OPEN ACCESS

Halal Innovation Journal on Advanced Bioscience Vol 2 No 1 (2026)

https://doi.org/ 10.70211/hijab

Check for updates

Research Article

Molecular and Analytical Technologies for Coffee Authentication and Traceability: a Bibliometric Analysis for Strengthening Halal Assurance Systems

Priyambodo[1], Nindy Permatasari[2]*, Siti Hamidatul Aliyah[3], Aulia Ulmillah[4]

Received: 31 Mei 2026	Revised: 12 Juni 2026	Accepted: 22 Juni 2026	Online: 22 Juni 2026

Abstract

Coffee authentication and traceability have become increasingly important due to growing concerns regarding food adulteration, product authenticity, geographical origin verification, and supply-chain transparency. These issues are particularly relevant for strengthening Halal Assurance Systems, which require reliable mechanisms to ensure product integrity and consumer confidence. This study aimed to evaluate global research trends related to molecular and analytical technologies for coffee authentication and traceability using a bibliometric approach. Bibliographic data were retrieved from the Scopus database in May 2026 using a structured search strategy focused on coffee, authentication, traceability, adulteration, and molecular identification technologies. After applying inclusion criteria limited to English-language journal articles published in their final stage, a total of 76 documents published between 1994 and 2026 were analyzed using Bibliometrix and Biblioshiny in R Studio. The results revealed a substantial increase in publication output during the last decade, with Brazil, China, and the United States emerging as the leading contributors. Keyword co-occurrence and thematic analyses identified authenticity, adulteration, chemometrics, food authentication, and traceability as the dominant research themes. Thematic evolution further demonstrated a transition from basic authenticity verification toward integrated approaches involving geographical origin determination, quality assessment, and supply-chain transparency. The findings highlight the complementary roles of molecular technologies and analytical methods in supporting reliable authentication systems. These developments provide a strong scientific foundation for strengthening Halal Assurance Systems through improved product verification, traceability, and fraud prevention within global coffee supply chains.

Keywords: adulteration detection; analytical technologies; bibliometric analysis; coffee authentication; halal assurance systems; molecular technologies; traceability;

INTRODUCTION

Halal assurance has become an increasingly important concern for Muslim consumers worldwide [1]. Beyond compliance with Islamic dietary principles, halal assurance encompasses broader aspects of product integrity, authenticity, traceability, transparency, and consumer confidence throughout the food supply chain [2]. The rapid growth of the global halal economy has intensified the need for reliable scientific approaches capable of verifying product authenticity and supporting the integrity of halal-certified products [3]. Consequently, the integration of advanced scientific technologies into food authentication systems has received increasing attention from both researchers and industry stakeholders.

Coffee occupies a unique position within the historical development of Muslim societies [4]. Although coffee is widely believed to have originated in the highlands of Ethiopia, its cultivation, commercialization, and widespread consumption were first developed in the Arabian Peninsula, particularly in Yemen, before spreading throughout the Islamic world and later to Europe and other regions [5], [6]. Coffeehouses subsequently became important centers of social interaction, commerce, and intellectual exchange within Muslim communities [7]. Today, coffee has evolved into one of the world's most economically important agricultural commodities, supporting extensive production, processing, trade, and retail industries across numerous countries [8].

The global expansion of coffee consumption has been accompanied by increasing diversification of coffee products and growing complexity of coffee supply chains [9]. Modern coffee products frequently involve multiple stages of processing, blending, flavoring, extraction, packaging, and international distribution [10]. Such complexity creates challenges related to product authenticity, adulteration, mislabeling, contamination, and geographical origin verification [11]. These issues not only affect product quality and consumer trust but may also influence efforts to maintain product integrity within halal assurance frameworks [12]. Consequently, authentication and traceability have become increasingly important components of contemporary coffee quality management systems.

To address these challenges, researchers have developed and applied a wide range of molecular and analytical technologies for coffee authentication and traceability. Molecular approaches such as polymerase chain reaction (PCR), real-time PCR, DNA extraction, molecular markers, and genetic analyses have been utilized to identify coffee species, verify varietal identity, and detect adulteration [13], [14]. At the same time, analytical technologies including spectroscopy, chromatography, mass spectrometry, chemometrics, and machine learning have emerged as powerful tools for chemical fingerprinting, origin verification, and quality assessment [15]. These technological advances have significantly improved the ability to evaluate coffee authenticity and monitor product movement across increasingly complex supply chains.

Recent studies have reported substantial progress in the application of molecular and analytical approaches for coffee authentication, food fraud detection, geographical origin verification, and traceability assessment [16], [17], [18], [19], [20]. However, existing research remains fragmented across multiple disciplines, including food chemistry, analytical science, molecular biology, agricultural science, and food quality management. Most studies have focused on specific technologies, analytical methods, or case-based applications, while a comprehensive understanding of the overall intellectual structure, thematic evolution, and emerging research trends within this field remains limited. Although numerous studies have investigated molecular and analytical technologies for coffee authentication, food quality control, and fraud detection, no bibliometric study has systematically mapped how these scientific developments may contribute to strengthening Halal Assurance Systems through enhanced authenticity verification, traceability, and supply-chain

integrity. Consequently, a comprehensive understanding of the intellectual structure, thematic evolution, and emerging research directions linking coffee authentication technologies with halal assurance remains lacking..

A systematic bibliometric assessment is therefore needed to evaluate the global development of molecular and analytical technologies for coffee authentication and traceability. Mapping publication trends, thematic structures, intellectual foundations, and emerging research directions can provide valuable insights into the evolution of this field and identify future opportunities for research and innovation. Such knowledge is particularly important for understanding how advances in authentication and traceability technologies may contribute to strengthening Halal Assurance Systems through improved product integrity, transparency, and consumer confidence.

