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Bibliometric Exploration of Research Trends and Opportunities in Coffee Post-Harvest Processing

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ABSTRACT

Coffee is a premier commodity that plays a crucial role in the global economy, with developing countries such as Brazil and Indonesia contributing over 90% of world coffee production. The post-harvest processing of coffee is a critical stage that determines the final quality and flavour profile of coffee beans, yet it still faces various challenges such as quality loss, contamination, and process efficiency. The objective of this bibliometric analysis is to examine the trajectory of research developments in coffee post-harvest processing. Results indicate that research on coffee post-harvest processing has grown significantly since 1991, with a dramatic increase in publications since 2015. Brazil, Indonesia, and Colombia dominate research contributions, reflecting their positions as major global coffee producers. However, non-producing countries such as France and Germany also demonstrate high research interest. The focus of research has evolved from fundamental aspects like coffee bean characteristics and chemical components to more complex processing methods such as fermentation and roasting. In recent years, increased attention has been given to sensory analysis, quality control, and food safety, including the prevention of mycotoxin contamination. Factors such as altitude of cultivation, processing methods (wet or dry), and fermentation techniques are shown to significantly influence coffee quality and sensory profiles. Research also highlights the importance of microorganisms in the fermentation process for developing coffee aroma. International research collaboration is quite intensive, with an average of 4.82 authors per document. Leading journals in this field include Coffee Science, Food Research International, and European Food Research and Technology. Current research trends are directed towards optimizing post-harvest processes to enhance coffee quality, developing more sophisticated analytical methods, and efforts to improve sustainability and add value in the global coffee production chain.

Keywords: Bibliometric Analysis, Coffee Processing, Food safety, Research trends

INTRODUCTION

Coffee is a premier commodity that plays a crucial role in the global industry. Developing countries such as Brazil and Indonesia contribute over 90% of global coffee production, providing income for 25 million small-scale farmers worldwide (Garcia-Freites et al., 2020). Countries like Brazil, Vietnam, Colombia, and Indonesia are the world's largest coffee producers (Prajogo et al., 2020).

Coffee beans are a significant agricultural commodity in international trade, with developing countries primarily serving as producers and developed countries in Europe and America as consumers. The coffee agriculture industry, particularly in upstream processes such as planting and harvesting, directly involves small-scale farmers, thus contributing directly to their economic welfare (Van Duy et al., 2023; Vegro and de Almeida, 2020a). The International Coffee Organisation reports that coffee bean consumption and demand continue to increase.
The coffee post-harvest process faces various challenges and issues, including quality loss, contamination, and process efficiency (Tesfa, 2019). Quality loss can occur due to improper handling, such as uneven drying or inadequate storage (Aung Moon et al., 2022; Błaszkiewicz et al., 2023; de Andrade et al., 2022). Contamination of coffee beans can originate from various sources, including pesticide residues, heavy metals, and other chemicals used during coffee cultivation. Furthermore, inefficient post-harvest processes can lead to resource waste and higher production costs (Seniūnaitė et al., 2014; Viegas et al., 2022).

Coffee post-harvest processing is a critical stage that determines the final quality and flavour profile of coffee beans. The process of maintaining and preserving coffee quality has become a serious concern for researchers in various countries. Diverse innovations and treatments for harvested coffee are continuously being developed to maximize coffee quality, such as research on innovations in separating the husk from coffee beans(Dominguez and Lavarias, 2022) treatments in the drying process (Arévalo et al., 2023; Konopatzki et al., 2022) and coffee bean fermentation(Milić et al., 2023; Wu et al., 2023).

To address these challenges, research and development of technology and innovation in coffee post-harvest processing have become crucial. The implementation of new methods, equipment, and techniques such as more efficient and environmentally friendly demucilaging, fermentation, washing, soaking, drying, and dehulling can enhance the quality and efficiency of the post-harvest process(Dominguez and Lavarias, 2022)(Milić et al., 2023; Wu et al., 2023). Research opportunities in coffee post-harvest processing remain extensive for developing new solutions and innovations that can enhance quality, efficiency, and sustainability. Research and

development in this field are crucial for maintaining competitiveness and increasing the added value of Indonesian coffee products in the global market. To systematically examine the development of research and innovation in coffee post-harvest processing, a bibliometric approach can be an effective method for mapping the current research landscape and identifying future opportunities.

Bibliometric-based research is a quantitative study that provides an overview of a research field (Merigó and Yang, 2017) This study involves analysing papers, authors, and journals to identify relevant research and trends in a particular field (Yoshida, 2010). The analysis includes identifying influential journals, highly cited papers, productive authors, and the thematic structure of the research field. This can help optimize and coordinate research efforts, identify research areas, and rank and characterize research performance.

