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Trends in Coffee Research in the Web of Science SCI-EXPANDED: A Bibliometric Analysis

Johan Sukweenadhi[1,2*], Yuh-Shan Ho[3]

[1]Department of Biotechnology, University of Surabaya, Surabaya East Java, Indonesia
[2]Center of Excellence for Food Products and Health Supplements for Degenerative Conditions, University of Surabaya, Surabaya East Java, Indonesia
[3]CT HO Trend. Taipei City, Songshan District, Taiwan
*Corresponding author: sukwee@staff.ubaya.ac.id
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ABSTRACT

This bibliometric study analyzes research topics and trends in coffee science using the Science Citation Index Expanded (SCI-EXPANDED) on the Web of Science. It examines 4,169 articles published from 1991 to 2023, focusing on influential publications, citation trends, and evolving research themes. The data highlight that Brazil, the United States, and European countries lead in coffee research output. Key institutions such as the Federal University of Lavras (UFLA), Universidade Estadual de Campinas (Unicamp), Spanish National Research Council (CSIC), and Nestle Research Centre (NRC) are major contributors. The study identifies the top ten most cited publications, which impact analytical methodologies, health benefits research, and industrial applications of coffee by-products. Citation trends show varied patterns, with some articles maintaining or increasing citations over time, while others have seen declines. Analysis of author keywords across three periods (1991-2001, 2002-2012, and 2013-2023) reveals shifting research interests toward antioxidants, phenolic compounds, and coffee by-products, reflecting an increased interest in the chemical properties of coffee and its potential uses, especially regarding sustainability and health benefits. The findings indicate the role of international collaboration and suggest opportunities to address challenges in coffee science through targeted future research.

Key words: Coffee research; bibliometrics; web of Science; research trends; international collaboration.

1 INTRODUCTION

Coffee, a widely used beverage with profound cultural, economic, and health ramifications, has been the focus of substantial scientific research (Gökcen & Sanlier, 2019). Despite the wide range of research in agriculture, chemistry, health, and technology, there has been a lack of systematic synthesis of these findings (Barrea et al., 2021; Ribeiro et al., 2022; Safe et al., 2023). The major goal of this bibliometric analysis is to address this gap by giving a structured overview of coffee research in the food science and technology category of the Science Citation Index Expanded (SCI-EXPANDED) on the Web of Science.

Recent improvements highlight the need of such syntheses, especially in light of rising worries about coffee's sustainability and consumer demand. For example, new study emphasizes governance issues in global supply chains and the necessity for collaborative breeding to fight climate concerns (Wright et al., 2024; Ngure & Watanabe, 2024). These studies highlight how sustainability activities may impact consumer behavior, such as preferences for certified, eco-friendly items that meet health and ethical standards.

This study uses bibliometric approaches to identify prolific writers, notable publications, and major collaborative networks that have changed the subject. To situate this work in the scientometric tradition, bibliometric analyses in related beverage fields—such as tea's role in health research (Lian et al., 2024), cocoa production in Africa (Otekunrin, 2025), and wine economics (Bazzani et al., 2024)—have effectively mapped trends, influential contributors, and interdisciplinary shifts, providing actionable insights for policy and innovation. Unlike previous bibliometric reviews, while focused bibliometric evaluations exist for coffee subdomains such as precision agriculture (Santana et al., 2021), a comprehensive, worldwide study of coffee research throughout food science and technology is still missing. Our research fills this gap by three decades of research using updated SCI-EXPANDED data and multi-dimensional indicators to identify larger patterns, such as sustainability and international collaboration, therefore expanding the methodological discussion in scientometrics. Understanding citation patterns and research trends is important for various reasons, including identifying groundbreaking works and substantial contributions, revealing emerging areas of interest, and highlighting shifts in research focus over time (Keramatfar & Amirkhani, 2019). Furthermore, mapping the collaborative networks between researchers and institutions might provide insight into the structure and dynamics of scientific collaboration in coffee research (Cabrera et al., 2020). Finally, the goals of this study are to inform and guide future research paths, ensuring that subsequent investigations are anchored in a thorough understanding of historical and present patterns. This can lead to more targeted, innovative, and significant research endeavours in the field of coffee science and technology. Specifically, this analysis addresses

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controversies in coffee research, such as debates on health benefits versus risks (e.g., antioxidant properties vs. potential carcinogens), and has implications for funding priorities, such as directing resources toward sustainability amid climate change threats (Pham et al., 2019), underscoring the urgency of synthesizing trends to inform policy and industry strategies.

To position this work within the broader scientometric tradition, the bibliometric studies in related food science fields was drawn, such as tea research (Ho & Ranasinghe, 2022), which employed similar "front page" filters (TI, AB, AK) to analyze trends in insulin resistance publications, revealing methodological parallels in keyword evolution and citation indicators. Unlike broader reviews on cacao drying or wine (e.g., analogous studies in food processing), our application of invariant citation metrics (C_{year}, TC_{year}, CPP_{year}) to coffee advances scientometrics by addressing a gap in commodity-specific analyses, justifying our focus on refined filters for accuracy in interdisciplinary domains

2 MATERIAL AND METHODS

Data used in this study were retrieved from the Clarivate Analytics Web of Science Core Collection, the online version of the Science Citation Index Expanded (SCI-EXPANDED) (data updated on 26 April 2024). According to the latest Journal Citation Reports (JCR) released by Clarivate on 20 June 2024, there is a total of 9,471 journals categorized under 178 Web of Science categories in SCI-EXPANDED as of 2023.A total of 141 journals were listed in the Web of Science category of food science and technology.

In 2011, Ho's research group proposed the innovative concept of a "front page" filter, including the article title, abstract, and author keywords, to enhance bibliometric studies using Topic (TS) in SCI-EXPANDED (Wang & Ho, 2011; Ho et al., 2024a). A decade later, a transformative shift in search methodologies unfolded with the introduction and widespread adoption of advanced search terms, specifically TI (title), AB (abstract), and AK (author keywords) as a "front page" filter within both SCI-EXPANDED and SSCI (Ho & Mukul, 2021; Usman & Ho, 2021; Giannoudis et al., 2021). The application of TI, AB, and AK as the primary "front page" methodology has since gained significant traction, extending its relevance to diverse bibliometric studies in recent years (Ho & Ranasinghe, 2022; Ho et al., 2023a).

Curly quotation marks (" ") and the Boolean operator "OR" were used which ensured the appearance of at least one search keyword in the terms of TI, AB, or AK from 1991 to 2023. The search keywords used were: "coffee", "coffea", and "coffees". To have more accurate analysis results, some terms missed spaces: "coffea eformis" and "coffee weed" found in the Web of Science category of food science and technology were also considered. Articles containing introduction, methods, results, discussion, and conclusions, were chosen for further analyses (Ho et al., 2010). Only full original research articles were included, excluding reviews, conference papers, editorials, letters, and other non-article document types, to focus on empirical contributions and ensure consistency in the dataset. It resulted in 4,212 document types of articles including 4,169 articles (99% of 4,212 documents) published during the period spanning 1991 to 2023. The full record in SCI-EXPANDED and the number of citations in each year for each article were checked and downloaded into Excel Microsoft 365, and additional coding was manually performed using the following functions in Microsoft Excel 365 (Li & Ho, 2008; Ho et al., 2024a). The functions used were (presented in alphabetical order) CONCATENATE, COUNTA, FILTER, FREEZE PANES, INSERT, LEN, LOWER, MATCH, PIVOT TABLE WIZARD, PROPER, RANK, REPLACE, SORT, SUM, and VLOOKUP. The journal impact factors (IF_{2023}) were taken from the Journal Citation Reports (JCR) presented in 2024. The SCI-EXPANDED database designates the reprint author as the corresponding author, we opted to use the term "corresponding author" instead (Chiu & Ho, 2007). Single-author articles, single-institution articles, and single-country articles with unspecified authorship were the first as well as corresponding authors, institutions, and countries respectively. In multi-corresponding author articles, all the corresponding authors, institutions, and countries were considered (Ho et al., 2023b). Articles with corresponding authors in the SCI-EXPANDED and the SSCI, that had only address but not affiliation names were checked out and the addresses were changed to be affiliation names (Ho et al., 2023b; Al-Moraissi et al., 2023).

Affiliations in England, Scotland, North Ireland (Northern Ireland), and Wales were reclassified as being from the United Kingdom (UK) (Chiu & Ho, 2005). Additionally, affiliations located in Turkiye were reclassified and identified as being from Turkey (Ho et al., 2024b).

The evaluation of publications was carried out using three citation indicators, including:

C_{year}: the number of citations received from the Web of Science Core Collection in a specific year (e.g., C_{2023} denotes the citation count for 2023) as proposed by Ho (2012).

TC_{year}: the total number of citations received from the Web of Science Core Collection from the year of publication until the end of the most recent year (2023 in this study; TC_{2023}) as introduced by Wang et al. (2011).