Therefore, this study aims to analyze global research trends related to molecular and analytical technologies for coffee authentication and traceability using a bibliometric approach. Specifically, the study examines annual scientific production, country contributions, thematic structures, keyword relationships, thematic evolution, and intellectual foundations of the field. The novelty of this research lies in its integration of bibliometric evidence with the broader perspective of Halal Assurance Systems, thereby providing a comprehensive understanding of how authentication and traceability technologies can support future halal integrity and transparency within coffee supply chains.

METHODS

Data Collection and Search Strategy

This study employed a bibliometric approach to evaluate global research trends related to molecular and analytical technologies for coffee authentication and traceability and their potential contributions to strengthening Halal Assurance Systems. Bibliographic data were retrieved from the Scopus database, which was selected due to its extensive coverage of peer-reviewed scientific literature and its widespread application in bibliometric research.

The literature search was conducted on May 30, 2026, using the following search query: ((TITLE-ABS-KEY(coffee OR Coffea OR "coffee bean*" OR "coffee product*" OR "coffee beverage*" OR "instant coffee") AND TITLE-ABS-KEY(authentication OR authenticity OR adulteration OR traceability OR fraud OR "food fraud") AND TITLE-ABS-KEY(DNA OR PCR OR qPCR OR "real-time PCR" OR ddPCR OR "digital PCR" OR "DNA barcoding" OR sequencing OR "DNA sequencing" OR "next-generation sequencing" OR NGS OR metabarcoding OR genomics OR genetic* OR molecular OR "molecular biology" OR "molecular authentication" OR "molecular detection" OR "molecular identification")) AND (EXCLUDE (SUBJAREA,"ENER") OR EXCLUDE (SUBJAREA,"MATH") OR EXCLUDE (SUBJAREA,"ARTS")) AND (LIMIT-TO (LANGUAGE,"English")) AND (LIMIT-TO (DOCTYPE,"ar")) AND (LIMIT-TO (PUBSTAGE,"final")))

The search strategy was designed to capture publications focusing on three principal components: (1) coffee and coffee-based products, (2) authentication, authenticity, adulteration, and traceability, and (3) molecular technologies applied to product verification and identification. To improve dataset relevance, documents indexed under the subject areas of Energy, Mathematics, and Arts and Humanities were excluded. Furthermore, the search results were limited to English-language journal articles published in their final form. After applying all inclusion and exclusion criteria, a total of 76 documents were retained for subsequent bibliometric analyses.

Data Processing and Bibliometric Analysis

The bibliographic records were exported from Scopus in CSV format, including citation information, bibliographic information, abstracts, keywords, and references. The exported dataset

was analyzed using the Bibliometrix package through the Biblioshiny web interface in R Studio version 4.5.2. Bibliometrix provides a comprehensive framework for quantitative evaluation of scientific literature and has been widely applied in bibliometric and scientometric studies [21].

Several performance indicators were examined to characterize the development of research on coffee authentication and traceability technologies. These indicators included annual scientific production, country scientific production, source productivity, thematic structures, thematic evolution, keyword co-occurrence patterns, and author co-citation networks. Annual scientific production was used to evaluate publication growth over time, while country scientific production was used to identify the geographical distribution of research activities.

Conceptual Structure Analysis

The conceptual structure of the field was explored through keyword co-occurrence analysis using author keywords[22]. The resulting co-occurrence network was used to identify major research themes and relationships among concepts associated with coffee authentication, adulteration detection, traceability, and technological development.

Thematic mapping was subsequently conducted to classify research themes according to their centrality and density values. Based on these parameters, themes were categorized into motor themes, niche themes, basic themes, and emerging or declining themes. This approach enabled the identification of well-developed themes, foundational research areas, specialized topics, and newly emerging directions within the field.

To further investigate the temporal development of research topics, thematic evolution analysis was performed. This analysis traced the progression and transformation of major themes across different time periods, thereby providing insights into shifts in scientific focus and research priorities over time.

Intellectual Structure Analysis

The intellectual structure of the research field was examined through author co-citation analysis [23]. Co-citation analysis identifies relationships among authors whose publications are frequently cited together and is commonly used to reveal the knowledge foundations and intellectual communities that shape a scientific domain. The resulting co-citation network was used to identify influential authors and major research clusters contributing to the advancement of coffee authentication and traceability technologies.

RESULT AND DISCUSSIONS

The bibliometric analysis was conducted using 76 articles retrieved from the Scopus database after applying predefined inclusion and exclusion criteria. The retrieved literature covers the period from 1994 to 2026. The starting year was not predetermined but corresponded to the earliest publication identified through the search strategy and eligibility criteria. This dataset provides insights into the historical development and evolution of research related to molecular and analytical technologies for coffee authentication and traceability. The results are presented through publication trends, source productivity, geographical distribution, conceptual structures, thematic development, and intellectual relationships within the field.

Annual Scientific Production

Annual scientific production analysis was performed to evaluate the temporal development of research on coffee authentication and traceability technologies (Figure 1). This analysis provides an

overview of publication growth and allows the identification of periods characterized by low, moderate, and rapid scientific expansion.

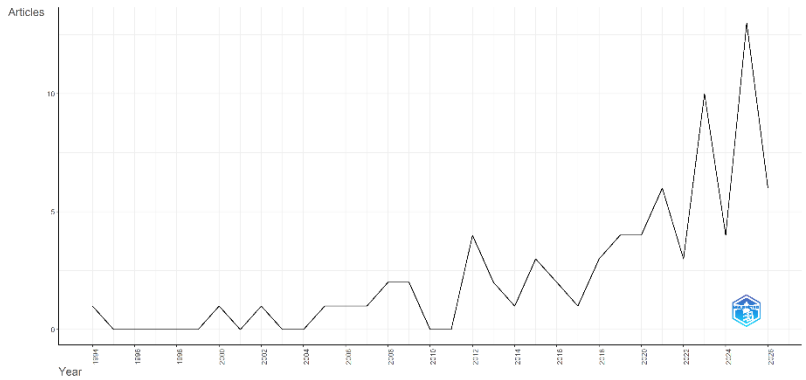

Figure 1. Annual Scientific Production of Coffee Authentication and Traceability Research (1994–2026).