Various published articles relate to bibliometric studies concerning coffee, such as research on knowledge about coffee consumption behaviour (Wang, 2024), studies on the relationship between sports and coffee/caffeine (Gutiérrez-Hellín et al., 2023) the effect of coffee/caffeine consumption on fat oxidation (Bento et al., 2023). and remote sensing technology in coffee farming methods [21]. To date, there have been no articles related to bibliometric analysis of post-harvest research on coffee, making it important to observe the developmental trends of research studies related to coffee post-harvest processing.

To support this bibliometric study, data on research articles related to coffee post-harvest processing were collected from the Scopus database. This study attempts to explore and review aspects of interest to scientists and packaging and food industry practitioners, such as (1) what are the trends in the development of coffee post-harvest research publications so far? (2) who are the most influential researchers on this research topic? (3) which countries contribute most to this research? (4) which journals and institutions publish most on this topic? (5) which publications are most cited? (6) examining research focus and conducting keyword analysis to identify future research opportunities.

METHODOLOGY

Data collection commenced with the identification of primary keywords "coffee" and "postharvest" for the formulation of an appropriate search query. The Scopus database was selected as the data source due to its comprehensive coverage and the quality of indexed journals. The data extraction procedure was conducted at 11:15 AM on 22 June 2022, with a temporal boundary established to mitigate temporal bias. The search, utilising Scopus' advanced interface, yielded a total of 333 documents, comprising 246 journal articles, 43 conference

papers, and 24 reviews. The data were subsequently exported in CSV or RIS format to facilitate further analysis.

The data cleansing process employed OpenRefine software version 3.6.1, chosen for its robust capabilities in handling large datasets. The cleansing procedure encompassed the removal of duplicates based on DOI or a combination of title and author, standardisation of author names, normalisation of institutional affiliations, verification of publication year consistency, and correction of typographical errors. Data validation was performed by examining the completeness of each entry and verifying data format consistency. This process was crucial to ensure data quality and reliability prior to further analysis.

Data analysis and visualisation utilised three primary software tools: Tableau version 2023.2 for general data visualisation, VOSviewer version 1.6.20 for bibliometric network analysis, and RStudio version 2024.4.1 with the bibliometrix package for advanced statistical analysis. The analysis encompassed annual publication trends, geographical distribution of research, identification of the most productive journals and authors, as well as keyword and research topic analysis. Network analysis was conducted to visualise collaborations among researchers, relationships between keywords, and thematic similarities among publications. Result visualisations included line graphs, heat maps, network diagrams, and thematic maps. The interpretation of results focused on identifying main trends in post-harvest coffee research, determining leading research groups and institutions, as well as identifying research gaps and potential future research directions.

RESULT

General Information

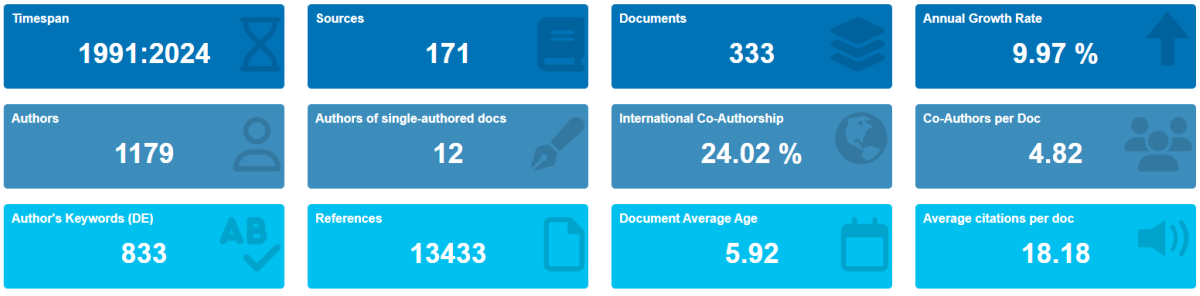

Figure 1. General bibliometric information on coffee post-harvest processing research from 1991 to 2024.

General information extracted from the Scopus database, using keywords related to coffee post-harvest processing, reveals that research on this theme began in 1991 and has continued to develop significantly until 2024. A total of 333 documents from 171 sources have

been published, with a growth rate of 9.97%. The average document age of 5.92 years indicates that the publications are relatively recent, yet they have a significant impact, as evidenced by an average of 18.18 citations per document.

Intensive collaboration among researchers is demonstrated by an average of 4.82 authors per document, with 24.02% representing international collaborations. This is further supported by the low number of single-author documents (15) compared to the total number of authors (1,179). Various types of publications were issued, including journal articles (246), conference papers (43), and reviews (24).

