraction and Cleaning

All retrieved records were exported as csv for systematic processing and analysis. The information provided in the data set comprised authors, year of publication, author affiliations, journal titles, keywords, citation counts, and countries of origin. Data cleaning comprised of standardization of records and removal of duplicate records for enhancing data accuracy and reliability. After cleaning of the data, they were used for bibliometric and network analyses.

2.5 Bibliometric Indicators and Network Analysis

The Bibliometrix package in R and the software VOSviewer (van Eck et al., 2010) were used for conducting bibliometric and network analyses. The analyses comprised of annual publication trends, analysis of citations, productive authors, institutions, countries, and journals to assess scientific productivity and research impact. Co-authorship, co-citation and the keyword co-occurrence analyses were also conducted to determine the patterns of collaboration, influential studies, and thematic structures of the microbial coffee fermentation study. Besides, keyword frequency and treemap visualizations were performed to identify key research areas and technology trends.

2.6 PRISMA-Based Screening

The publications have been screened in a systematic and transparent manner according to the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) framework. The first database search resulted in a wide range of studies that were then screened according to a pre-established inclusion and exclusion criteria. Titles and abstracts, and author/index keywords, were used as screening tools to ensure relevance of the articles to microbial

fermentation and coffee quality enhancement. Full-text verification was only used to test ambiguous cases. A total of 237 publications were selected after the screening process for further bibliometric analysis.

2.7 Use of Generative Artificial Intelligence (AI)

ChatGPT Plus was used as a generative artificial intelligence (AI) tool exclusively for organizing, initial synthesizing and verifying of the findings from the vast number of scientific papers in the bibliometric database. The use of AI was limited to supporting literature screening, and identifying recurring research themes during manuscript preparation. All information extracted and bibliometric output have been checked, validated and verified by the author before being added to the study. The author takes full responsibility for the accuracy, integrity, interpretation and final presentation of all results and conclusions reported in this study.

3. RESULTS AND DISCUSSION

3.1. Descriptive Characteristics of the Dataset

A total of 237 publications have been obtained from Scopus database from January 2020 to February 2026 (Table 1). The publications were disseminated in 96 academic journals, and 929 authors made these papers. This shows a substantial and worldwide research community that study microbial processes that play a role in the fermentation of coffee. This research field is multidisciplinary, comprising 27,681 cited references and 625 author keywords (van Eck et al., 2010; Cruz-O'Byrne et al., 2020).

Table 1. Descriptive statistics of the bibliometric dataset

Description	Results
Documents	237
References	27,681
Authors	929
Authors Keyword	625
Articles	199
Books chapters	3
Conference Paper	5
Conference Review	1
Review	27

3.2. Annual Growth of Scientific Publications

The number of publications on annual production of microbial coffee fermentation related research articles clearly shows the upward trend from 2020 to 2025 (Figure 2), which suggests the growing scientific interest in the technologies and microbial processes of coffee.