The annual publication trend showed a generally increasing pattern over the study period. During the early years between 1994 and approximately 2011, publication output remained relatively low, with only occasional articles published. A gradual increase became apparent after 2012, followed by a more substantial rise after 2020. The highest publication output was recorded in 2025, indicating growing scientific interest in coffee authentication, adulteration detection, and traceability technologies. Overall, the results demonstrate an expanding research field with increasing scholarly attention during the last decade.

Most Relevant Sources

The analysis of source productivity was conducted to identify the journals that have contributed most substantially to the development of coffee authentication and traceability research (Table 1). Source analysis provides insight into the disciplinary orientation and publication outlets that dominate this field.

Table 1. Most Relevant Sources in Coffee Authentication and Traceability Research.

Sources	Number of Articles
Food Chemistry	8
Journal Of Agricultural and Food Chemistry	5
Food Control	4
LWT	4
Food Additives and Contaminants	3
Food Research International	3
Foods	3
Talanta	3
Journal of Aoac International	2
Journal of The Science of Food and Agriculture	2

The results revealed that *Food Chemistry* was the most productive source, contributing eight articles to the dataset. The *Journal of Agricultural and Food Chemistry* ranked second with five publications, followed by *Food Control* and *LWT*, each contributing four articles. Other important publication outlets included *Food Additives and Contaminants*, *Food Research International*, *Foods*, and *Talanta*. The concentration of publications within food science, analytical chemistry, and food quality

journals indicates the multidisciplinary nature of coffee authentication research and highlights the importance of analytical and quality assurance approaches within the field.

Global Distribution of Research Activities

The geographical distribution of scientific production was analyzed to identify the countries contributing to the development of research on coffee authentication and traceability technologies (Figure 2). This analysis provides an overview of the global participation and research intensity across different regions.

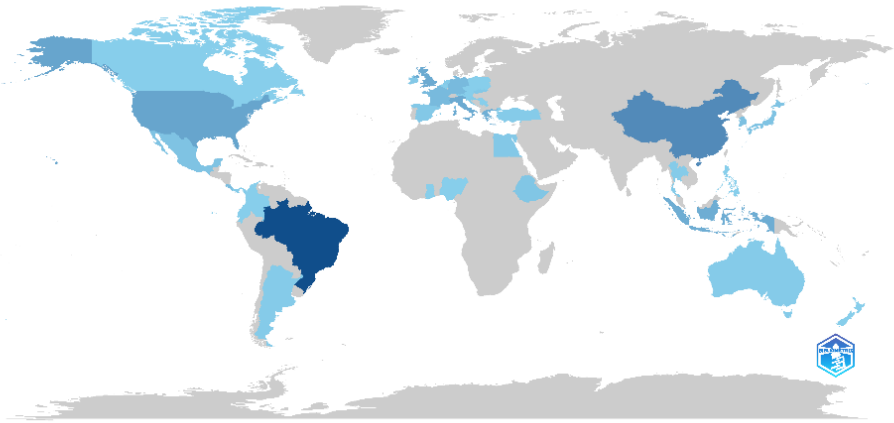

Figure 2. Global Distribution of Research Activities in Coffee Authentication and Traceability Research.

The results demonstrated that research activities were distributed across multiple continents, although contributions were concentrated in a limited number of countries. Brazil emerged as the leading contributor, followed by China and the United States. Several European countries also demonstrated notable research activity, while contributions from countries in Asia, Africa, and Latin America were comparatively lower. Indonesia appeared among the contributing countries, indicating participation in research related to coffee authentication and traceability technologies. Overall, the results suggest that scientific production in this field is dominated by countries with strong coffee industries, advanced analytical research infrastructure, and active food science research communities.

Conceptual Structure of Research Themes

The conceptual structure of the research field was investigated through keyword co-occurrence analysis using author keywords (Figure 3). This approach identifies major research themes and reveals relationships among concepts that frequently appear together within the literature. The co-occurrence network revealed several interconnected thematic clusters. One cluster was centered on adulteration, traceability, and quality, indicating strong research attention toward product integrity and supply-chain transparency. A second cluster focused on authentication and molecular technologies, including PCR, DNA extraction, DNA quantification, and SNP-based approaches. Another cluster emphasized authenticity, chemometrics, food authentication, and analytical methods, highlighting the importance of analytical technologies in product verification. Additionally, a smaller cluster associated with geographical origin, machine learning, and classification approaches reflected the increasing use of computational tools for authentication and traceability studies. The network structure demonstrates the multidisciplinary nature of coffee authentication research and the integration of molecular, analytical, and data-driven approaches

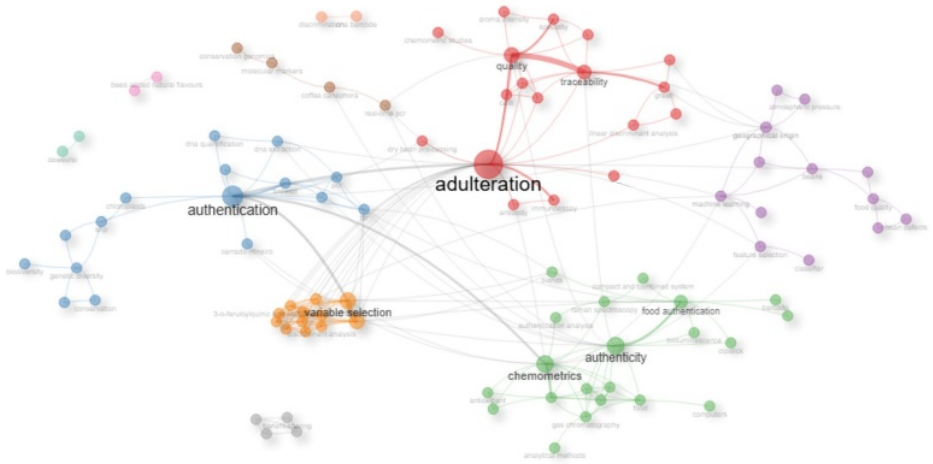

Figure 3. Conceptual Structure of Research Themes Based on Author Keyword Co-occurrence.