CPP_{year}: the average number of citations per publication ($CPP_{2023} = TC_{2023}/TP$), where TP denotes the total number of publications, as suggested by Ho (2013).

Using C_{year}, $TC_{year,}$ and CPP_{year} is advantageous owing to their invariability and ensured repeatability as compared to the number of citations from the Web of Science Core Collection directly (Ho & Hartley, 2016).

Six publication indicators were utilized to evaluate the publication performance of countries and institutions, as proposed by Ho and Kahn (2014):
TP: total number of articles.
IP: number of articles published by a single country (IP_C) or a single institution (IP_I).
CP: number of internationally collaborative articles (CP_C) or inter-institutionally collaborative articles (CP_I).
FP: number of first-author articles.
RP: number of corresponding-author articles.
SP: number of single-author articles.

In addition, six citation indicators (CPP_{2023}) related to the six publication indicators were employed to evaluate the impact of publications on countries and institutions, as proposed by Ho and Mukul (2021). Descriptive bibliometric indicators were chosen for their repeatability and focus on trends (as per Ho & Hartley, 2016). However, this limits inferential insights, such as causal relationships, which could be addressed in future studies using advanced methods like regression.

3 RESULTS

3.1 Language

In their 2017 study, Monge-Nájera and Ho delineate the fundamental attributes of languages within a research domain, leveraging metrics such as the average number of citations per publication ($CPP_{year} = TC_{year}/TP$) and the average number of authors per publication ($APP = AU/TP$) as pivotal indicators (Monge-Nájera & Ho, 2017). Analyzing a comprehensive dataset spanning from 1991 to 2023, comprising 4,169 articles centered on coffee-related topics and indexed within the Web of Science category of food science and technology in the SCI-EXPANDED, the study encompasses works across ten distinct languages (Table 1). The predominant language of publication is English, accounting for 97% (4,048 articles) of the total articles, each featuring an average of 4.9 authors per article. A significant finding of the analysis reveals a substantial discrepancy in citation rates between English and non-English articles. Specifically, the CPP_{2023} for English articles stands at 30 citations, markedly higher than the CPP_{2023} for non-English articles, which registers at 4.8 citations. Further scrutiny elucidates that only a minor fraction of non-English articles, 18 out of 121 (15%), attain a TC_{2023} of 10 or more, with the highest TC_{2023} of 47 citations for a single article.

3.2 Characteristics of publication outputs

In 2007, a relationship between the average number of citations per publication (*CPP*) in a year and article life was proposed to understand publications on a specific research topic and their citation history (Chuang et al., 2007). The article life with *CPP* for all the 4,169 coffee-related articles in the category of food science and technology is displayed in Figure 1.

It takes *CPP*s three full years to reach a peak of 3.7 citations. A comparison of the other research topics was also shown in Figure 1. Articles related to coffee had shorter citation life than some research topics: a peak appeared in four and five full years for breast reconstruction (Li et al., 2020) and child sexual abuse (Vega-Arce et al., 2019) with a *CPP* of 3.0 and 4.2 citations respectively. Articles related to fracture non-union (Giannoudis et al., 2021) had longer citation life. It took *CPP*s about three full years to reach a plateau and up to a peak in ten full years with a *CPP* of 2.4 citations. In the case of aerosol (Zhang et al., 2012) and coffee which had a similar increasing trend to reach a peak in three full years but different decreasing trends. However, articles related to coffee had higher *CPP* of the peak than that of aerosol (Zhang et al., 2012). Comparing the five topics in Figure 2, articles in the coffee field had higher citations after two years since publication.

Table 1: Citations and authors according to the language.

Language	*TP*	%	*TP**	*AU*	*APP*	TC_{2023}	CPP_{2023}
English	4,048	97	4,047	19,957	4.9	121,098	30
Japanese	49	1.2	49	224	4.6	259	5.3
German	33	0.79	32	70	2.2	148	4.5
Portuguese	13	0.31	13	67	5.2	74	5.7
Italian	13	0.31	13	54	4.2	62	4.8
French	9	0.22	9	19	2.1	31	3.4
Spanish	1	0.024	1	6	6.0	4	4.0
Chinese	1	0.024	1	4	4.0	0	0
Polish	1	0.024	1	4	4.0	2	2.0
Czech	1	0.024	1	1	1.0	0	0

TP: number of articles; *TP**: number of articles with author information in the SCI-EXPANDED; *AU*: number of authors; *APP*: number of authors per article; TC_{2023}: the total number of citations from Web of Science Core Collection since publication year until the end of 2023; CPP_{2023}: average number of citations per article ($CPP_{2023} = TC_{2023}/TP$).

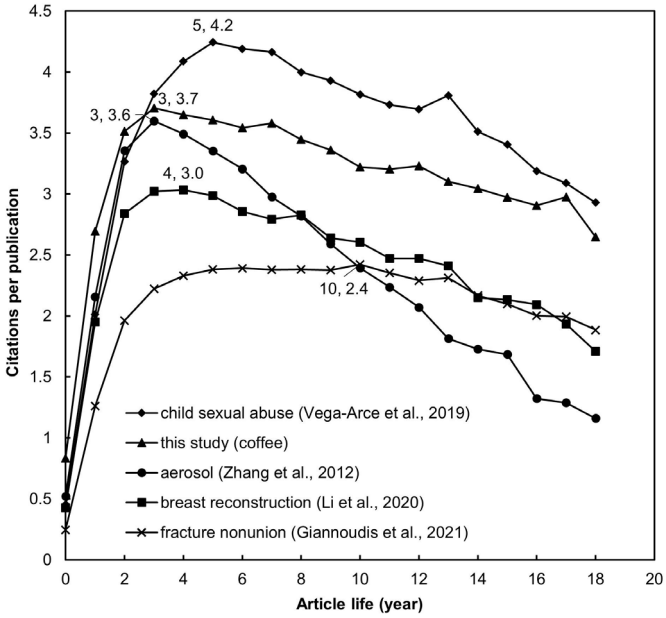

Figure 1: Comparison of citations per publication by article life.

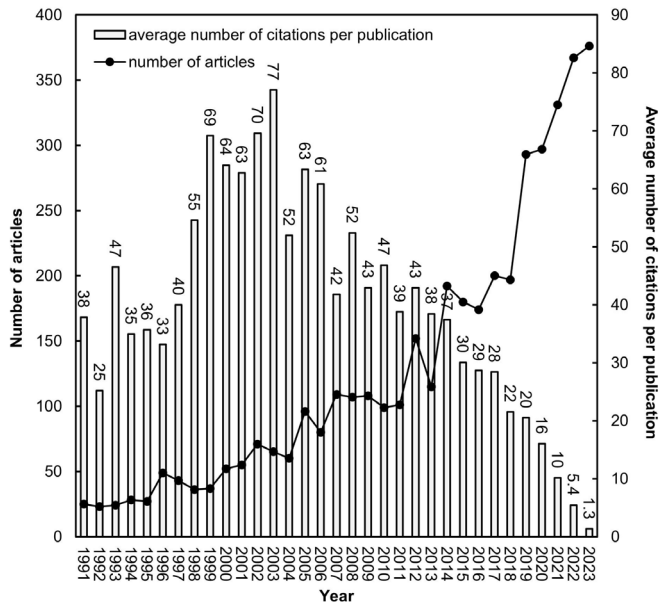

Figure 2: Number of coffee-related articles and average number of citations per publication by year.

We adopted a correlation proposed by Ho (2013) between the annual number of articles (*TP*) and their average number of citations per publication (CPP_{year}) by year to understand the development trends and impact of articles on a research topic. Figure 2 illustrates the trend in the number of articles over time. A significant shift occurred in the last decade, with the number of articles fluctuating but exhibiting an overall sharply increasing trend.

In 2003, 65 articles had the greatest CPP_{2023} of 77 citations, which was slightly higher than other years from 1999 to 2006.It is generally accepted that citation frequency is highly correlated with the length of time since publication; newly published papers require time to accumulate citations. According to what can be seen in Figure 2, it takes *CPP*s about a decade to reach a plateau, like other evaluated scientific fields (Li et al., 2020; Ho et al., 2022; Al-Moraissi et al., 2023).

3.3 Journals

A total of 4,169 coffee-related articles were published in 168 journals in the Web of Science category of food science and technology in the SCI-EXPANDED from 1991 to 2023. The 3,900 articles (94% of 4,169 articles) were published in 122 of the141 journals in the category in 2023 from Journal Citation Reports (JCR). Altogether 269 articles were published in 46 journals that were not listed in the SCI-EXPANDED in 2023. The characteristics of the journal based on the journal's impact factor (IF_{year}), the average number of authors per publication (*APP*), and the average number of citations per publication (CPP_{year}) as basic information of the journal in a research topic were proposed (Giannoudis et al., 2021). Table 2 shows the top 10 most productive journals with some articles (*TP*), IF_{2023}, *APP*, and CPP_{2023}.The *Journal of Agricultural and Food Chemistry* (IF_{2023} = 5.7) published the most 462articles, representing 11% of 4,169 articles followed closely by *Food Chemistry* (IF_{2023} = 8.5). Compared to the top ten productive journals in Table 2, plant viruses articles published in the *Journal of Agricultural and Food Chemistry* had the highest CPP_{2023} of 64 citations while articles in the *Foods* (IF_{2023} = 4.7) with 185 articles had only a CPP_{2023} of 7.7 citations. The *APP* ranged from 5.9 authors in the *Foods* to 4.4 authors in the *Journal of Food Engineering*.