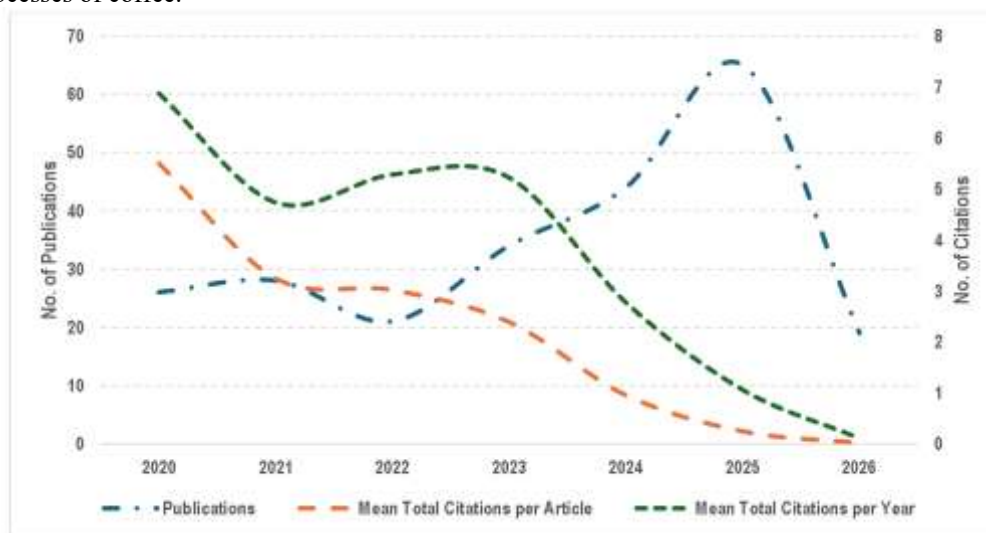


Figure 2. Annual scientific production and citation trends in microbial coffee fermentation research (2020–2026).

In 2025, the number of publications grew to 65 articles, the highest number of publications in the study period. The trend is in line with the greater significance of the microbial fermentation process as a tool to enhance coffee quality and develop quality differentiated specialty coffee products (Haile & Kang, 2019). The rate of publication continued to rise, but the citation frequency per article has decreased in more recent years, as is typical in bibliometric analyses because the number of cites that can be found on recently published articles is limited by the time they have been published. The surge in publications since 2023 could also be linked to the increasing global interest in the application of controlled fermentation technologies, microbial starter cultures, and other innovative postharvest processing methods that are gaining momentum to enhance the flavors and consistency of coffee beverages (Shen et al., 2024; Ferreira et al., 2023).

3.3. Most Productive Authors

Based on the publication volume and citation impact, the authors were selected using bibliometric analysis to identify the pertinent authors of the microbial fermentation in coffee processing. Rosane Freitas Schwan was the most prolific author (38 publications), emphasizing her great contributions to microbial ecology and fermentation processes of coffee (Figure 3(a)). Other top authors are Nádia Narra Batista (22 publications), Disney Ribeiro Dias (20), Lucas Louzada Pereira (18) and Ana Paula Bressani (14). The distribution of publications shows that scientific production is highly skewed with a small number of very productive researchers, in line with Lotka's law of scientific productivity. This trend is also reflected in the citation analysis results as presented in Figure 3(b). Schwan is also the most cited author (548 citations), which means that he has a great influence in the field. Other authors with a number of more than 100 citations are Batista (363), Martínez (223), Dias (212), Borém (194) and Bressani (193).

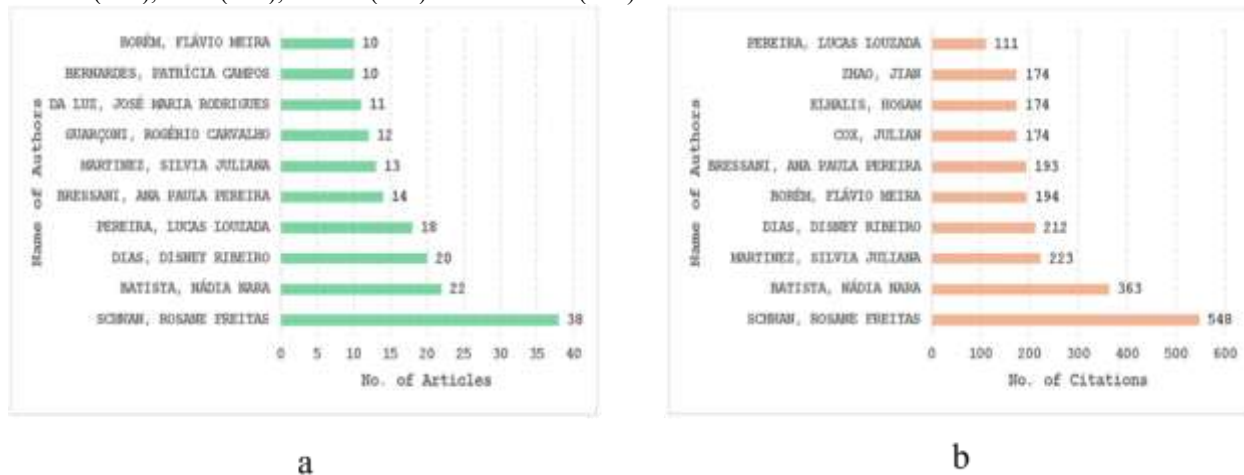


Figure 3. (a) Authors with the number of articles; (b) Authors with the number of citations