Thematic Structure of Coffee Authentication and Traceability Research

The thematic structure of the field was evaluated using thematic mapping analysis, which classifies research themes according to their centrality and density values (Figure 4). This approach enables the identification of well-developed themes, foundational topics, specialized areas, and emerging research directions.

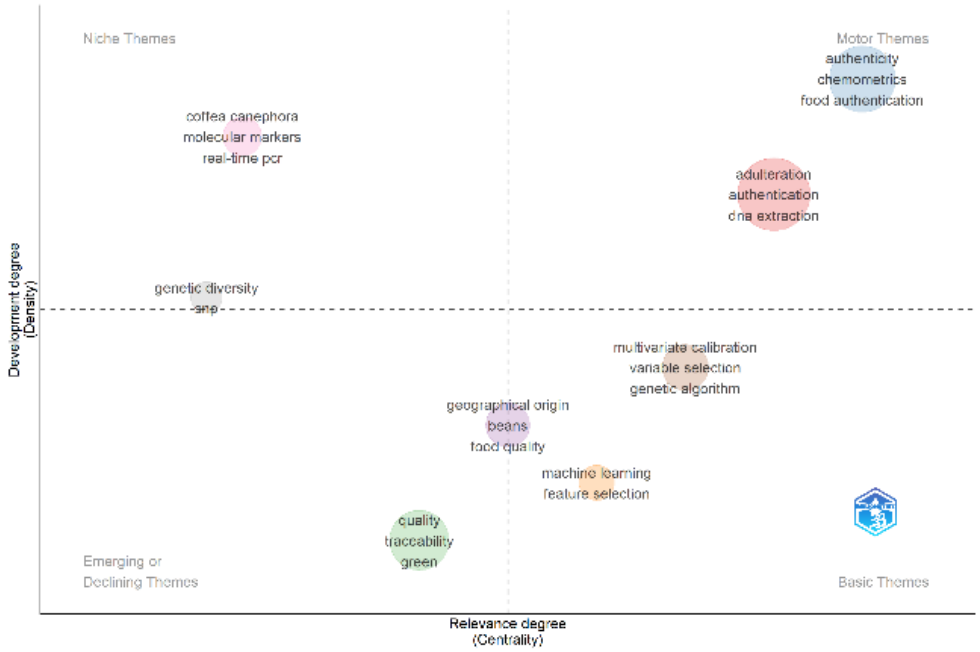

Figure 4. Thematic Structure of Coffee Authentication and Traceability Research.

The thematic map revealed several distinct thematic groups. Motor themes were dominated by authenticity, chemometrics, and food authentication, indicating that these topics represent well-developed and influential areas within the research field. Another motor theme cluster included adulteration, authentication, and DNA extraction, reflecting the importance of molecular approaches for product verification and fraud detection. Basic themes consisted of machine learning, multivariate calibration, variable selection, and genetic algorithms, suggesting their role as supporting methodologies for authentication studies. Niche themes were represented by Coffea canephora,

molecular markers, and real-time PCR, indicating specialized areas of investigation. Meanwhile, themes associated with quality, traceability, and green coffee were positioned within the emerging or developing thematic region of the map.

Evolution of Research Themes

Thematic evolution analysis was conducted to examine the temporal progression of major research topics and to identify shifts in scientific focus across different periods (Figure 5).

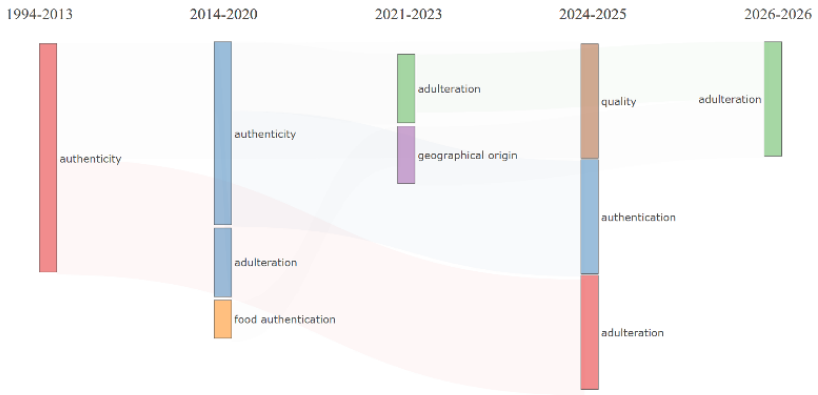

Figure 5. Evolution of Research Themes in Coffee Authentication and Traceability Research.

The thematic evolution analysis demonstrated a progressive transformation of research interests over time. During the earliest period, authenticity emerged as the dominant theme. In subsequent years, research expanded toward food authentication and adulteration-related topics. More recent periods showed increasing attention to geographical origin verification, quality assessment, and authentication systems. The results indicate that the field has evolved from basic authenticity verification toward more comprehensive approaches incorporating product integrity, origin determination, and supply-chain transparency. The continuity of several themes across different periods further highlights their sustained importance within coffee authentication and traceability research.

Intellectual Structure of the Research Field

The intellectual structure of the field was explored through author co-citation analysis, which identifies influential authors and research communities based on patterns of joint citation (Figure 6). The co-citation network revealed several major intellectual clusters within the field. One cluster was dominated by authors such as Bertrand, Combes, Pereira, and Caixeta, whose studies contributed substantially to coffee genetics, varietal identification, and molecular authentication. A second cluster included authors such as Pellegrino, Trouslot, and Oliveira, reflecting research focused on authenticity assessment and product characterization. A third cluster was represented by authors including Monakhova, Kemsley, Watson, and related researchers associated with chemometrics, spectroscopy, and food authentication methodologies. The presence of multiple interconnected clusters indicates that the field has developed through contributions from diverse scientific disciplines, including molecular biology, food chemistry, analytical science, and agricultural research.