2. Publication Development Trend

An analysis of publication trends is necessary to identify developments in post-harvest coffee research. The graph in Figure 2 is divided into three phases. The initial phase spans from 1990 to 2002, characterized by low and sporadic publication rates. During this period, there were several years without any publications, indicating that research interest in this field was not yet significant.

The second phase covers the period from 2003 to 2014, during which there was an increase in the number of publications, albeit still at a low level, ranging from 3 to 11 publications per year, with the highest number of publications (11 documents) occurring in 2013. This demonstrates a growing interest in coffee post-harvest research.

In the third phase, from 2015 to 2024, there was a dramatic increase in the number of publications annually. A significant surge began in 2015, peaking in 2022 with 53 publications. Although there was a slight decline after 2022, the number of publications remained substantially higher compared to the first and second phases. Factors potentially contributing to this trend include the global increase in coffee consumption (Vegro and de Almeida, 2020b), as well as a more intensive focus on efforts to improve coffee product quality (Mahingsapun et al., 2022; Tran et al., 2016). This development reflects the scientific community's responsiveness to market dynamics and consumer demands for high-quality coffee, and indicates potential for sustained growth in research in this field in the future.

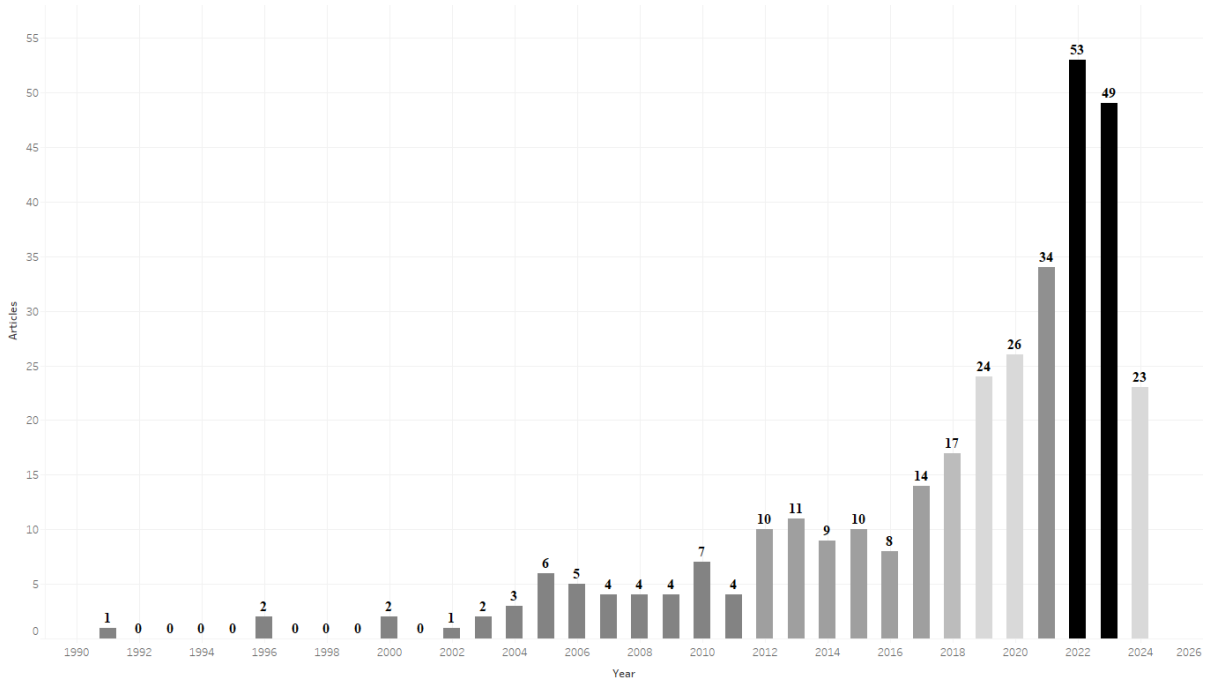

Figure **2.** Annual publication trend of coffee post-harvest processing research from 1991 to 2024

Most Influential Researcher

Research on coffee post-harvest processing has garnered significant attention from several eminent scholars in this field. Our analysis reveals that research contributions are measured not solely by the quantity of publications, but also by the impact and influence of their work within the scientific community. The following presents a concise profile of the five most influential researchers based on our bibliometric analysis.