Finally, there are a few authors with a lower number of publications, such as Julian Cox, Zhao Jian and Hosam Elhalis, whose relatively high citation counts (174 each) indicate their research impact despite the lower number of publications. In general, it seems that productivity and influence can be attributed to a small group of researchers who have a key role in the progress of the research on microbial fermentation in coffee.

3.4. Most Productive Institutions and Countries

Bibliometric Analysis is the method of analysis allowed us to determine institutions and countries that were involved into researching the topic of microbial fermentation in coffee processing (Figure 4). Productivity of institutions was measured by their publications, while the role of countries was determined using the citation impact method (van Eck et al., 2010).

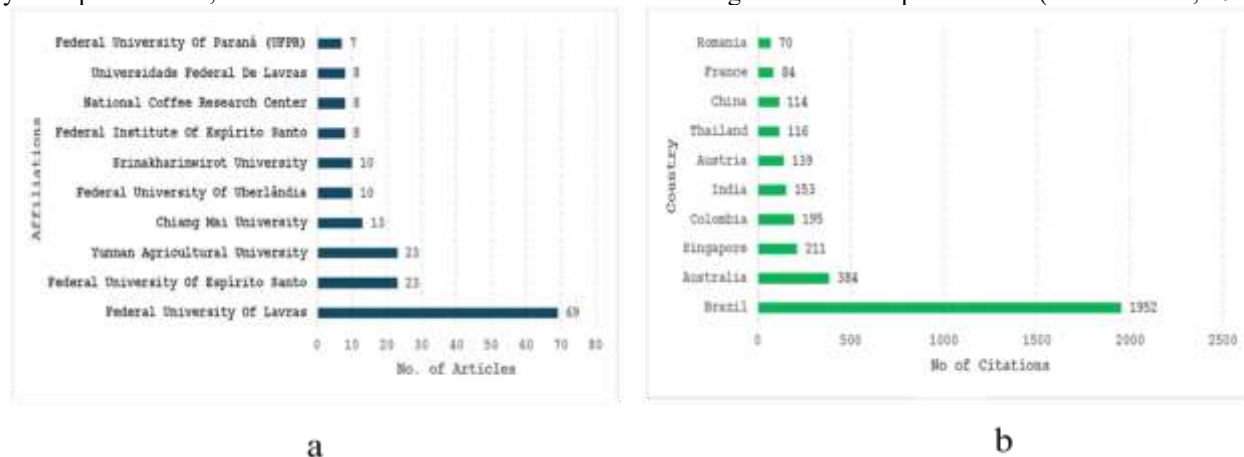


Figure 4. (a) Most Productive Institutions and (b) Countries

Federal University of Lavras stood out as the top publishing university with 69 articles, showing their high level of research in coffee science and fermentation. With regards to this finding, it can be seen that Brazilian universities are the dominant universities in research, considering that Brazil is the largest producer of coffee (Elhalis et al., 2023). Country-level analysis based on citation counts (Figure 4(b)) shows that Brazil is the most influential, with 1,952 citations, far exceeding other countries. This highlights its strong research capacity and global influence in coffee fermentation studies. Moreover, the results suggest from the findings, the Federal University of Lavras became the most productive institute due to 69 publications and the strong focus of its research towards coffee science and fermentation. From the findings, it can be noted that Brazilian universities are leading because of the research carried out in the country since Brazil is known to be the world's largest producer of coffee and hence scientific research (Elhalis et al., 2023). At the country level analysis

3.6. Authorship and Collaboration Networks

The authorship analysis reveals a grouping of research into microbial fermentation in coffee, in the form of several collaboration groups (Figure 7). The nodes represent author(s); links are co-authorship. The bigger the nodes are, the more productive they are or the more tightly they are linked together. The researcher who is at the center of one of the major clusters is Rosane Freitas Schwan, whose team includes researchers such as Nádia Nara Batista and Disney Ribeiro Dias. The topics researched in the cluster include microbial ecology and fermentation microbiology. A second cluster has to do with microorganism identification and fermentation characterization, while a third has to do with fermentation management.