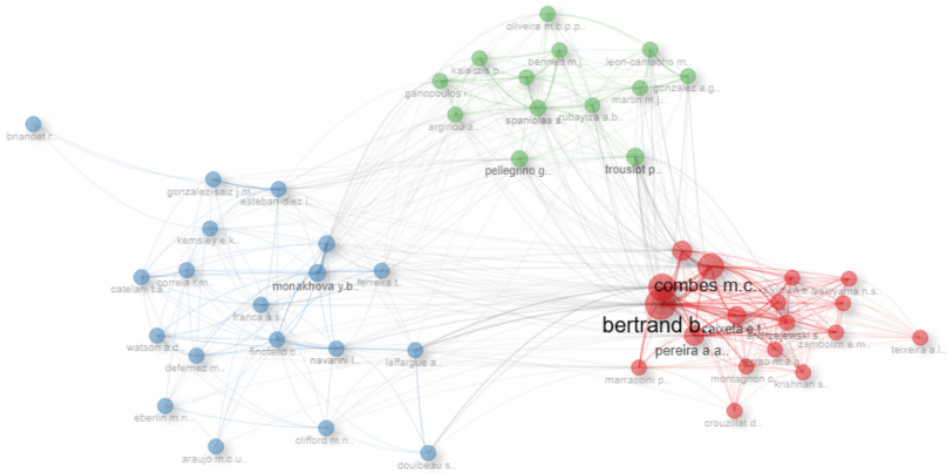

Figure 6. Author Co-citation Network in Coffee Authentication and Traceability Research.

Discussion

The bibliometric analysis revealed a substantial increase in scientific interest in coffee authentication and traceability technologies over the last three decades. The annual publication trend demonstrated relatively limited research activity during the early years of the study period, followed by a notable expansion after 2012 and accelerated growth after 2020. This pattern reflects the increasing importance of food authenticity, supply-chain transparency, and fraud prevention within the global food industry. The growing demand for premium coffee products, specialty coffee markets, and geographical origin certification has likely contributed to the increased need for reliable authentication and traceability systems [24]. As coffee products become more diversified and integrated into complex international supply chains, ensuring product authenticity has become a critical challenge for producers, regulators, and consumers [25].

The analysis of publication sources further highlighted the multidisciplinary nature of this research field. The dominance of journals such as *Food Chemistry*, *Journal of Agricultural and Food Chemistry*, *Food Control*, *LWT*, and *Talanta* indicates that coffee authentication research is strongly rooted in food science, analytical chemistry, and quality assurance. This finding suggests that researchers have increasingly relied on advanced analytical methods to address challenges associated with adulteration detection, authenticity verification, and traceability assessment. The prominence of these journals also reflects the growing recognition that authentication technologies are essential components of modern food integrity systems and are no longer limited to traditional quality control approaches.

The geographical distribution of scientific production demonstrated the leading roles of Brazil, China, and the United States in advancing research related to coffee authentication and traceability. Brazil's dominance is not surprising given its position as one of the world's largest coffee producers and exporters [26]. The country's extensive coffee industry has generated strong incentives for research on varietal identification, geographical origin verification, and quality assurance [27]. China has emerged as a major contributor due to its rapidly expanding capabilities in analytical chemistry, chemometrics, machine learning, and food authentication research. Meanwhile, the United States continues to contribute significantly through advanced research infrastructure and interdisciplinary collaborations involving food science, agricultural research, and analytical technologies. The geographical pattern also reflects differences in research investment, analytical infrastructure, and scientific publication capacity among coffee-producing countries. Although Indonesia appeared among the contributing countries, its scientific output remained relatively

modest compared with these leading nations. This finding is noteworthy considering Indonesia's strategic position as a major coffee-producing country, one of the world's largest coffee-consuming markets, and the country with the largest Muslim population [28], [29], [30]. The disparity highlights significant opportunities for strengthening research capacity and international collaboration in coffee authentication and traceability studies.

The keyword co-occurrence network revealed that research in this field is organized around several interconnected thematic clusters. The first major cluster focused on adulteration, traceability, and quality, emphasizing the growing importance of product integrity and supply-chain transparency. A second cluster was centered on authentication and molecular technologies, including PCR, DNA extraction, DNA quantification, and SNP-based approaches. These methods provide highly specific biological information and have become valuable tools for species identification, varietal discrimination, and fraud detection [31]. A third cluster highlighted authenticity, chemometrics, and food authentication, reflecting the widespread adoption of analytical technologies for product verification. Finally, the emergence of machine learning and geographical origin verification demonstrates increasing interest in data-driven approaches capable of supporting large-scale authentication and traceability systems [32]. Collectively, these findings indicate that coffee authentication research has evolved into a multidisciplinary field integrating molecular biology, analytical chemistry, food science, and computational methods.

The thematic map provides further insight into the maturity and development of research themes within the field. The identification of authenticity, chemometrics, and food authentication as motor themes indicates that analytical approaches currently represent the most influential and well-developed research area. This observation is consistent with the dominance of food chemistry and analytical science journals identified in the source analysis. Analytical technologies such as spectroscopy, chromatography, mass spectrometry, and chemometric modeling offer rapid, non-destructive, and highly accurate approaches for product authentication, making them particularly attractive for industrial applications. In contrast, molecular markers, real-time PCR, and Coffea canephora-related studies were classified as niche themes, suggesting that molecular approaches represent specialized but highly developed research domains. Although molecular technologies may currently occupy a smaller thematic space than analytical methods, their ability to provide direct biological evidence makes them indispensable for species-level authentication and adulteration detection.