Table 1. Top 5 most influential researchers in coffee post-harvest processing research

Authors	**Articles**	**Articles Fractionalized**
Flávio Meira Borém	23	4.84
Lucas Louzada Pereira	14	1.77
Dirk Selmar	9	2.93
Rogério Carvalho Guarçoni	8	0.84
Marcelo Ribeiro Malta	8	1.49

Research on coffee post-harvest processing has attracted the attention of several prominent researchers. Flávio Meira Borém emerges as the most prolific author with 23 articles and the highest fractional score of 4.84, indicating his significant role in this field. He is followed by Lucas Louzada Pereira with 14 articles and Dirk Selmar with 9 articles, both making substantial contributions with fractional scores of 1.77 and 2.93, respectively. Rogério Carvalho Guarconi and Marcelo Ribeiro Malta, despite having an equal number of articles (8),

demonstrate differences in their fractional scores, potentially reflecting varying levels of collaboration or distinct research foci.

Distribution of Publications by Country

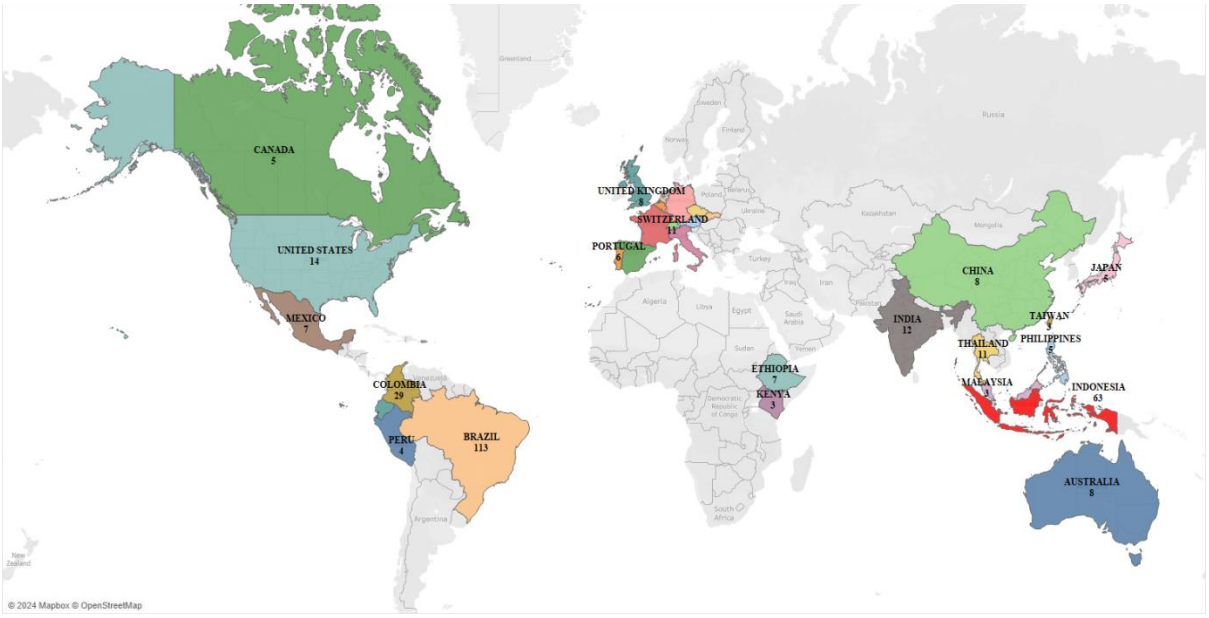

Figure 3. Geographic distribution of publications on coffee post-harvest processing research by country.

This analysis aims to examine the contributions of various countries and identify global research centers, with potential for international collaboration. Results indicate (Figure 3) that major coffee-producing countries dominate publications on this topic. The highest number of publications originates from Brazil, with a total of 113 documents, followed by Indonesia (63 documents) and Colombia (29 documents). The data indicate that Brazil, Indonesia, and Colombia contribute significantly to research output, reflecting their positions as primary global coffee producers. The data also reveals active participation from non-major producing countries, particularly from Europe. Countries such as France (23 publications), Germany (19), and Italy (10) indicate significant research interest and international collaboration in this field.

Total Publications of Each Journal

Bibliometric data table 2 reveals that Coffee Science is the journal with the highest number of publications, totalling 247 articles, followed by IOP Conference Series: Earth and Environmental Science with 25 articles, and Food Research International with 16 articles. This distribution of publications indicates that research related to coffee post-harvest processing is predominantly published in journals associated with coffee, environment, and food technology. Various articles are also published in highly reputable journals such as the Journal of

Agricultural and Food Chemistry (8 articles) and Food Chemistry (6 articles), demonstrating the relevance and quality of research in this field.

Journals such as LWT, Journal of Food Process Engineering, and Biodiversitas highlight the interdisciplinary nature of this research, also illustrating the complexity and breadth of topics in coffee post-harvest processing, which involves aspects such as processing technology, food chemistry, microbiology, and environmental science. The presence of conference journals like IOP Conference Series and AIP Conference Proceedings in the top list underscores the importance of scientific forums in disseminating current research on coffee post-harvest processing.