In 2023, the landscape of scholarly journals within the food science and technology domain witnessed notable distinctions in impact factors (IF_{2023}), underscoring the dynamic nature of academic publishing. *Nature Food* emerged as the frontrunner among 141 journals in this category within the SCI-EXPANDED, boasting an impressive IF_{2023} of 23.6. This singular article in *Nature Food* exemplifies the journal's prowess in attracting high-impact research contributions. Following closely behind, *Trends in Food Science & Technology* secured the second position with an IF_{2023} of 15.1, solidifying its standing as a prominent outlet for scholarly discourse in the field, despite their commendable *IF*s, the *Comprehensive Reviews in Food Science and Food Safety* (IF_{2023} of 12) ranked third and did not feature any coffee-related articles.

3.4 Publication performances: countries and institutions

There were 28 articles (0.67% of 4,169 articles) without affiliations in the SCI-EXPANDED. A total of 4,141 articles were published by authors affiliated with 105 countries including 3,173 single-country articles (77% of 4,141 articles) published by authors from 79 countries with a

CPP_{2023} of 30 citations and 968 internationally collaborative articles (23%) published by authors from 98 countries with a CPP_{2023} of 28 citations. The results demonstrated that international collaboration appeared to be associated with lower citation averages in the coffee research. It is widely recognized that two authors: the first and the corresponding authors are considered the most contributed authors in a research article (Riesenberg & Lundberg, 1990). Table 3 presents a comparison of the top 10 productive countries, using six publication indicators and six related citation indicators (Ho & Mukul, 2021). Six of the top 10 countries were European countries, two Asian countries, and two American countries. Brazil ranked the top in four publication indicators with a *TP* of 611 articles (15% of 4,141 articles), an IP_C of 473 articles (15% of 3,173 single-country articles), an *FP* of 580 articles (14% of 4,141 first-author articles), and an *RP* of 573 articles (14% of 4,141 corresponding-author articles). The USA ranked the top with a CP_C of 184 articles (19% of 968 internationally collaborative articles) and an *SP* of 17 articles (13% of 130 single-author articles).

Compared to the top 10 productive countries in Table 3, the UK with a *TP* of 203 articles, an IP_C of 79 articles, an *FP* of 121 articles, an *RP* of 126 articles, and an *SP* of nine articles had the highest CPP_{2023} of 50, 78, 63, 62, and 155 citations for total articles, single-country articles, first-author articles, corresponding-author articles, and single-author articles respectively. France with a CP_C of 114 articles had the highest CPP_{2023} of 39 citations for internationally collaborative articles.

Table 2: The top 10 most productive journals in the Web of Science category of food science and technology in the SCI-EXPANDED.

Journal	*TP* (%)	IF_{2023}	*APP*	CPP_{2023}
Journal of Agricultural and Food Chemistry	462 (11)	5.7	4.7	64
Food Chemistry	460 (11)	8.5	5.0	43
Food Research International	240 (5.8)	7.0	5.3	28
Foods	185 (4.4)	4.7	5.9	7.7
LWT-Food Science and Technology	134 (3.2)	6.0	5.0	25
European Food Research and Technology	115 (2.8)	3.0	4.9	32
Journal of the Science of Food and Agriculture	103 (2.5)	3.3	4.8	32
Food Additives and Contaminants Part A-Chemistry Analysis Control Exposure & Risk Assessment	100 (2.4)	2.3	4.8	26
Journal of Food Science	95 (2.3)	3.2	4.5	26
Journal of Food Engineering	85 (2.0)	5.3	4.4	36

TP: total number of articles; %: percentage of articles in all articles; IF_{2023}: journal impact factor in 2023; *APP*: average number of authors per article; CPP_{2023}: average number of citations per publication ($CPP_{2023} = TC_{2023}/TP$).

Table 3: Top 10 productive countries.

Country	*TP*	*TP* (n = 4,141)		IP_C (n = 3,173)		CP_C (n = 968)		*FP* (n = 4,141)		*RP* (n = 4,141)		*SP* (n = 130)	
		R (%)	CPP_{2023}	*R* (%)	CPP_{2023}	*R* (%)	CPP_{2023}	*R* (%)	CPP_{2023}	*R* (%)	CPP_{2023}	*R* (%)	CPP_{2023}
Brazil	611	1 (15)	26	1 (15)	25	2 (14)	29	1 (14)	25	1 (14)	25	6 (5.4)	25
USA	427	2 (10)	33	3 (7.7)	33	1 (19)	33	3 (7.1)	35	3 (7.4)	35	1 (13)	24
Italy	371	3 (9.0)	32	2 (8.4)	34	7 (11)	25	2 (7.6)	33	2 (7.5)	33	14 (2.3)	21
Germany	363	4 (8.8)	34	5 (7.2)	35	3 (14)	33	4 (6.8)	36	4 (6.9)	35	2 (11)	63
Spain	299	5 (7.2)	39	7 (5.5)	45	4 (13)	29	6 (5.4)	42	6 (5.8)	40	9 (3.1)	57
Japan	278	6 (6.7)	26	4 (7.4)	25	14 (4.5)	34	5 (6.1)	26	5 (6.2)	26	5 (6.2)	16
China	265	7 (6.4)	16	6 (5.7)	15	8 (8.6)	19	7 (5.4)	15	7 (5.3)	15	16 (1.5)	54
UK	203	8 (4.9)	50	14 (2.5)	78	5 (13)	33	12 (2.9)	63	10 (3.0)	62	4 (6.9)	155
France	173	9 (4.2)	38	15 (1.9)	36	6 (12)	39	13 (2.6)	42	13 (2.8)	41	9 (3.1)	11
Portugal	161	10 (3.9)	36	9 (3.4)	38	12 (5.4)	32	9 (3.1)	40	9 (3.3)	36	N/A	N/A

TP: number of total articles; *TP R* (%): total number of articles and the percentage of total articles; IP_CR (%): rank and percentage of single-country articles in all single-country articles; CP_CR (%): rank and percentage of internationally collaborative articles in all internationally collaborative articles; *FP R* (%): rank and the percentage of first-author articles in all first-author articles; *RP R* (%): rank and the percentage of corresponding-author articles in all corresponding-author articles; *SP R* (%): rank and the percentage of single-author articles in all single-author articles; CPP_{2023}: average number of citations per publication ($CPP_{2023} = TC_{2023}/TP$); N/A: not available.

Figure 3 delineates the dynamic trajectory of research output among the top four leading nations in productivity for the year 2023. China's scholarly endeavours commenced in 2002, culminating in a cumulative total of 265 articles by 2023, positioning it at the 7th rank. Notably, from 2015 onwards, China exhibited a remarkable surge in output, cresting at 60 articles in 2023, thereby securing the pinnacle position.

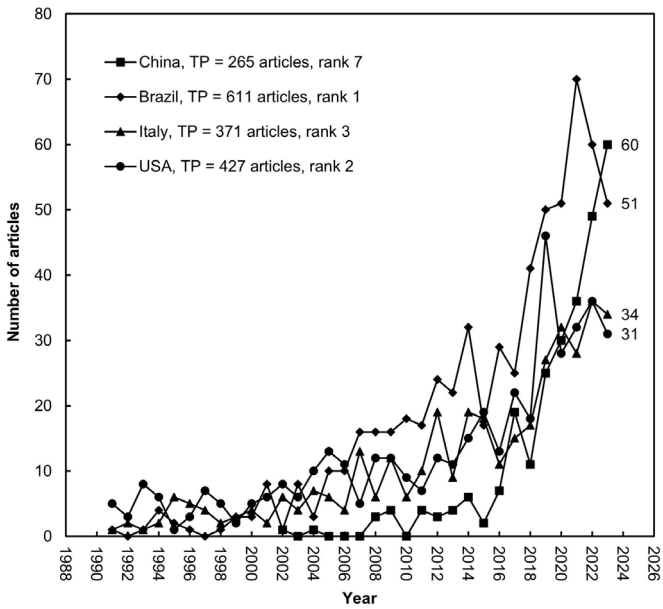

Figure 3: Development trends of the top four productive countries in 2023.