The thematic evolution analysis demonstrated a clear progression of research interests over time. Early studies were primarily focused on authenticity verification, reflecting initial efforts to establish reliable methods for distinguishing genuine coffee products from fraudulent alternatives. Subsequent research expanded toward food authentication and adulteration detection, indicating growing concerns regarding food fraud and product integrity. More recent studies increasingly emphasized geographical origin verification, quality assessment, and traceability systems. This progression suggests a shift from simple authenticity testing toward comprehensive approaches that integrate origin determination, supply-chain monitoring, and quality assurance. Such evolution mirrors broader developments in global food systems, where consumers, regulators, and certification bodies increasingly demand transparency and accountability throughout the production chain [33].

The intellectual structure of the field further supports the multidisciplinary character of coffee authentication research. The co-citation network revealed distinct communities of researchers specializing in molecular authentication, coffee genetics, food chemistry, chemometrics, and analytical methodologies. The presence of multiple interconnected intellectual clusters indicates that advances in coffee authentication have been driven by collaboration among researchers from diverse scientific backgrounds. This interdisciplinary foundation has facilitated the integration of molecular and

analytical technologies, enabling more robust and reliable authentication systems than would be possible through a single methodological approach.

One of the most important findings of this study is the complementary relationship between molecular and analytical technologies. Rather than competing approaches, these technologies address different dimensions of authentication and traceability. Molecular methods provide direct biological evidence regarding species identity, varietal composition, and genetic authenticity, whereas analytical methods generate chemical fingerprints capable of identifying geographical origin, processing history, and compositional characteristics [34], [35]. The integration of these approaches may therefore represent the most promising strategy for future authentication systems. Recent developments in machine learning, artificial intelligence, and advanced statistical modeling further enhance the potential for combining multiple data sources into comprehensive authentication frameworks capable of supporting real-time decision-making and large-scale supply-chain monitoring [36].

The findings of this study also have important implications for strengthening Halal Assurance Systems. Although coffee is generally recognized as a halal commodity, modern coffee products often undergo complex processing, blending, flavoring, extraction, and distribution processes that may introduce risks related to adulteration, contamination, and misrepresentation [37]. Consequently, halal assurance increasingly requires more than simple ingredient verification. Effective halal assurance depends upon the ability to verify product authenticity, confirm ingredient integrity, detect unauthorized substitutions, and ensure transparency throughout the supply chain [38], [39]. The major research themes identified in this study-including authentication, adulteration detection, traceability, quality assessment, molecular identification, and analytical verification-closely align with these requirements.

This study has several limitations that should be acknowledged. The analysis was based exclusively on the Scopus database and was limited to English-language journal articles published in their final form. Consequently, relevant publications indexed in other databases or published in other languages may not have been captured. In addition, bibliometric analysis primarily evaluates publication patterns and intellectual structures rather than the technical performance of individual authentication technologies. Future studies may integrate multiple databases and systematic review approaches to provide a more comprehensive understanding of technological developments in coffee authentication and traceability research.

Overall, the bibliometric evidence demonstrates that coffee authentication and traceability research has evolved into a dynamic and multidisciplinary scientific field characterized by increasing technological sophistication and growing relevance to food integrity. The continued expansion of research activities, coupled with advances in molecular, analytical, and computational technologies, is expected to further enhance the reliability of authentication systems. These developments not only contribute to product quality and supply-chain transparency but also provide important scientific foundations for strengthening Halal Assurance Systems in the global coffee industry.

CONCLUSION

This bibliometric study demonstrated that research on molecular and analytical technologies for coffee authentication and traceability has grown substantially over the past three decades, with authenticity, adulteration detection, chemometrics, food authentication, and traceability emerging as the dominant research themes. The findings indicate a clear transition from basic authenticity verification toward integrated approaches involving geographical origin determination, quality assessment, and supply-chain transparency. Furthermore, the results highlight the complementary roles of molecular technologies, such as PCR-based methods and molecular markers, and analytical approaches, including spectroscopy, chromatography, mass spectrometry, and chemometrics, in

supporting reliable product verification. These developments provide a strong scientific foundation for strengthening Halal Assurance Systems by enhancing product integrity, traceability, authenticity, and consumer confidence. Future research should focus on integrating molecular authentication, analytical fingerprinting, artificial intelligence, and digital traceability technologies to establish more comprehensive, transparent, and robust halal verification frameworks for the global coffee industry.

AUTHORS INFORMATION

Corresponding Authors

Nindy Permatasari – Department of Plantation Crop Cultivation, Politeknik Negeri Lampung (Indonesia);
https://orcid.org/0009-0002-2659-0531
Email: nindypermatasari@polinela.ac.id

Authors

Priyambodo – Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Lampung (Indonesia);
https://orcid.org/0000-0003-1856-2637
Email: priyambodo@fmipa.unila.ac.id

Nindy Permatasari – Department of Plantation Crop Cultivation, Politeknik Negeri Lampung (Indonesia);
https://orcid.org/0009-0002-2659-0531
Email: nindypermatasari@polinela.ac.id

Siti Hamidatul Aliyah –Center for Biomedical Research, National Research and Innovation Agency (Indonesia)
https://orcid.org/0000-0003-0017-3123
Email: siti117@brin.go.id

Aulia Ulmillah – Universitas Islam Negeri Raden Intan Lampung (Indonesia);
https://orcid.org/0000-0002-8609-4575
Email: aulia@radenintan.ac.id

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] W. Ahmed, A. Najmi, H. M. Faizan, and S. Ahmed, "Consumer behaviour towards willingness to pay for Halal products: An assessment of demand for Halal certification in a Muslim country," *British Food Journal*, vol. 121, no. 2, pp. 492–504, Oct. 2018, doi: 10.1108/BFJ-02-2018-0085.

[2] N. Ab Rashid and J. Bojei, "The relationship between halal traceability system adoption and environmental factors on halal food supply chain integrity in Malaysia," *Journal of Islamic Marketing*, vol. 11, no. 1, pp. 117–142, Jun. 2019, doi: 10.1108/JIMA-01-2018-0016.