Table 2. Top 10 journals publishing research on coffee post-harvest processing

No.	Source	Articles	Total Citation	Publisher	Country	Q
1	Coffee Science	27	143	Editora UFLA	Brazil	Q3
2	Iop Conference Series: Earth and Environmental Science	25	49	IOP Publishing Ltd.	United Kingdom	Na
3	Food Research International	16	651	Elsevier Ltd.	United Kingdom	Q1
4	European Food Research and Technology	10	307	Spinger Verlag	Germany	Q1
5	Foods	10	100	MDPI	Switzerland	Q1
6	Journal Of Agricultural and Food Chemistry	8	298	American Chemical Society	United States	Q1
7	Food Chemistry	6	524	Elsevier Ltd.	United Kingdom	Q1
8	Acta Horticulturae	5	18	International Society for Horticultural Science	Belgium	Q4
9	Food Control	5	145	Elsevier B.V.	Netherlands	Q1
10	LWT	5	86	Academic Press	United States	Q1

6. Most Cited Articles

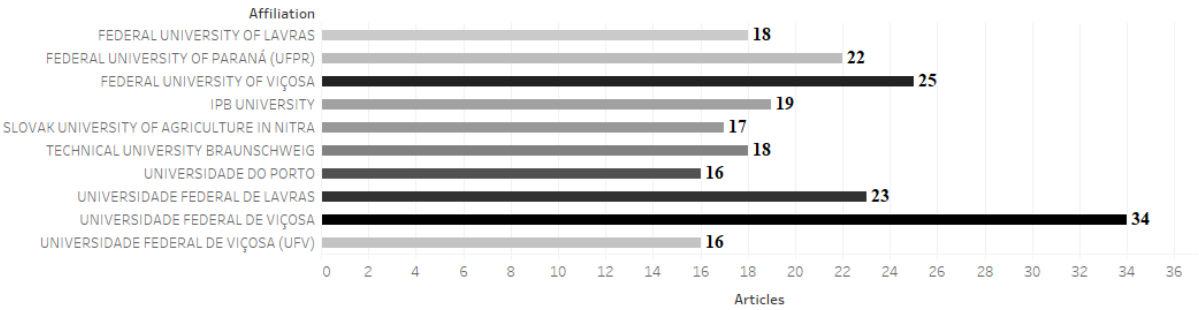

Figure 4. Distribution of publications on coffee post-harvest processing research by institutional affiliation.

The distribution of total publications by affiliation is dominated by universities from Brazil, with Universidade Federal de Viçosa leading with 76 publications, followed by Universidade Federal de Lavras with 51 publications, and Federal Institute of Espírito Santo (IFES) with 35 publications. This dominance reflects Brazil's position as the world's primary coffee producer. The presence of institutions from various countries, such as IPB University (Indonesia, 19 publications), Technical University Braunschweig (Germany, 18 publications), and Slovak University of Agriculture in Nitra (17 publications), demonstrates the global nature of this research, involving both coffee-producing and consuming nations.

The diversity of contributing institutions, including universities, research institutes, and industry entities like the Nestlé Research Center, illustrates a multi-stakeholder approach in knowledge development in this field. Significant contributions from institutions in developing countries, particularly Brazil and Indonesia, indicate efforts to enhance the value-added of coffee products through post-harvest research. Meanwhile, the involvement of institutions from developed countries such as Germany, Belgium, and Australia demonstrate global interest in improving the quality and sustainability of the coffee supply chain.

The Most Cited Articles

Table 3. Top 10 most cited articles in coffee post-harvest processing research

Authors	year	Journal	TC	Conclusions	Ref.
Thierry Joëta, Andréina Laffargue, Frédéric Descroix, Sylvie Doulbeau, Benoît Bertrand, Alexandre de kochko, Stéphane Dussert	2010	Food Chemistry	185	Chlorogenic acids and fatty acids in beans are regulated by mean air temperature during seed development. Conversely, total lipids, total soluble solids, total sugars, total polysaccharides, and total chlorogenic acids are not influenced by climate. Glucose is positively affected by altitude, while sorbitol content after wet processing directly depends on glucose content in fresh beans.	(Joët et al., 2010)
Gilberto V. de Melo Pereira, Dão P. de Carvalho Neto, Antonio I. Magalhães Júnior, Zulma S. Vásquez, Adriane B.P. Medeiros, Luciana	2017	Food Chemistry	182	Volatile compounds in green coffee beans have minimal impact on the final aroma. Odorant-active compounds from post-harvest processing influence coffee aroma composition. The main odorant-active compounds in	(G. V. de Melo Pereira et al., 2019)