At the institutional level, the determined institution of the corresponding author might be a home base of the study or the origin of the paper (Ho, 2012). Concerning institutions, 1,758 coffee-related articles (42% of 4,141 articles) originated from single institutions with a CPP_{2023} of 34 citations while 2,383 articles (58%) were inter-institutional collaborations with a CPP_{2023} of 26 citations. The results showed that inter-institutional collaborations decreased citations in the coffee research. The top 10 productive institutions and their characteristics are presented in Table 4 and Figure 4 (Ho & Mukul, 2021). Six of the 10 productive institutions were in Braziland one in Germany, Portugal, Spain, and Switzerland respectively. The Federal University of Lavras in Brazil (UFLA) ranked the top in four of the six publication indicators with a *TP* of 86 articles (2.1% of 4,141 articles), an IP_I of 35 articles (2.0% of 1,758 single-institution articles), an *FP* of 71 articles (1.7% of 4,141 first-author articles), and an *RP* of 71 articles (1.7% of 4,141 corresponding-author articles). The Universidade Estadual de Campinas in Brazil (Unicamp) ranked at the top with a CP_I of 61 articles (2.6 % of 2,383 inter-institutionally collaborative articles). The Spanish National Research Council in Spain (CSIC) ranked the top with, an *SP* of three articles (2.3% of 130 single-author articles).

Compared to the top 10 productive institutions in Table 4, the Spanish National Research Council in Spain (CSIC) with a *TP* of 49 articles and an *SP* of three articles had the

Table 4: Top 10 most productive institutions.

Institution	*TP*	*TP* (n = 4,141)		IP_I (n = 1,758)		CP_I (n = 3,383)		*FP* (n = 4,141)		*RP* (n = 4,141)		*SP* (n = 130)	
		R (%)	CPP_{2023}	*R* (%)	CPP_{2023}	*R* (%)	CPP_{2023}	*R* (%)	CPP_{2023}	*R* (%)	CPP_{2023}	*R* (%)	CPP_{2023}
UFLA	86	1 (2.1)	25	1 (2.0)	28	2 (2.1)	23	1 (1.7)	28	1 (1.7)	28	N/A	N/A
Unicamp	76	2 (1.8)	28	12 (0.85)	36	1 (2.6)	26	5 (0.89)	37	6 (0.94)	35	3 (1.5)	51
U Porto	71	3 (1.7)	31	2 (1.8)	24	4 (1.6)	36	2 (1.2)	34	2 (1.3)	34	N/A	N/A
TU Munich	58	4 (1.4)	29	5 (1.4)	22	7 (1.4)	34	7 (0.85)	28	7 (0.87)	27	12 (0.77)	1.0
UFRJ	56	5 (1.4)	50	9 (1.0)	39	4 (1.6)	55	3 (1.0)	41	3 (1.0)	39	12 (0.77)	4.0
UFMG	50	6 (1.2)	35	4 (1.5)	43	16 (1.0)	28	4 (0.92)	41	4 (1.0)	40	N/A	N/A
UEL	49	7 (1.2)	27	30 (0.46)	22	3 (1.7)	28	8 (0.82)	24	8 (0.80)	25	N/A	N/A
CSIC	49	7 (1.2)	56	3 (1.8)	61	25 (0.76)	48	5 (0.89)	58	4 (1.0)	58	1 (2.3)	69
NRC	47	9 (1.1)	56	14 (0.80)	76	8 (1.4)	47	10 (0.72)	62	11 (0.72)	64	12 (0.77)	0
USP	46	10 (1.1)	23	21 (0.57)	8.4	6 (1.5)	27	14 (0.56)	12	15 (0.60)	16	N/A	N/A

TP: total number of articles; *TP R* (%): total number of articles and percentage of total articles; IP_I *R* (%): rank and percentage of single-institute articles in all single-institute articles; CP_I *R* (%): rank and percentage of inter-institutionally collaborative articles in all inter-institutionally collaborative articles; *FP R* (%): rank and percentage of first-author articles in all first-author articles; *RP R* (%): rank and percentage of corresponding-author articles in all corresponding-author articles;*SP R* (%): rank and the percentage of single-author articles in all single-author articles;CPP_{2023}: average number of citations per publication ($CPP_{2023} = TC_{2023}/TP$); N/A: not available.

UFLA: Federal University of Lavras, Brazil; Unicamp: Universidade Estadual de Campinas, Brazil; U Porto: University of Porto, Portugal; TU Munich: Technical University of Munich, Germany; UFRJ: Federal University of Rio de Janeiro, Brazil; UFMG: Federal University of Minas Gerais, Brazil; UEL: State University of Londrina, Brazil; CSIC: Spanish National Research Council, Spain; NRC: Nestle Research Center, Switzerland; USP: University of Sao Paulo, Brazil.

highest CPP_{2023} of 56 and 69 citations for total articles and single-author articles respectively. The Nestle Research Center in Switzerland (NRC) with an IP_I of 14 articles, an *FP* of 30 articles, and an *RP* of 30 articles had the highest CPP_{2023} of 76, 62, and 64 citations for single-institution articles, first-author articles, and corresponding-author articles respectively. The Federal University of Rio de Janeiro in Brazil (UFRJ) with a CP_I of 39 articles had the highest CPP_{2023} of 55 citations for inter-institutionally collaborative articles.

The data shows that inter-institutional collaborations account for 58% of the articles but have a lower average number of citations per publication (CPP_{2023}) than articles originating from single institutions. This could be due to a variety of factors, such as the complexity of coordinating research across multiple institutions, differences in research focus or methodology, or the time it takes for collaborative research to gain recognition in the field. The average number of citations per publication (CPP_{2023}) is a measure of the impact of the research output.

3.5 The ten most frequently cited articles

Total citations are updated from time to time on the Web of Science Core Collection. To improve the bibliometric study, the total number of citations from the Web of Science Core Collection from the publication year until the end of the most recent year of 2023 (TC_{2023}) was applied to improve the bias using data from the database directly (Wang et al., 2011). A total of 3,019 articles (72% of 4,169 articles), 4,085 articles (99% of 4,140 articles with abstract in SCI-EXPANDED), and 2,503 articles (69% of 3,626 articles with author keywords in SCI-EXPANDED) contain search keywords in their title, abstract, and author keywords respectively. Furthermore, 3,215 articles (77% of 4,169 articles) contain search keywords in their title or author keywords. Only two of the top ten most frequently cited articles contain search keywords in their title. Search keywords could be found in author keywords in the five articles. It was recommended that search keywords in article title or author keywords have more focus on a bibliometric study topic (Ho & Mukul, 2021). Citations of a highly cited