Figure 7. Author Collaboration Network

In addition to that, the connected dots depict clusters of various disciplines, including microbiology, food sciences, and agricultural biotechnologies, which indicates multidisciplinary and collaboration. The cooperation is essential for the promotion of new knowledge about fermentation processes, and in the quality improvement of the coffee (Bernardes et al., 2024).

3.7. Organization Collaboration Network

The organization collaboration network (Figure 8a) shows collaboration between universities and research centers. Nodes are institutions and links are research shared by more than one institution. Several Brazilian universities are central nodes, denoting their prominent role in coffee science and fermentation studies. This is in line with the fact that Brazil is a leader in world coffee production and research and has strong academic institutions (Samoggia et al., 2019).

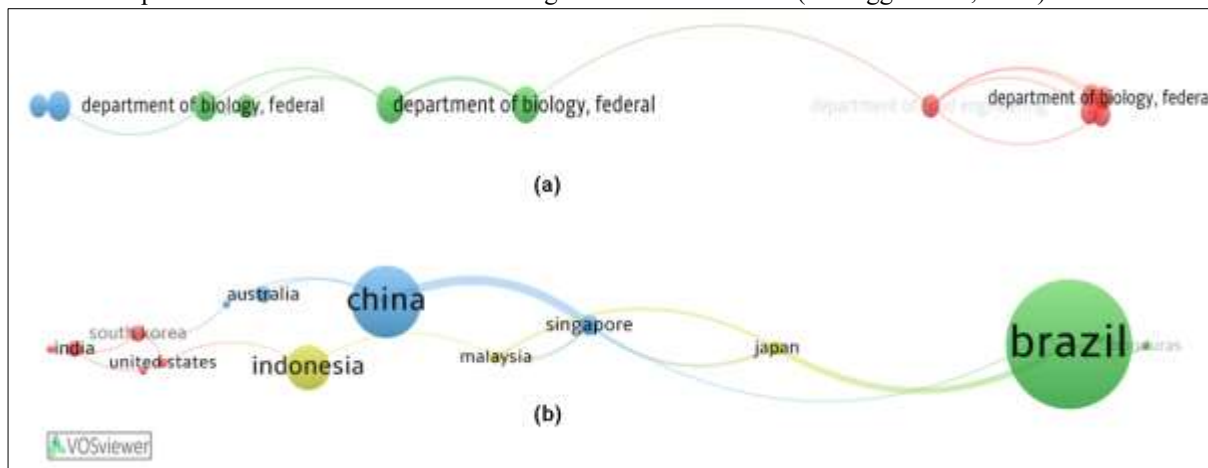


Figure 8. Co-Authorship Network (a) Organizations & (b) Country.

Such co-operations are commonly found in special research teams on food microbiology and agricultural biotechnology. Institutional partnerships provide the opportunity to bring together different disciplines, which has led to better understanding of the fermentation processes and thus technologies that can be used to improve the quality of coffee (Wagner et al., 2025).

3.8. Country Collaboration Network

Partnerships between universities and research centers are indicated in the organisation collaboration network (Figure 8a). Nodal points are institutions and links indicate co-authored research. Various Brazilian universities are present as central nodes, which also have a high interest in coffee science and fermentation research. The country level network (Figure 8b) displays the world-wide research and collaboration. Brazil seems to be the most influential, as it has high research production and has been important in coffee fermentation studies (Sttela, et al., 2015; Borem et al., 2024). Additionally, China plays an important role with strong linkages with Singapore, Malaysia, Japan and other countries

2025; Bernardes et al., 2024). As a whole, the tree map visualization is congruent with present research trends, the search for microbial control, process optimization, and technology-assisted quality enhancement in specialty coffee production systems.