P.S. Vandenberghe, Carlos R. Soccol				coffee are not found in raw beans	
Florac De Bruyn, Sophia Jiyuan Zhang, Vasileios Pothakos, Julio Torres, Charles Lambot, Alice V. Moroni, Michael Callanan, Wilbert Sybesma, Stefan Weckx, Luc De Vuyst	2016	Food Microbiology	172	During dry processing, acetic acid bacteria (i.e., Acetobacter and Gluconobacter) are most abundant, along with Pichia and non-Pichia yeasts (Candida, Starmerella, and Saccharomycopsis). Accumulation of related metabolites (e.g., gluconic acid and sugar alcohols) occurs in dry processing..	(De Bruyn et al., 2017)
Nicola Caporaso, Martin B. Whitworth, Chenhao Cui, Ian D. Fisk	2018	Food Research International	169	Single coffee bean variability can reach up to 179% CV. The most variable compounds are 2,3-butanediol, 3-ethylpyridine, and hexanal.	(Caporaso et al., 2018)
Sven Knopp, Gerhard Bytof, Dirk Selmar	2015	European Food Research and Technology	145	Dry processing increases fructose and glucose in coffee beans. Wet processing decreases sugar content in green coffee beans. Sucrose content remains unaffected by coffee processing methods. Minor sugars such as galactose and mannose are minimal.	(Knopp et al., 2006)
Aske Skovmand Bosselmann, Klaus Donsa, Thomas Oberthur, Carsten Smith Olsen, Anders Ræbild, Herman Usma	2009	Agriculture, Ecosystems and Environment	123	Shade negatively impacts sensory attributes, while altitude positively affects physical quality. Shade effects vary between high and low altitude areas. Shade reduces small beans in lowland areas. Shade trees can influence C. arabica cv. Caturra in highlands.	(Bosselmann et al., 2009)
Naresh Magan, David Aldred	2005	Food Additives and Contaminants	109	Issues exist during harvest and post-harvest. Efficient drying to prevent A. ochraceus formation is necessary. Typically, <12-13% moisture content in green coffee is recommended to avoid OTA contamination. Coffee is hygroscopic and thus absorbs water during storage and transportation.	(Magan and Aldred, 2005)

Gilberto Vinícius de Melo Pereira, Ensei Netob, Vanete Thomaz Soccol, Adriane Bianchi Pedroni Medeiros, Adenise Lorenci Woiciechowski, Carlos Ricardo Soccol,	2015	Food Research International	105	pH values correlate with bacterial growth, with lower pH in inoculated coffee bean fermentation. P. fermentans dominates yeast populations, maintained at over 80% in inoculated coffee bean fermentation. Inoculated fermentation increases yeast-derived metabolites, affecting the volatile fraction of coffee beans. Sucrose supplementation does not disrupt P. fermentans growth, maintaining wild bacteria.	(G. V. de Melo Pereira et al., 2015)
Mohammed Worku, Bruno de Meulenaer, Luc Duchateau, Pascal Boeckx	2017	Food Research International	103	Caffeine and chlorogenic acids contents decrease with altitude, while sucrose increases. Altitude affects acidity, physical quality, and sucrose content. Shade and post-harvest methods interact with altitude on coffee quality. Dry processing yields higher coffee bean quality than wet processing.	(Worku et al., 2018)
Oscar Gonzalez-Rios, Mirna L. Suarez-Quiroz, Renaud Boulanger, Michel Barel, Bernard Guyot, Joseph-Pierre Guiraud, Sabine Schorr-Galindo,	2006	Journal of Food Composition and Analysis	103	Mucilage removal from green coffee beans affects coffee aroma. Microbial removal enhances bean aroma. Mechanical mucilage removal causes unpleasant aromas in coffee beans. The HS-SPME method effectively extracts volatile compounds for coffee sample characterization.	(Gonzalez-Rios et al., 2007)

6. Keyword Analysis

The visualisation analysis (Figure 5) reveals four primary interconnected clusters, with 'coffee' as the central and largest keyword. This structure reflects the complexity and interrelation of various aspects in coffee post-harvest processing. The relationships between these clusters demonstrate that research in this field does not focus solely on a single aspect, but involves interactions between processing methods, sensory quality, food safety, and agronomic aspects.

The blue cluster is closely related to coffee processing, including "coffee arabica", "caffeine", and "coffee processing". The red cluster focuses on sensory aspects and quality, encompassing "sensory analysis", "quality control", and "postharvest". The green cluster pertains to food safety and contamination, involving keywords such as "mycotoxin", "food contamination", and "aspergillus". The yellow cluster relates to agronomic and chemical aspects of coffee, including "seeds", "plant seed", and "volatile organic compounds".