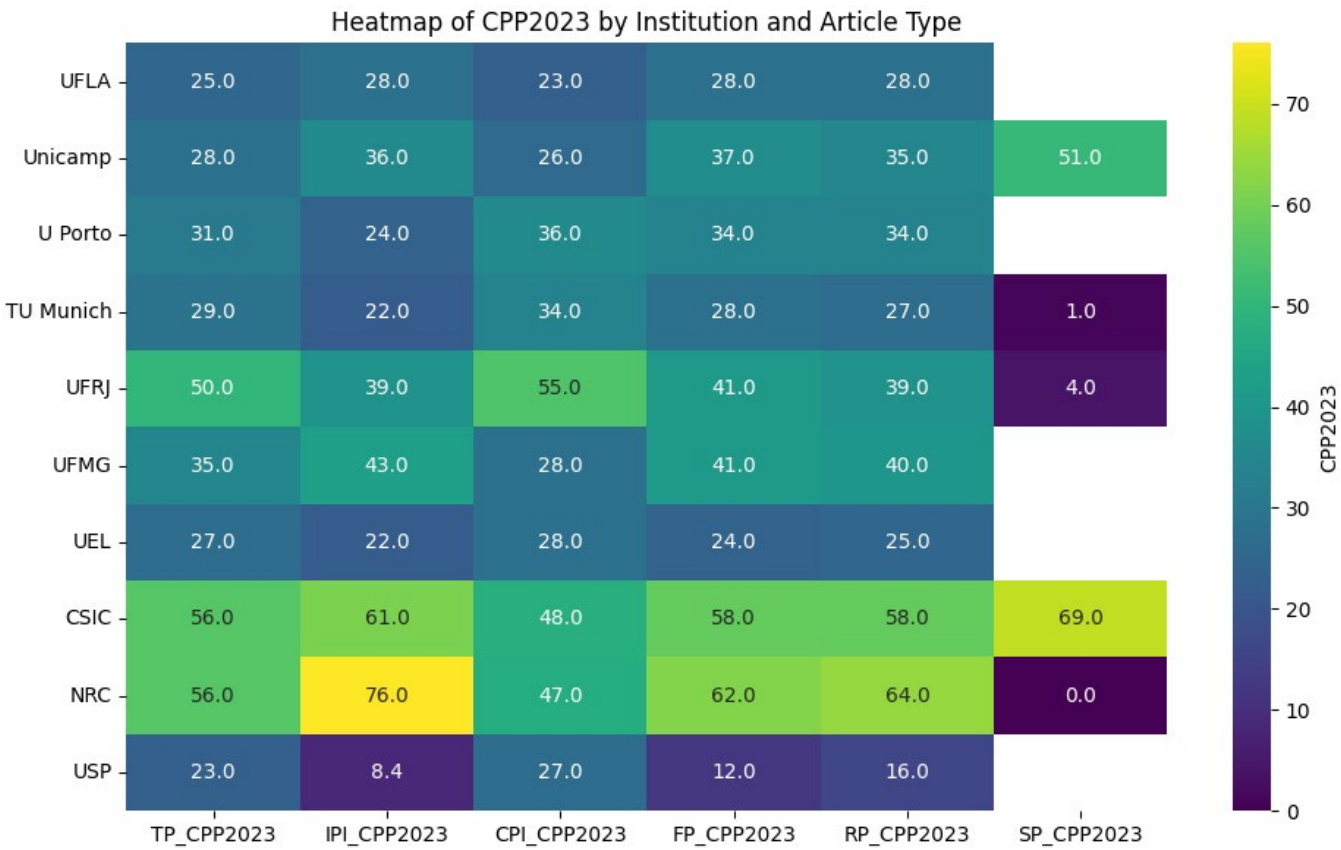

Figure: 4 Heatmap of CPP_{2023} by Institution and Article Type. This heatmap visualizes the average citations per publication (CPP2023) for top institutions across various article types (TP: total publications; IPI: independent publications; CPI: collaborative publications; FP: first-author publications; RP: corresponding-author publications; SP: single-author publications). Institutions are listed on the y-axis (e.g., UFLA: Federal University of Lavras; Unicamp: Universidade Estadual de Campinas; etc.), and article types on the x-axis. Color intensity ranges from dark purple (low CPP_{2023}) to yellow (high CPP_{2023}), with a color bar on the right indicating the scale from 0 to 70. Data derived from **Table 4**, highlighting variations in citation impact, such as higher values for single-author articles at NRC and CSIC.

article are not always high (Ho, 2014). It is necessary to understand the citation history of a highly cited article. The citation histories of the coffee-related articles contain search keywords in their title or author keywords are shown in Figure 5. The article by Clifford et al. (2003) experienced a steady rise in citations over 17 years following its publication, peaking at 99 citations in 2019 before gradually declining thereafter. Likewise, the article authored by Ballesteros et al. (2014) exhibited a significant surge in citations, culminating in a peak of 98 citations in 2021, followed by a subsequent decline. Articles by Nardini et al. (2002) with a TC_{2023} of 288 citations (ranked 10th) and Cavin et al. (2002) with a TC_{2023} of 321 citations (ranked 6th) had a low C_{2023} of five and six citations respectively.

Table 5 shows the top 10 most frequently cited articles with search keywords in their title or author keywords. M.N. Clifford from the University of Surrey in the UK published the three first-author articles which ranked in the top three. Only three articles ranked in the top ten in both TC_{2023} and C_{2023}. They were summarized as follows:

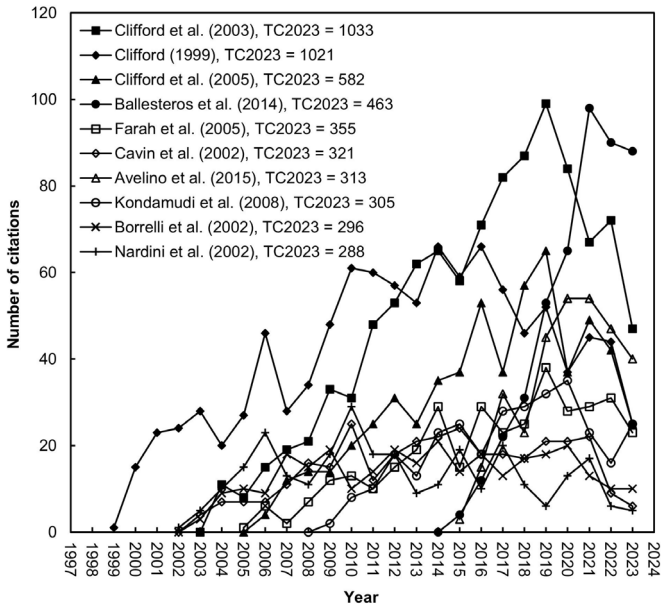

Figure 5: Citation histories of the top ten most frequently cited articles with search keywords in their titles or author keywords.

Table 5: The top ten most frequently cited articles with search keywords in their title or author keywords.

Rank (TC_{2023})	Rank (C_{2023})	Title	Country	Reference
1 (1,033)	2 (47)	Hierarchical scheme for LC-MS^n identification of chlorogenic acids	UK	Clifford et al. (2003)
2 (1,021)	14 (25)	Chlorogenic acids and other cinnamates - nature, occurrence and dietary burden	UK	Clifford (1999)
3 (582)	14 (25)	Discriminating between the six isomers of dicaffeoylquinic acid by LC-MS^n	UK	Clifford et al. (2005)
4 (463)	1 (88)	Chemical, functional, and structural properties of spent coffee grounds and coffee silverskin	Portugal	Ballesteros et al. (2014)
5 (355)	24 (23)	Effect of roasting on the formation of chlorogenic acid lactones in coffee	USA, Brazil	Farah et al. (2005)
6 (321)	519 (6)	Cafestol and kahweol, two coffee specific diterpenes with anticarcinogenic activity	Switzerland, Austria	Cavin et al. (2002)
7 (313)	5 (40)	The coffee rust crises in Colombia and Central America (2008-2013): Impacts, plausible causes and proposed solutions	France, Colombia, Costa Rica, Guatemala, Panama, Nicaragua	Avelino et al. (2015)
8 (305)	14 (25)	Spent coffee grounds as a versatile source of green energy	USA	Kondamudi et al. (2008)
9 (296)	190 (10)	Chemical characterization and antioxidant properties of coffee melanoidins	Italy	Borrelli et al. (2002)
10 (288)	663 (5)	Absorption of phenolic acids in humans after coffee consumption	Italy	Nardini et al. (2002)

R: rank of the article by citations (C_{2023} or TC_{2023}) among the top ten most frequently cited coffee articles; C_{2023}: the number of citations of an article in 2023 only; TC_{2023}: the total number of citations from Web of Science Core Collection since publication year to the end of 2023.

1. Hierarchical scheme for LC-MS^n identification of chlorogenic acids (Clifford et al., 2003)

The article was published by four authors from the University of Surrey in the UK with a TC_{2023} of 1,033 citations (ranked 1st) and a C_{2023} of 47 citations (ranked 2nd). The study of the fragmentation behaviour of chlorogenic acids in coffee research has key implications for coffee quality and authenticity. By identifying specific isomers, researchers can assess the quality and authenticity of coffee beans, ensure consistent flavour profiles and preventing adulteration. Chlorogenic acids, which have antioxidant properties, can also be used to assess their bioavailability and potential health benefits. The use of LC-MS and hierarchical key for isomer discrimination enhances our ability to characterize natural compounds in various contexts, contributing to coffee quality control (Clifford et al., 2003).

2. Chemical, functional, and structural properties of spent coffee grounds and coffee Silverskin (Ballesteros et al., 2014)

The article was published by three authors from the University of Minho in Portugal with a TC_{2023} of 463 citations (ranked 4th) and a C_{2023} of 88 citations (ranked 1st). This study evaluated the chemical composition, functional properties, and structural characteristics of spent coffee grounds (SCG) and coffee silverskin (CS) to identify their potential for re-utilization in industrial processes. SCG and CS are lignocellulosic, with sugars polymerized to cellulose and hemicellulose fractions. However, their composition and hemicellulose sugars differ significantly. SCG and CS particles have low porosity and similar melting points but differ in morphology and crystallinity. They have good water and oil holding capacities, emulsion activity, stability, and antioxidant potential, making them suitable for use in food and pharmaceutical fields (Ballesteros et al., 2014).

3. The coffee rust crises in Colombia and Central America (2008-2013): Impacts, plausible causes, and proposed solutions (Avelino et al., 2015)

The article was published by 10 authors from nine institutions in France, Colombia, Costa Rica, Guatemala, Panama, and Nicaragua with a TC_{2023} of 313 citations (ranked 7th) and aC_{2023} of 40 citations (ranked 5th). Coffee rust, a leaf disease caused by the fungus *Hemileiavastatrix*, has been causing epidemics in several countries, including Colombia, Central America, Mexico, Peru, and Ecuador. The onset of these epidemics is influenced by economic conditions, crop management decisions, and weather conditions. Production has been significantly reduced in Colombia and Central America, impacting the livelihoods of smallholders and harvesters. Coffee is often the only source of income for these populations, affecting food security indirectly. The main drivers of these epidemics are economic and meteorological factors. Low coffee profitability periods and increased input costs have led to suboptimal coffee management, increasing plant vulnerability to pests and diseases. A common factor in recent epidemics was a reduction in diurnal thermal amplitude, which likely decreased the latency period of the disease. These epidemics should be considered a warning for the future, as they were exacerbated by climate change-related weather conditions. Actions include developing resistant coffee cultivars, creating early warning systems, designing crop management systems adapted to climate change and pest and disease threats, and implementing socio-economic solutions like training and organizational strengthening (Avelino et al., 2015).