3.10. Implications for Microbial Fermentation Mechanisms

The bibliometric analysis shows that the most highly-cited research papers in microbial coffee fermentation have a very strong interest in the biochemical and microbiological mechanisms involved in the development of quality. The many references to yeast, lactic acid bacteria and metabolism suggest that a considerable amount of research is being conducted on the microbial pathways involved in the transformation of substrate and the production of metabolites during fermentation. In previous research, yeasts were identified as being key microorganisms in the transformation of sugars that are found in the coffee mucilage into aroma-active compounds, such as alcohols and esters, linked to the fruity and floral sensory properties of coffee (Bernardes et al., 2024). Simultaneously, lactic acid bacteria help to produce organic acids that control product pH, acidity balance and mouthfeel in the final product (Elhalis et al., 2023). Acetic acid bacteria are also involved in oxidative metabolism that may also contribute to flavor complexity when properly controlled.

The biochemical transformation of coffee beans during fermentation is controlled by this dynamic succession process of the interactions between the microbes. The bibliometric focus on citations around these studies suggests that microbial metabolism and metabolite production continue to be an important focus of the overall research on the fermentation of coffee. Recent mechanistic studies also showed that microbial fermentation affects the composition of coffee beans by degrading sugars, converting amino acids, biosynthesizing esters, and producing organic acids (Cassimiro et al., 2023; da Silva et al., 2021; Borém et al., 2024). Selected yeast and lactic acid bacteria species had a remarkable contribution to the generation of compounds that impact the fruity, floral and wine-like sensory profiles of the fermented products (Cassimiro et al., 2023; da Silva et al., 2021). In addition, it was observed that microbial activity during fermentation impacts precursor compounds during roasting that lead to the formation of Maillard reaction products, thus affecting the final cup quality, as demonstrated by metabolomic studies (Madrid-Restrepo et al., 2025; Istighfarah et al., 2026; de Melo Pereira et al., 2025). Based on these results, the scientists conclude that microbial metabolism contributes significantly to the process of flavor differentiation and specialty coffee quality improvement, and that using probiotics or biofloc to produce favorable coffee flavor could be a more environmentally friendly approach to flavor alteration than traditional chemical processes. Overall, there seems to be a shift from the descriptive microbial studies of coffee fermentation towards mechanism and process oriented studies. This change highlights the role of microbial control in ensuring uniform and good quality coffee production.

3.11. Emerging Technologies in Coffee Fermentation

As for the specific directions of the development of microbial coffee technology, the bibliometric analysis showed a remarkable technological innovation trend that has been observed in the gradual co-occurrence of terms like starter cultures, controlled fermentation and anaerobic fermentation. These trends are associated with the increasing scientific work for moving away from un-controlled and spontaneous fermentation towards more controlled and reproducible fermentation systems. Well cited research has suggested that the use of microbial starter cultures can be beneficial to the control of fermentation pathways and consequently for the development of the desired taste characteristics and sensory consistency (Bressani et al., 2021). Furthermore, anaerobic fermentation has received significant attention because of its potential to control the availability of oxygen and affect the microbial metabolism responsible for the development of aromas and flavors (Ferreira et al., 2023; Shen et al., 2024). Further evidence of the synergy of chemistry, microbiology and biotechnology in coffee fermentation research is the growing use of analytical tools like Gas Chromatography-Mass Spectrometry (GC-MS), Liquid Chromatography-Mass Spectrometry (LC-MS/MS), Quantitative Polymerase Chain Reaction (qPCR) and High Throughput Sequencing (HTS) (Lee et al., 2015; De Bruyn et al., 2017). These technologies facilitate the detailed description of microbial populations, production of metabolites, and identification of volatile compound profiles related to specialty coffee quality. Self-induced anaerobic fermentation systems and bioreactor-scale fermentations also show that controlled fermentation processes can achieve improved microbial management, fermentation reproducibility, and sensory consistency under larger-scale production conditions (Cassimiro et al., 2023; Peñuela-Martínez et al., 2025; Amaral et al., 2025). These developments together demonstrate the continuous development of research on coffee fermentation towards technology- and precision-assisted fermentation systems for optimized specialty coffee quality.