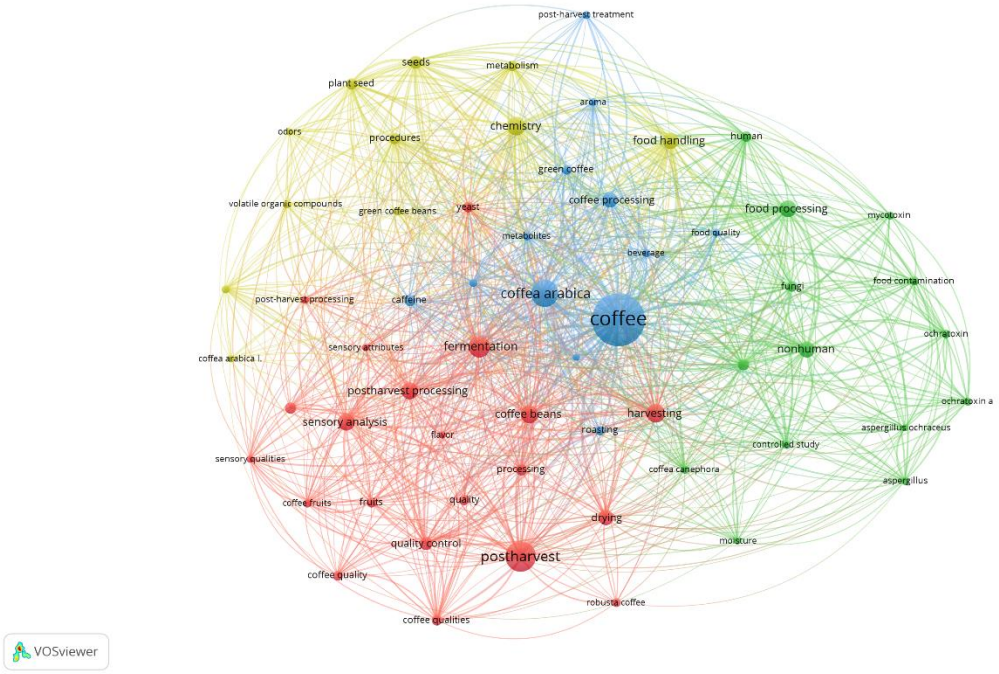

Figure 5 Visualization of keyword co-occurrence network in coffee post-harvest processing research

The interconnections among keywords illustrate the complexity and interrelation of various aspects in coffee post-harvest processing. For instance, the lines connecting "fermentation" with "aroma" and "sensory attributes" indicate the importance of fermentation processes in shaping the sensory profile of coffee (Perez et al., 2023). The connection between "food handling" and "food contamination" emphasizes the significance of good handling practices to avoid contamination. The link between "green coffee" and "roasting" illustrates critical stages in coffee processing that affect final quality (Bauer et al., 2018).

The varying node sizes indicate the frequency of keyword occurrence in the literature. Besides "coffee", keywords such as "postharvest", "coffee arabica", and "fermentation" have relatively large sizes, signifying that these aspects receive significant attention in research. The presence of keywords like "mycotoxin" and "ochratoxin" in the green cluster indicates a

research focus on food safety related to fungal contamination in coffee (Heintz et al., 2021; Pakshir et al., 2021; Ráduly et al., 2020). Meanwhile, the presence of "controlled study" and "human" signifies research involving human subjects, possibly related to the effects of coffee consumption (Safe et al., 2023) or sensory evaluation (Bruno et al., 2020).

Whilst our analysis indicates positive trends in coffee post-harvest processing research, it is crucial to note that significant gaps remain. For instance, research on the socio-economic impact of post-harvest practices on smallholder farmers remains limited, and studies on the environmental sustainability of various processing methods require further investigation.