3.6 Research focuses and their development trends

The article title, abstract, author keywords, and *Keywords Plus* convey the most important information about the research. Therefore, word distribution analysis is very useful for evaluating research focuses and their development trends in a specific research topic (Wang & Ho, 2016). In 2010, Ho's group proposed distributions of words in article titles and abstracts, author keywords, and *Keywords Plus* in different periods to determine research focuses and their development trends (Zhang et al., 2010; Wang & Ho, 2016). The articles with author keyword information in SCI-EXPANDED were distributed across three periods as follows: 273 articles from 1991-2001, 959 articles from 2002-2012, and 2,576 articles from 2013-2023. For temporal analyses of author keywords and research trends, articles were divided into three periods (1991-2001, 2002-2012, and 2013-2023) to capture early development, mid-growth, and recent acceleration in coffee research output, as evidenced by the increasing publication trends observed in Figure 2. Specifically, 1991-2001 represents an early development phase with modest and stable article numbers; 2002-2012 captures mid-growth with gradual increases; and 2013-2023 aligns with recent acceleration, marked by a sharp upward trajectory in publications (e.g., fluctuating but overall surging in the last decade). This division follows methodological conventions in bibliometric studies for trend analysis (e.g., Ho et al., 2023a) and allows for meaningful comparisons of evolving themes, such as the rise in sustainability and health-related keywords, without arbitrary splits. The top 20 most frequently used author keywords in coffee research, excluding the search keywords, along with their distribution across three sub-periods (1991-2001, 2002-2012, and 2013-2023), are presented in Table 6. The author keywords "caffeine", "chlorogenic acid", "chlorogenic acids", "roasting", and "ochratoxin A" was the most commonly utilized, appearing in 234, 149, 146, 146, and 144 articles, respectively. "Antioxidant activity", "phenolic compounds", "spent coffee

grounds", and "chlorogenic acid" were getting popular to be author keywords. Word cluster analysis was utilized to identify the primary research focuses and their developmental trends, as outlined by Mao, Wang and Ho (2010). The primary research foci within the field of coffee research were assessed through word cluster analysis, utilizing the outcomes of word analysis as a foundational word bank.

Four possible main research topics in coffee research were evaluated. All articles containing supporting words were calculated each year. The development trends of the four main research focus in coffee research are presented in Figure 6.

Processing and analysis supported by words, for example, 'analyse', 'analysing', 'analysis', 'brew', 'brewing', 'chromatography', 'evaluation', 'extract', 'extracting', 'extraction', 'extracts', 'ferment', 'fermentation', 'fermentations', 'fermented', 'method', 'model', 'process', 'processed', 'processes', 'processing', 'processing and analysis', 'roast', 'roasted', 'roasting', 'roasts', and 'spectrometry'. This cluster pertains to the methods and processes involved in coffee production.

Types and components supported by words, for example, 'acid', 'arabica', 'bean', 'beans', 'bioactive', 'caffeine', 'chlorogenic', 'compound', 'compounds', 'green', 'phenolic', 'robusta', 'types and components', and 'volatile'. This cluster includes words related to different types of coffee and their components. Research into different types and components of coffee has shown a steady increase, reaching 3,034 articles by 2024. This trend reflects a growing interest in exploring the diverse varieties of coffee, such as Arabica and Robusta, and their specific bioactive compounds like caffeine, chlorogenic acids, and phenolics (Clifford et al., 2003; Farah et al., 2005). These studies are crucial for understanding the distinct characteristics of each coffee type and identifying beneficial components that could potentially enhance health outcomes. The rise in research can be attributed to several factors: firstly, the vast diversity of coffee species stimulates ongoing investigation into their unique biochemical profiles and sensory attributes (Grosso et al., 2017). Secondly, heightened awareness of the health benefits associated with coffee compounds, such as antioxidants and chlorogenic acids, drives the detailed analysis of these components (Barrea et al., 2021; López-García et al., 2014). Finally, the impact of climate change on coffee production underscores the importance

Table 6: The 20 most frequently used author keywords.

Author keywords	*TP*	1991-2023 Rank (%) n = 3,626	1991-2001 Rank (%) n = 209	2002-2012 Rank (%) n = 947	2013-2023 Rank (%) n = 2,470
caffeine	234	1 (6.5)	1 (9.1)	2 (6.1)	1 (6.4)
chlorogenic acid	149	2 (4.1)	129 (0.48)	3 (5.1)	2 (4.0)
chlorogenic acids	146	3 (4.0)	9 (2.9)	5 (4.3)	3 (4.0)
roasting	146	3 (4.0)	5 (3.8)	4 (4.9)	4 (3.7)
ochratoxin A	144	5 (4.0)	2 (8.1)	1 (7.4)	11 (2.3)
antioxidant activity	120	6 (3.3)	N/A	8 (3.3)	5 (3.6)
antioxidant	107	7 (3.0)	23 (1.4)	12 (2.7)	6 (3.2)
coffea arabica	107	7 (3.0)	23 (1.4)	7 (3.5)	7 (2.9)
acrylamide	104	9 (2.9)	N/A	6 (3.6)	8 (2.8)
green coffee	92	10 (2.5)	15 (1.9)	13 (2.5)	10 (2.6)
polyphenols	89	11 (2.5)	23 (1.4)	19 (1.9)	9 (2.8)
Maillard reaction	75	12 (2.1)	5 (3.8)	8 (3.3)	19 (1.5)
roasted coffee	65	13 (1.8)	4 (4.3)	14 (2.3)	22 (1.4)
antioxidants	64	14 (1.8)	15 (1.9)	19 (1.9)	14 (1.7)
HPLC	63	15 (1.7)	3 (4.8)	8 (3.3)	54 (0.89)
melanoidins	63	15 (1.7)	46 (1.0)	8 (3.3)	30 (1.2)
tea	61	17 (1.7)	5 (3.8)	16 (2.2)	24 (1.3)
phenolic compounds	60	18 (1.7)	N/A	101 (0.53)	12 (2.2)
sensory analysis	56	19 (1.5)	11 (2.4)	35 (1.1)	15 (1.7)
spent coffee grounds	54	20 (1.5)	N/A	297 (0.21)	13 (2.1)

TP: total number of articles containing the search keywords; *R*: rank; N/A: not available.

of studying different coffee types and their adaptability to changing environmental conditions, further motivating research efforts in this area (Raveendran & Murthy, 2022).

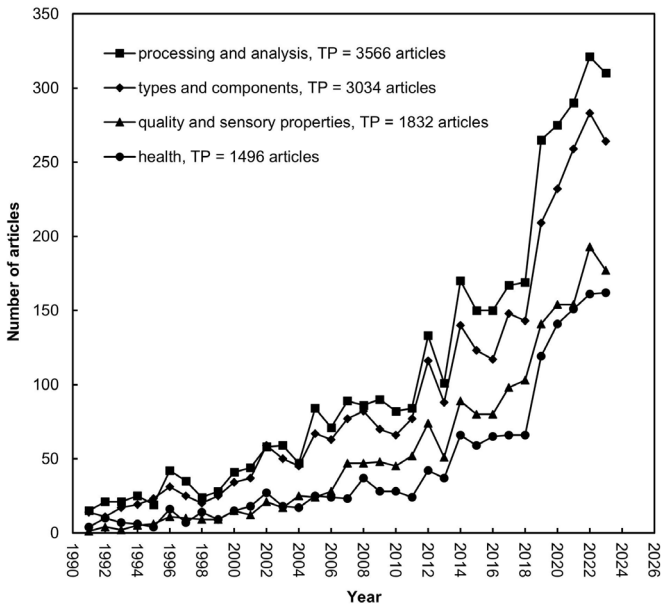

Figure 6: The development trends of four main research focus in coffee research.

Quality and sensory properties supported by words, for example,: 'aftertaste', 'aroma', 'attribute', 'attributes', 'flavor', 'flavors', 'qualitative', 'qualities', 'quality', 'quality and sensory properties', 'sensorial', 'sensory', 'taste', 'tasted', 'tastes', and 'tasting'. This cluster relates to the quality assessment and sensory characteristics of coffee. Research focused on the quality and sensory properties of coffee has shown a notable upward trend, with 1,832 articles published by 2024. This surge underscores the growing importance placed on understanding and optimizing the taste, aroma, and overall sensory experience of coffee. The trend can be attributed to several factors: firstly, increasing consumer preferences for high-quality specialty coffee drive the need for detailed research into enhancing sensory attributes such as flavour, aroma, and aftertaste. Consumers are increasingly discerning and seek exceptional sensory experiences from their coffee, which encourages researchers to explore methods for consistently achieving these qualities (Giacalone et al., 2019). Secondly, the competitive nature of the coffee market, particularly within the specialty coffee sector, fuels continuous improvements in coffee quality. As coffee businesses vie for consumer loyalty and market share, investing in research to enhance sensory qualities becomes imperative. Lastly, advancements in sensory science have provided more sophisticated methodologies for evaluating coffee quality. These tools and techniques facilitate the precise assessment of sensory attributes, enabling researchers to identify key factors influencing coffee flavour profiles and to develop strategies for quality enhancement (Servín-Juárez et al., 2021). Together, these factors contribute to the upward trajectory of research focused on the quality and sensory properties of coffee, reflecting both consumer demand and industry innovation.