3.12. Research Gaps and Future Directions

Although significant advances have been made in the study of microbial coffee fermentation, the bibliometric analysis uncovers some of the key challenges that remain to be overcome in advancing the field. The major challenge is the lack of a standardized fermentation protocol in order to achieve reproducibility and comparability with other studies (Cruz-O'Byrne et al., 2020; Donthu et al., 2021). Fermentation time, oxygen, inoculation, and environment are still found to have an impact on fermentation consistency and sensory results. Also, the connection between microbial activity and measurable parameters for cup quality is reportedly still not fully understood (Cruz-O'Byrne et al., 2020; Donthu et al., 2021). The direct relationship between the dynamics of the microbial community, the formation of metabolites, and the sensory quality of the product needs to be clarified, although key microorganisms involved in fermentation are identified (Madrid-Restrepo et al., 2025; Istighfarah et al., 2026; de Melo Pereira et al., 2025; Hu et al., 2025; Wanita et al., 2026). This accentuates the need for integrated approaches involving microbiology, metabolomics, analytical chemistry, and sensory evaluation. Other constraints are that several fermentation studies are performed under lab-scale conditions and

have limited application in farm-scale and/or industrial processing conditions (Sttela et al., 2015; Borém et al., 2024; de Paula Amaral et al., 2025). Commercialization of scaling up of controlled fermentation technologies is thus a significant challenge. Future research efforts will be better directed towards establishing a standardized fermentation platform, conducting large-scale trials in field settings, and undertaking multi-omics analysis in order to understand the microbial interactions involved in fermentation of coffee. Further, the use of data driven techniques such as predictive fermentation modeling, machine learning, and intelligent process monitoring provide opportunities for optimization and quality assurance of specialty coffee. The above research issues need to be addressed in order for microbial fermentation to become a viable and scientifically sound method of producing specialty coffee.

4. CONCLUSIONS

The aims of this study are to thoroughly analyze the past and present state of the world's research on microbial coffee fermentation from 2020 to 2026, utilizing a bibliometric approach. The findings show that this is a rapidly growing and multidisciplinary field, with growing numbers of publications and with a well-developed international network of collaboration. A number of significant studies have been cited for their focus on the key role that microorganisms such as yeasts and lactic acid bacteria play in the biochemical reactions that affect the flavor, odor and quality of coffee. The results also show a clear shift from spontaneous to controlled and technology-based fermentation processes, such as using anaerobic fermentation methods and starter cultures. The results of the network and keyword analyses are consistent with the current research and strongly point towards two research areas: microbial ecology and metabolite formation, as well as sensory quality evaluation. Recent research also indicates that process optimization and precision fermentation are emerging research areas. Despite these improvements, however, there are a number of challenges such as the absence of a standard protocol for fermentation, and the lack of connection between microbial dynamics and sensory results. These gaps can be broken down by interdisciplinary and data-driven approaches, which will be critical to the advancement of fermentation technologies. In conclusion, this research highlights the significance of controlled microbial fermentation as a vital process in enhancing the quality of coffee and advancing specialty coffee production systems.