[3] L. A. H. F. Dashti, T. Jackson, A. West, and L. Jackson, "Enhancing halal food traceability: a model for rebuilding trust and integrity in Muslim countries," *Journal of Islamic Marketing*, vol. 15, no. 12, pp. 3382–3408, Aug. 2024, doi: 10.1108/JIMA-06-2023-0167.

[4] A. Sachedina, "The politics of the coffee pot: Its changing role in history-making and the place of religion in the Sultanate of Oman," *Hist. Anthropol. Chur.*, vol. 30, no. 3, pp. 233–255, May 2019, doi: 10.1080/02757206.2019.1594803.
[5] H. Mahamid and C. Nissim, "Sufis and Coffee Consumption: Religio-Legal and Historical Aspects of a Controversy in the Late Mamluk and Early Ottoman Periods," *Journal of Sufi Studies*, vol. 7, no. 1–2, pp. 140–164, 2018, doi: https://doi.org/10.1163/22105956-12341311.
[6] T. Tadesse, B. Tesfaye, and G. Abera, "Coffee production constraints and opportunities at major growing districts of southern Ethiopia," *Cogent Food Agric.*, vol. 6, no. 1, p. 1741982, Jan. 2020, doi: 10.1080/23311932.2020.1741982.
[7] E. Noaime, C. Alalouch, A. Mesloub, H. Hamdoun, H. Gnaba, and M. M. Alnaim, "Sustainable cities and urban dynamics: The role of the café culture in transforming the public realm," *Ain Shams Engineering Journal*, vol. 16, no. 3, p. 103320, 2025, doi: https://doi.org/10.1016/j.asej.2025.103320.
[8] C. L. R. Vegro and L. F. de Almeida, "Chapter 1 - Global coffee market: Socio-economic and cultural dynamics," in *Coffee Consumption and Industry Strategies in Brazil*, L. F. de Almeida and E. E. Spers, Eds., Woodhead Publishing, 2020, pp. 3–19. doi: https://doi.org/10.1016/B978-0-12-814721-4.00001-9.
[9] R. Utrilla-Catalan, R. Rodríguez-Rivero, V. Narvaez, V. Díaz-Barcos, M. Blanco, and J. Galeano, "Growing Inequality in the Coffee Global Value Chain: A Complex Network Assessment," *Sustainability*, vol. 14, no. 2, 2022, doi: 10.3390/su14020672.
[10] R. C. Alves, F. Rodrigues, M. Antónia Nunes, A. F. Vinha, and M. B. P. P. Oliveira, "Chapter 1 - State of the art in coffee processing by-products," in *Handbook of Coffee Processing By-Products*, C. M. Galanakis, Ed., Academic Press, 2017, pp. 1–26. doi: https://doi.org/10.1016/B978-0-12-811290-8.00001-3.
[11] A. Haider *et al.*, "Food authentication, current issues, analytical techniques, and future challenges: A comprehensive review," *Compr. Rev. Food Sci. Food Saf.*, vol. 23, no. 3, p. e13360, May 2024, doi: https://doi.org/10.1111/1541-4337.13360.
[12] H. Hesim and S. A. Alkadrie, "Modeling Supply Chain Integrity in Food Manufacturing: Contamination Risk, Implementation Barriers, and an Islamic Governance-Based Framework," *International Journal of Business and Innovation Management*, vol. 1, no. 1, pp. 58–77, Apr. 2026, [Online]. Available: https://journal.unesa.ac.id/index.php/ijbim/article/view/52972
[13] V. Fanelli, I. Mascio, M. M. Miazzi, M. A. Savoia, C. De Giovanni, and C. Montemurro, "Molecular Approaches to Agri-Food Traceability and Authentication: An Updated Review," *Foods*, vol. 10, no. 7, 2021, doi: 10.3390/foods10071644.
[14] N. Nehal, B. Choudhary, A. Nagpure, and R. K. Gupta, "DNA barcoding: a modern age tool for detection of adulteration in food," *Crit. Rev. Biotechnol.*, vol. 41, no. 5, pp. 767–791, Jul. 2021, doi: 10.1080/07388551.2021.1874279.
[15] C. Liu, Z. Zuo, F. Xu, and Y. Wang, "Authentication of Herbal Medicines Based on Modern Analytical Technology Combined with Chemometrics Approach: A Review," *Crit. Rev. Anal. Chem.*, vol. 53, no. 7, pp. 1393–1418, Oct. 2023, doi: 10.1080/10408347.2021.2023460.
[16] H. Chen *et al.*, "Geographical Origin Traceability of Tea (Camellia sinensis): A Comprehensive Review of Analytical Techniques, Chemometric Approaches, and Future Perspectives," *Foods*, vol. 15, no. 11, 2026, doi: 10.3390/foods15111936.