Health supported by words, for example, 'activity', 'antibacterial', 'anti-inflammatory', 'antimicrobial', 'antioxidant', 'antioxidants', 'antioxidative', 'antiradical', 'consumption', 'diet', 'dietary', 'diets', 'health', and 'healthy'. This cluster focuses on the health-related aspects of coffee consumption. Research focused on the health aspects of coffee consumption has experienced significant growth, with 1,496 articles published by 2024.

4 DISCUSSION

4.1 Characteristics of publication outputs

Studies have shown that research topics with broader appeal or relevance to a wider audience tend to attract more citations over a shorter period. Coffee, being a widely consumed beverage and a subject of interest in various fields such as health, agriculture, and industry, may garner more immediate attention and citations due to its widespread relevance (Grosso et al., 2017). Coffee is known to possess a wide array of bioactive components, including phenolic acids, flavonoids, and alkaloids, which are attributed to various health benefits such as potential protective effects on the liver, blood sugar regulation, and neurological protection (Hu et al., 2019). These functional properties of coffee may contribute to its broader research appeal and relevance, thereby attracting earlier and higher citations compared to other research topics. Additionally, the level of novelty and impact of the findings presented in the coffee-related articles could play a role in the accelerated citation growth. Research that introduces groundbreaking concepts, innovative methodologies, or significant implications for practice and policy tends to attract attention and citations at a faster rate (Zhang et al., 2021).

Research on the health effects of coffee consumption may intersect with breast reconstruction and fracture non-union. For example, studies investigating the influence of coffee on bone health may relate to fracture non-union (Macedo et al., 2015), while research on coffee's impact on post-operative recovery and tissue healing could potentially intersect with breast reconstruction (Rosendahl et al., 2015). The experience of psychological distress could potentially overlap with research on coping mechanisms or mental health support, which may include the influence of dietary habits like coffee consumption. Coffee contains bioactive compounds that could have implications for pain management, recovery, and the healing process, potentially

linking it to areas such as post-operative care, rehabilitation, and mental health support following traumatic experiences (López-García et al., 2014).

Moreover, the dynamics of the scientific community and publishing landscape may also contribute to the observed trends. Factors such as collaboration networks, publication strategies, and visibility of research outputs can influence the dissemination and reception of research findings, impacting the citation trajectory of articles across different topics. The varying rates of citation growth and decline reflect the multifaceted nature of scholarly communication and research impact (Hou et al., 2020). The earlier peak in citations for coffee-related articles compared to other topics likely stems from a combination of factors including topic relevance, novelty of findings, and broader research appeal. These factors collectively contribute to the distinctive citation patterns observed across different research domains.

The significant shift observed in the trend of the number of articles over time, particularly showing a sharply increasing trajectory in the last decade, could be analysed against the backdrop of the broader research landscape and the specific domain of coffee-related studies. One unique pattern that could be identified regarding the development trend is the increasing recognition of coffee as a subject of interdisciplinary interest. Coffee encompasses a wide array of research areas, including but not limited to health sciences, agriculture, chemistry, and social sciences (Santana et al., 2021). This interdisciplinary nature of coffee-related studies has likely contributed to a surge in publications as researchers from various fields recognize the importance and relevance of coffee in their respective domains. Moreover, the evolving understanding of the health impacts of coffee consumption and its functional properties has likely fuelled the increase in research output. Over the years, numerous studies have highlighted the potential health benefits associated with coffee, such as its antioxidant properties, effects on cognitive function, and potential protective effects against certain diseases (Barrea et al., 2021). This growing body of evidence likely motivates researchers to delve deeper into coffee-related research, leading to the observed rise in the number of articles.

4.2 Coffee-related Research Journals

The analysis of coffee-related research articles from 1991 to 2023 provides valuable insights into the field's growth and impact over time (Figure 7). This could be due to the increasing global consumption of coffee and the need to understand its impacts on health, environment, and economy (Grosso et al., 2017; Poole et al., 2017). The extensive publication of 4,169 articles in 168 journals underscores the significant academic interest in coffee studies. The concentration of 95% of these publications in key journals, such as the *Journal of Agricultural and Food Chemistry* and

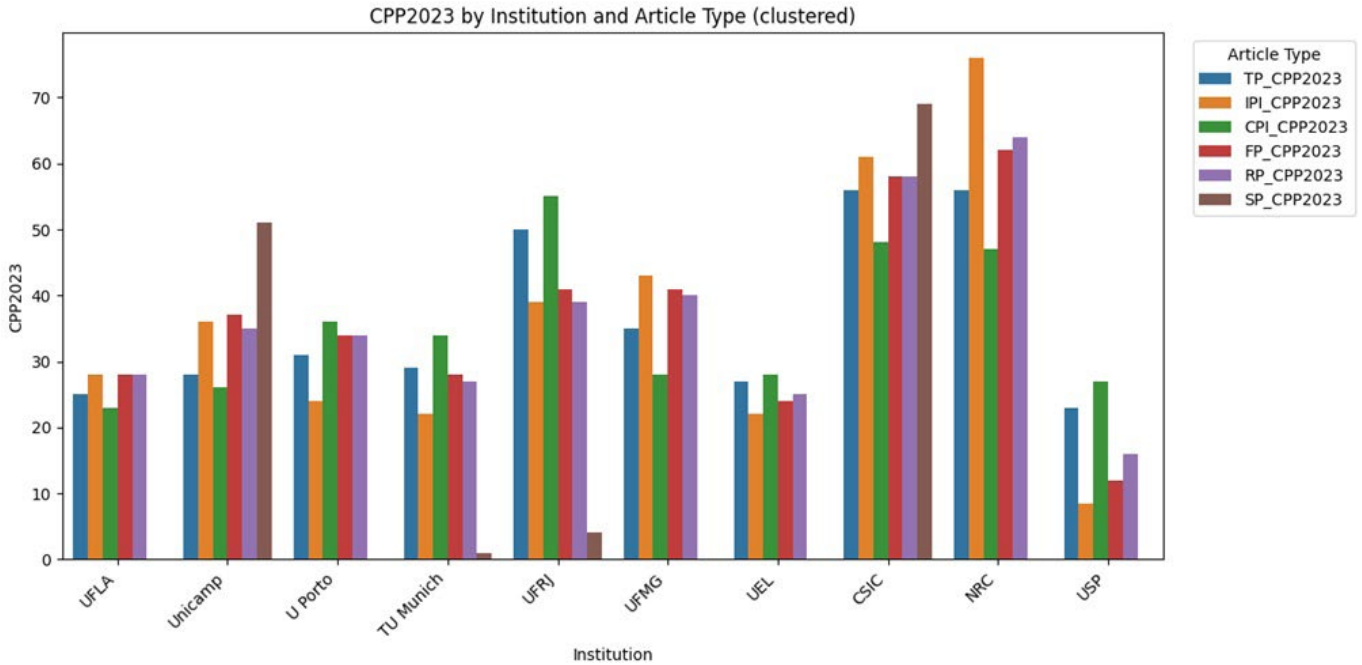

Figure 7: Clustered Bar Chart of CPP_{2023} by Institution and Article Type. This bar chart displays the average citations per publication (CPP_{2023}) for selected institutions, clustered by article type (TP: blue; IPI: orange; CPI: green; FP: red; RP: purple; SP: brown). Institutions are on the x-axis (e.g., UFLA, Unicamp, etc.), and CPP2023 values on the y-axis (ranging from 0 to 70). The chart illustrates citation patterns, with notable highs in single-author (SP) and independent (IPI) articles for institutions like NRC and CSIC, complementing the heatmap in Figure 4 for a comparative view of institutional performance.

Food Chemistry, indicates the dominance of high-impact journals in the field. These journals might have a strong focus on food and agricultural chemistry, which includes coffee-related research. Therefore, they attract submissions from researchers in this field. This is further evidenced by their high impact factors (IF_{2023} = 5.7 and 8.5, respectively) and the high average number of citations per publication (CPP_{2023} = 64 for the *Journal of Agricultural and Food Chemistry*).

The presence of 269 articles in 46 journals not listed in the SCI-EXPANDED in 2023 suggests the emergence of new platforms for coffee research, indicating the field's potential expansion. The variation in citation patterns and the average number of authors per publication (*APP*) among the top journals reflect the diverse research focus and collaboration trends in the field. For instance, the Foods journal, with an *APP* of 5.9, indicates extensive multi-author contributions, while its relatively lower CPP_{2023} of 7.7 suggests a lower citation impact compared to other leading journals. These journals might cater to specific areas of coffee research, aim to reach a wider audience by being freely accessible, serve particular regions or cultures, pioneer in new areas of study, or appeal to multi-disciplinary audiences (Fabian, 2023). Despite not being on the SCI-EXPANDED list, these journals can still uphold high standards and rigorous peer-review processes, making them significant platforms for coffee-related research.