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REFERENCES

1. Haile, M., & Kang, W. H. (2019). The role of microbes in coffee fermentation and their impact on coffee quality. *Journal of Food Quality*, 2019(1), 4836709.
2. Shen, X., Wang, Q., Wang, H., Fang, G., Li, Y., Zhang, J., & Liu, K. (2024). Microbial characteristics and functions in coffee fermentation: A review. *Fermentation*, 11(1), 5.
3. de Souza Gomes, M., Maciel de Oliveira, L., & Diniz Santos, L. (2023). Coffee fermentation process: A review. *Food Research International (Ottawa, Ont.)*, 169, 112793-112793.
4. de Melo Pereira, V.G., Soccol, V. T., Brar, S. K., Neto, E., & Soccol, C. R. (2017). Microbial ecology and starter culture technology in coffee processing. *Critical reviews in food science and nutrition*, 57(13), 2775-2788.
5. Shen, X., Wang, Q., Wang, H., Fang, G., Li, Y., Zhang, J., & Liu, K. (2025). Microbial Characteristics and Functions in Coffee Fermentation: A Review. *Fermentation*, 11(1), 5. <https://doi.org/10.3390/fermentation11010005>
6. Bressani, A. P., Martinez, S. J., Evangelista, S. R., Dias, D. R., & Schwan, R. F. (2018). Characteristics of fermented coffee inoculated with yeast starter cultures using different inoculation methods. *LWT*, 92, 212–219. <https://doi.org/10.1016/j.lwt.2018.02.029>
7. Neyra-Vergara, T. J., Melendrez-Mauriola, O., Cubas-Heredia, B. Y., Contreras-Ocupa, G. N., Herrera-Salazar, D. M., Diaz-Mundaca, E. E., Rivera-Botonares, R. S., & Hernández-Martínez, E. (2025). Coffee fermentation from traditional to controlled and its impact on sensory quality: A review. *Coffee Science*, 20, e202355. <https://doi.org/10.25186/v20i.2355>
8. Cruz-O'Byrne, R., Piraneque-Gambasica, N., Aguirre-Forero, S., & Ramirez-Vergara, J. (2020). Microorganisms in coffee fermentation: A bibliometric and systematic literature network analysis related to agriculture and beverage quality (1965-2019).
9. Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of business research*, 133, 285-296.
10. Van Eck, N., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *scientometrics*, 84(2), 523-538.
11. Elhalis, H., Cox, J., & Zhao, J. (2023). Coffee fermentation: Expedition from traditional to controlled process and perspectives for industrialization. *Applied Food Research*, 3(1), 100253. <https://doi.org/10.1016/j.afres.2022.100253>

12. Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of informetrics*, 11(4), 959-975.
13. Small, H. (1973). Co-citation in the scientific literature: A new measure of the relationship between two documents. *Journal of the American Society for information Science*, 24(4), 265-269.
14. Lee, L. W., Cheong, M. W., Curran, P., Yu, B., & Liu, S. Q. (2015). Coffee fermentation and flavor—An intricate and delicate relationship. *Food chemistry*, 185, 182-191.
15. De Bruyn, F., Zhang, S. J., Pothakos, V., Torres, J., Lambot, C., Moroni, A. V., ... & De Vuyst, L. (2017). Exploring the impacts of postharvest processing on the microbiota and metabolite profiles during green coffee bean production. *Applied and environmental microbiology*, 83(1), e02398-16.
16. Sttela, D., Pedro, D., Gerson, S., & Isquierdo, E. (2015). Post-harvest effects on beverage quality and physiological performance of coffee beans. *African Journal of Agricultural Research*, 10, 1457–1466.
17. Samoggia, A., & Riedel, B. (2019). Consumers' Perceptions of Coffee Health Benefits and Motives for Coffee Consumption and Purchasing. *Nutrients*, 11(3), 653. <https://doi.org/10.3390/nu11030653>
18. Wagner, C. S., Whetsell, T. A., & Mukherjee, S. (2019). International research collaboration: Novelty, conventionality, and atypicality in knowledge recombination. *Research policy*, 48(5), 1260-1270.
19. Todhanakasem, T., Ngo, T., Pornpukdeewattana, S., Charoenrat, T., Young, B., & Wattanachaisaerekul, S. (2024). The relationship between microbial communities in coffee fermentation and aroma with metabolite attributes of finished products. *Foods*, 13(15), 2332. <https://doi.org/10.3390/foods13152332>
20. Hu, F., Yu, H., Fu, X., Li, Z., Dong, W., Li, G., ... & Bi, X. (2025). Characterization of volatile compounds and microbial diversity of Arabica coffee in honey processing method based on different mucilage retention treatments. *Food Chemistry: X*, 25, 102251.
21. Polanía Rivera, A. M., López Silva, J., Torres-Valenzuela, L., & Plaza-Dorado, J. L. (2024). From waste to taste: Coffee by-products as starter cultures for sustainable fermentation and improved coffee quality. *Sustainability*, 16(23), 10763.
22. Bernardes, P. C., Coelho, J. M., Martins, P. M. M., & Schwan, R. F. (2024). Microbial ecology and fermentation of *Coffea canephora*. *Frontiers in Food Science and Technology*, 4, 1377226.
23. de Jesus Cassimiro, D. M., Batista, N. N., Fonseca, H. C., Naves, J. A. O., Coelho, J. M., Bernardes, P. C., ... & Schwan, R. F. (2023). Wet fermentation of *Coffea canephora* by lactic acid bacteria and yeasts using the self-induced anaerobic fermentation (SIAF) method enhances the coffee quality. *Food Microbiology*, 110, 104161.
24. da Silva, B. L., Pereira, P. V., Bertoli, L. D., Silveira, D. L., Batista, N. N., Pinheiro, P. F., ... & Bernardes, P. C. (2021). Fermentation of *Coffea canephora* inoculated with yeasts: Microbiological, chemical, and sensory characteristics. *Food Microbiology*, 98, 103786.
25. Borem, F. M., Salvio, L. G. A., Correa, J. L. G., Alves, A. P. C., SANTOS, C. M. D., Haeberlin, L., ... & Schwan, R. F. (2024). Influence of Fermentation Time and Inoculation of Starter Culture on the Chemical Composition of Fermented Natural Coffee Followed by Depulping. *Anais da Academia Brasileira de Ciências*, 96(suppl 1), e20240083.
26. Madrid-Restrepo, M. A., León-Inga, A. M., Peñuela-Martínez, A. E., Cala, M. P., & Reyes, A. (2026). Metagenomic, metabolomic, and sensorial characteristics of fermented *Coffea arabica* L. var. Castillo beans inoculated with microbial starter cultures. *Msystems*, 11(1), e01364-25.
- Peñuela-Martínez, A. E., Osorio-Giraldo, C. V., Buitrago-Zuluaga, C., & Medina-Rivera, R. D. (2025). Development of Fermentation Strategies for Quality Mild Coffee Production (*Coffea arabica* L.) Based on Oxygen Availability and Processing Time. *Foods*, 14(17), 3001.
- Amaral, E. P., Entringer, T. L., Veloso, T. G. R., da Luz, J. M. R., Pimenta, L. H. B., Moreli, A. P., Pereira, L. L., & da Silva, M. de C. S. (2026). Microbial dynamics and impact of controlled fermentation in *Coffea arabica* over 288 h. *Food Bioscience*, 75, 108081. <https://doi.org/10.1016/j.fbio.2025.108081>
27. Istighfarah, Z., Wijaya, C. H., Nuraida, L., Noor, E., & Kusuma, W. A. (2026). The effect of microbial community in the self-induced anaerobic fermentation on the aroma precursor development of geothermal coffee. *Sustainable Food Technology*.
28. de Melo Pereira, G. V., da Silva Vale, A., Ribeiro-Barros, A. I., Rodrigues, L. R. S., Mirção, G. M. D. F. B., Camilo, B., ... & Soccol, C. R. (2025). Integrated microbial–metabolomic analysis reveals how fermentation contributes to the unique flavor of African Arabica coffee. *Food Chemistry: Molecular Sciences*, 100344.
29. Wanita, Y. P., Ushada, M., Damayanti, E., & Sukartiko, A. C. (2026). Comprehensive Characterisation of the Robusta Coffee Postharvest Processes: Insight into Physicochemical, Volatile Compounds, and Sensory Preferences. *Pertanika J. Trop. Agric. Sci*, 49(1), 257-283.