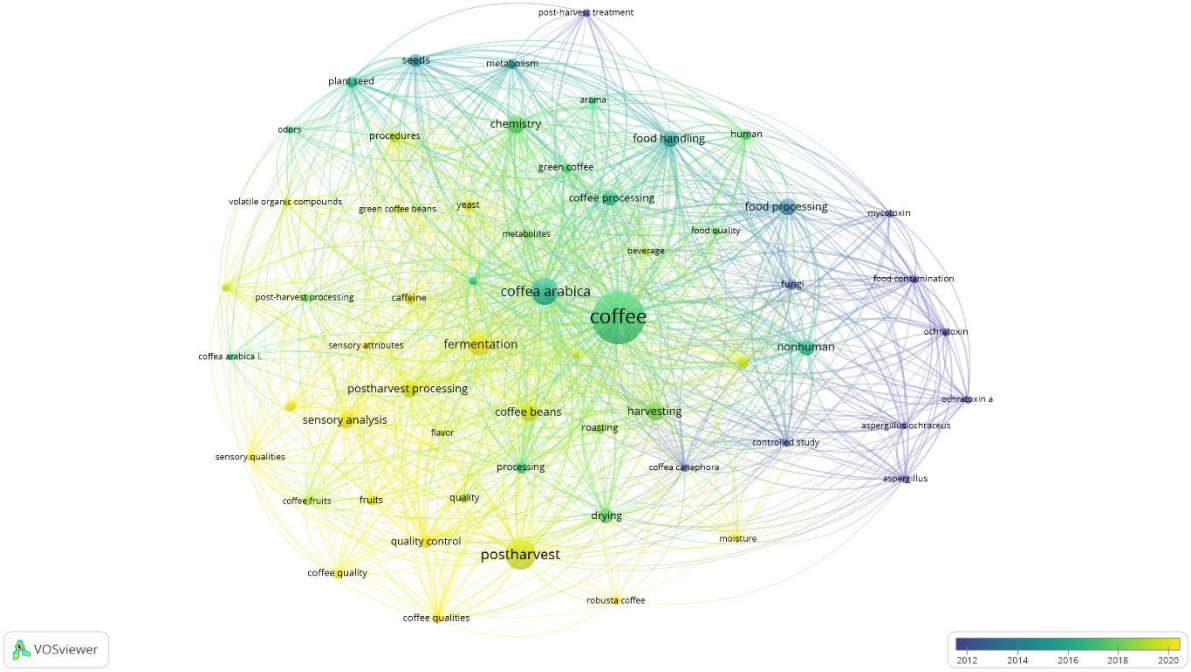

Figure 6 Temporal evolution of research themes in coffee post-harvest processing (2012-2020)

This visualization (Figure 6) illustrates the evolution of research focus in coffee post-harvest processing from 2012 to 2020. A significant shift and development in research topics are evident throughout this period.

In the early years (2012-2014), denoted by purple, the research focus was predominantly on fundamental aspects such as "seeds", "plant seed", and "volatile organic compounds". This indicates that during this period, research was primarily concerned with the basic characteristics of coffee beans and their chemical components. Over time, the focus shifted towards processing methods, marked by the emergence of blue-colored keywords such as "coffee processing", "roasting", and "fermentation" in the middle period (around 2014-2016). This shift signifies an increased interest in coffee processing techniques that can influence the final product quality.

In the latter years (2018-2020), indicated by yellow and green colors, research development trends towards more complex and diverse areas. Keywords such as "sensory analysis", "quality control", and "postharvest" become more prominent, demonstrating increased attention to quality aspects and sensory evaluation of coffee. Additionally, the emergence of keywords like "food handling", "food contamination", and "mycotoxin" in green color signifies growing awareness of food safety importance in the coffee industry. This development reflects the industry's increasingly complex understanding of factors affecting coffee quality, from upstream to downstream, as well as rising safety and quality standards in global coffee production.

CONCLUSION

Based on this bibliometric analysis, current research trends tend towards the optimisation of post-harvest processes to enhance coffee quality, the development of more sophisticated analytical methods, and efforts to improve sustainability and add value in the global coffee production chain. Research on coffee post-harvest processing has developed significantly since 1991, with a dramatic increase in publications since 2015. Brazil, Indonesia, and Colombia dominate research contributions, reflecting their positions as major global coffee producers. However, non-producing countries such as France and Germany also demonstrate high research interest. The focus of research has evolved from fundamental aspects like coffee bean characteristics and chemical components to more complex processing methods such as fermentation and roasting. In recent years, increased attention has been given to sensory analysis, quality control, and food safety, including the prevention of mycotoxin contamination. Factors such as altitude of cultivation, processing methods (wet or dry), and fermentation techniques are shown to significantly influence coffee quality and sensory profiles. Research also highlights the importance of microorganisms in the fermentation process for developing coffee aroma. International research collaboration is quite intensive, with an average of 4.82 authors per document. Leading journals in this field include Coffee Science, Food Research International, and European Food Research and Technology. Current research trends are directed towards optimizing post-harvest processes to enhance coffee quality, developing more sophisticated analytical methods, and efforts to improve sustainability and add value in the global coffee production chain. However, it is important to acknowledge that this analysis is limited to publications indexed by Scopus, which may not encompass all relevant literature, particularly from developing countries that may be underrepresented in this database. Future research could expand this analysis by including additional data sources and cross-linguistic

perspectives to provide a more comprehensive understanding of the field. Whilst this bibliometric analysis offers valuable insights into the research landscape of coffee post-harvest processing, it is crucial to recognise that this study has several limitations. Firstly, the analysis only includes publications indexed by Scopus, which may not encompass all relevant literature, particularly from developing countries.

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