[17] P. R. Polu, M. Vyas, and M. Ravindra Babu, "State-of-the-Art Analytical Technologies for Detection of Food Adulteration: Advances, Validation, and Future Horizons," *Crit. Rev. Anal. Chem.*, pp. 1–27, Feb. 2026, doi: 10.1080/10408347.2026.2625392.
[18] D. Fernando, A. R. A. Madja, A. A. M. B. Hastuti, D. Santosa, and A. Rohman, "Trending analytical methods in assessing coffee authentication: An overview of reviews and bibliometric analysis," *Journal of Food Measurement and Characterization*, vol. 19, no. 12, pp. 9319–9353, 2025, doi: 10.1007/s11694-025-03666-z.
[19] J. Frigerio *et al.*, "Convergent technologies to tackle challenges of modern food authentication," *Heliyon*, vol. 10, no. 11, Jun. 2024, doi: 10.1016/j.heliyon.2024.e32297.
[20] C. Chen *et al.*, "Research Progress of Traceability Technologies for Large-Scale Geographical Specialty Food Origins," *Food Reviews International*, pp. 1–34, Feb. 2026, doi: 10.1080/87559129.2026.2631784.
[21] M. Aria and C. Cuccurullo, "bibliometrix: An R-tool for comprehensive science mapping analysis," *J. Informetr.*, vol. 11, no. 4, pp. 959–975, 2017, doi: https://doi.org/10.1016/j.joi.2017.08.007.
[22] D. K. Narong and P. Hallinger, "A Keyword Co-Occurrence Analysis of Research on Service Learning: Conceptual Foci and Emerging Research Trends," *Educ. Sci. (Basel).*, vol. 13, no. 4, 2023, doi: 10.3390/educsci13040339.
[23] P. K. Hota, B. Subramanian, and G. Narayanamurthy, "Mapping the Intellectual Structure of Social Entrepreneurship Research: A Citation/Co-citation Analysis," *Journal of Business Ethics*, vol. 166, no. 1, pp. 89–114, 2020, doi: 10.1007/s10551-019-04129-4.
[24] V. León-Bravo, F. Ciccullo, and F. Caniato, "Traceability for sustainability: seeking legitimacy in the coffee supply chain," *British Food Journal*, vol. 124, no. 8, pp. 2566–2590, Apr. 2022, doi: 10.1108/BFJ-06-2021-0628.
[25] J. A. Barreto Peixoto, J. F. Silva, M. B. P. P. Oliveira, and R. C. Alves, "Sustainability issues along the coffee chain: From the field to the cup," *Compr. Rev. Food Sci. Food Saf.*, vol. 22, no. 1, pp. 287–332, Jan. 2023, doi: https://doi.org/10.1111/1541-4337.13069.
[26] T. Agnola, L. Ambrosini, E. Beretta, and G. Gremlich, "Empowering Global Supply Chains Through Blockchain-Based Platforms: New Evidence from the Coffee Industry," *FinTech*, vol. 4, no. 1, 2025, doi: 10.3390/fintech4010003.
[27] G. H. Sera, B. Volsi, V. Mariucci Júnior, C. T. M. Pereira, and T. S. Telles, "Production and trade of specialty coffee in Brazil," *Sci. Rep.*, vol. 15, no. 1, p. 42403, 2025, doi: 10.1038/s41598-025-26620-x.
[28] R. W. Hefner, "Christians, Conflict, and Citizenship in Muslim-Majority Indonesia," *Rev. Faith Int. Aff.*, vol. 15, no. 1, pp. 91–101, Jan. 2017, doi: 10.1080/15570274.2017.1284403.
[29] M. I. Ma'ruf, D. M. Ngo, Z. Bacsi, and N. Bozsik, "Evaluating the competitiveness of leading coffee-producing nations: A comparative advantage analysis across coffee product categories," vol. 10, no. 1, 2025, doi: doi:10.1515/opag-2025-0457.
[30] F. Ashardiono and A. Trihartono, "Optimizing the potential of Indonesian coffee: a dual market approach," *Cogent Soc. Sci.*, vol. 10, no. 1, p. 2340206, Dec. 2024, doi: 10.1080/23311886.2024.2340206.
[31] M. M. F. Azizi, H. Y. Lau, and N. Abu-Bakar, "Integration of advanced technologies for plant variety and cultivar identification," *J. Biosci.*, vol. 46, no. 4, p. 91, 2021, doi: 10.1007/s12038-021-00214-x.
[32] L. Zhang, Z. Qin, B. Xu, W. Li, Y. Wu, and G. Li, "Machine learning-driven intelligent transformation of food safety: from multi-source risk identification to whole-chain

preventive control," *Crit. Rev. Food Sci. Nutr.*, vol. 66, no. 18, pp. 3368–3385, Jul. 2026, doi: 10.1080/10408398.2025.2605110.
[33] A. Gerardi, "Chapter 70 - Global Food Safety Initiative (GFSI): underpinning the safety of the global food chain, facilitating regulatory compliance, trade, and consumer trust," in *Present Knowledge in Food Safety*, M. E. Knowles, L. E. Anelich, A. R. Boobis, and B. Popping, Eds., Academic Press, 2023, pp. 1089–1098. doi: https://doi.org/10.1016/B978-0-12-819470-6.00058-5.
[34] S. Sentellas and J. Saurina, "Authentication of Cocoa Products Based on Profiling and Fingerprinting Approaches: Assessment of Geographical, Varietal, Agricultural and Processing Features," *Foods*, vol. 12, no. 16, 2023, doi: 10.3390/foods12163120.
[35] M. Wang, H. Lin, H. Lin, P. Du, and S. Zhang, "From Species to Varieties: How Modern Sequencing Technologies Are Shaping Medicinal Plant Identification," *Genes (Basel).*, vol. 16, no. 1, 2025, doi: 10.3390/genes16010016.
[36] M. Shamsuddoha, H. Zimmerman, T. Nasir, and M. N. Sakib, "Autonomous Supply Chains: Integrating Artificial Intelligence, Digital Twins, and Predictive Analytics for Intelligent Decision Systems," *Information*, vol. 17, no. 4, 2026, doi: 10.3390/info17040371.
[37] T. Ferreira, L. Galluzzi, T. de Paulis, and A. Farah, "Three centuries on the science of coffee authenticity control," *Food Research International*, vol. 149, p. 110690, 2021, doi: https://doi.org/10.1016/j.foodres.2021.110690.
[38] A. Amid, "Halal Detection Technologies," in *Solving Halal Industry Issues Through Research in Halal Sciences*, A. Amid, A. A. M. Elgharbawy, and W. A. Abualsunun, Eds., Singapore: Springer Nature Singapore, 2024, pp. 41–54. doi: 10.1007/978-981-97-3843-4_3.
[39] R. M. Ellahi, L. C. Wood, M. Khan, and A. E.-D. A. Bekhit, "Integrity Challenges in Halal Meat Supply Chain: Potential Industry 4.0 Technologies as Catalysts for Resolution," *Foods*, vol. 14, no. 7, 2025, doi: 10.3390/foods14071135.