4.3 Publication Performances: Countries and Institutions

Countries like Brazil and Colombia are among the largest coffee producers in the world. This means they have a significant stake in the coffee industry, from farming to export. As a result, these countries might invest heavily in research to improve their coffee crops, develop more efficient farming techniques, and understand global coffee markets better (Santana et al., 2021; Silva et al., 2023). Meanwhile. Countries like the USA and Germany are known for their substantial investment in scientific research. This funding can support a wide range of studies, including those related to coffee. For instance, research might be conducted to understand the health effects of coffee, develop new brewing methods, or explore the environmental impact of coffee production. Countries with leading academic and research institutions, such as the USA, Germany, and the UK, often produce high-quality research across various fields, including coffee-related studies. These institutions might house specific departments or research groups focusing on food science, agriculture, or specifically coffee research. The USA, in particular, shows a high degree of international collaboration in coffee-related research. This suggests a strong network of researchers across different countries working together (Cabrera et al., 2020). Collaborative research often brings together diverse perspectives and expertise, leading to more comprehensive and impactful studies. In countries like Italy and Spain, coffee is more than just a beverage; it's an integral part of the culture. This cultural significance might drive interest in understanding more about coffee, from its chemical composition and potential health benefits to its societal role and economic impact (Grosso et al., 2017; Poole et al., 2017). Moreover, countries with a large consumer market for coffee, such as the USA and Japan, might conduct research to understand consumer behaviour and preferences. This could include studies on taste preferences, consumption patterns, and the influence of marketing on coffee purchases.

High-quality research often stems from rigorous methodologies, innovative approaches, and significant findings. In the context of coffee research, advancements in coffee production technology or discoveries about coffee's functional properties could lead to high-quality studies (Godos et al., 2014). For instance, breakthroughs in optimizing coffee bean fermentation or roasting processes could result in impactful research that garners many citations.

The focus on areas of high interest, such as the health benefits of coffee (Grosso et al., 2017) or the environmental impact of coffee production, could be driven by societal trends and demands. For example, as consumers become more health-conscious, research into the health benefits of coffee (like its antioxidant properties or potential protective effects against certain diseases) could attract significant attention. Similarly, in an era of increasing environmental awareness (Usman & Ho, 2021), studies on sustainable coffee farming practices or the carbon footprint of coffee production could be highly cited.

Collaboration can lead to more comprehensive and impactful studies by bringing together diverse expertise and perspectives. In coffee research, this could involve collaborations between agronomists, food scientists, chemists, and health experts. For example, a study on the health benefits of coffee could benefit from the expertise of food scientists (who can analyze the chemical composition of coffee), health experts (who can study its effects on the human body), and statisticians (who can ensure the data is analyzed correctly).

China's rapid growth in coffee-related research could be attributed to several factors. The country has been investing heavily in scientific research, particularly in sectors that have significant economic impact. The coffee industry in China has been growing, both in terms of production and consumption. This growth likely spurred increased research into optimizing coffee cultivation techniques and improving bean quality (Hu et al., 2019). Additionally, as global interest in the health effects of coffee consumption continues to rise, Chinese researchers may be contributing to this body of knowledge by studying the potential health benefits and risks associated with coffee.

Brazil is one of the world's largest coffee producers, so it's no surprise that the country shows a consistent output of coffee-related research. Brazilian researchers are likely focused on improving coffee crop yields and developing disease-resistant coffee varieties, both of which are crucial for maintaining the country's strong position in the global coffee market. Additionally, as sustainability becomes an increasingly important factor in agriculture, Brazilian researchers may also be working on ways to enhance the sustainability of coffee farming practices (Macedo et al., 2015; Silva et al., 2023).

The fluctuations in research output from Italy and the USA could be indicative of shifts in research focus or funding over the years. For instance, peaks in research output could coincide with major breakthroughs in coffee science or increased funding for coffee research (Pham et al, 2019). On the other hand, troughs could reflect periods of economic downturn or shifts in research priorities. It's also possible that these fluctuations reflect the interdisciplinary nature of coffee research, with different disciplines contributing to the field at different times.

The institutions listed in Table 4 are likely to have specific research focus areas and expertise related to coffee. For instance, the Federal University of Lavras in Brazil (UFLA) and the Universidade Estadual de Campinas in Brazil (Unicamp) have strong agricultural and food science departments, given Brazil's status as a major coffee producer. These institutions could be conducting research into optimizing coffee cultivation techniques, improving bean quality, and understanding the health effects of coffee consumption (Pantaleão & Cortese, 2018). UFLA is home to the Coffee Science journal, which publishes high-quality research in all scientific areas of coffee. The journal represents important contributions to the development of coffee science in fields such as agricultural, biological, food science, waste management, health, and social sciences. UFLA also maintains a strong focus on coffee research, with studies ranging from the evaluation of Brazilian Canephora coffee using NIR spectroscopy and discriminant chemometric techniques to the development of sustainable practices in coffee culture.

Unicamp, on the other hand, has been involved in a project called Coffee Change, which brings together researchers from various fields such as climatology, agronomy, communication, linguistics, and economics. The project aims to answer questions related to the challenges and opportunities of the coffee sector in the context of climate change. Unicamp's research in coffee science is not only interdisciplinary but also highly relevant to the current global issues of climate change and sustainability.

Institutions with a high CPP_{2023}, such as the Spanish National Research Council (CSIC), whose conducting innovative research that introduces new concepts or techniques in coffee science. This could include breakthroughs in understanding the chemical composition of coffee, optimizing coffee processing methods, or discovering new health benefits of coffee. For example, they uncovered important insights about the effects of coffee consumption on human health.

The geographical location of the institutions could also play a role in their research output and focus. Institutions in major coffee-producing countries like Brazil might focus more on agricultural aspects of coffee research, while institutions in countries with high coffee consumption, like Germany, might be studying the health effects of coffee consumption, the sensory properties of different coffee varieties, or the psychological effects of coffee. Peaks in research output could coincide with major breakthroughs or discoveries in coffee research. For instance, the remarkable surge in China's research output from 2015 onwards could be linked to significant advancements in coffee production technology or discoveries about coffee's functional properties. For example, Chinese researchers might have made breakthroughs in optimizing coffee cultivation techniques, improving bean quality, or understanding the health effects of coffee consumption. This surge in research output could also reflect China's growing coffee industry and increased investment in scientific research.

CSIC's research is indeed highly influential and widely recognized in the field. One of their studies found that the crema, the thin creamy layer of foam that sits on top of espresso, positively impacts consumer appreciation and perception of coffee. The study found that the presence of the crema enhanced consumers' visual perception of coffee, which in turn guided their expectations and experience of the coffee's taste. This kind of innovative research introduces new concepts in coffee science and can lead to high-quality studies that garner many citations.

NRC's research is not only academically rigorous but also relevant to the industry and consumers. One of their studies, conducted in collaboration with Nespresso, found that the crema of coffee positively impacts consumer appreciation and perception of coffee. The study found that the presence of the crema enhanced the release of the coffee's aroma above the cup and in the nose. This kind of research, which focuses on practical applications of coffee research such as improving the taste and quality of coffee products, understanding consumer preferences, and exploring the health benefits of coffee, is likely to be highly cited.

Meanwhile, UFRJ's research might be focused on areas such as improving coffee crop yields, developing disease-resistant coffee varieties, enhancing the sustainability of coffee farming practices, or studying the health effects of coffee consumption. One of their studies investigated the effects of regular and decaffeinated roasted coffee extracts and bioactive compounds on in vitro probiotic bacterial growth. The study found that regular coffee extracts improved the growth of certain probiotic strains, thus exerting a prebiotic effect. This

kind of interdisciplinary research, which involves collaboration between experts in agriculture, food science, chemistry, health sciences, and other fields, can lead to impactful studies that garner many citations.

4.4 The ten most frequently cited article

Ballesteros et al. (2014) investigated the chemical, functional, and structural properties of spent coffee grounds and coffee silverskin. These are by-products of the coffee industry and are often discarded as waste. However, this research highlighted their potential use in industrial processes due to their beneficial properties, such as high antioxidant activity and dietary fiber content. This study could have significant implications for waste management in the coffee industry and contribute to more sustainable practices. This article exhibited a significant surge in citations, culminating in a peak of 98 citations in 2021, followed by a subsequent decline.

Cavin et al. (2002) focused on cafestol and kahweol, two coffee-specific diterpenes, and their anticarcinogenic activity. The study found that these compounds could potentially protect against certain types of cancer. This research contributes to our understanding of the health effects of coffee and could have significant implications for public health. The research might have initially attracted a lot of attention due to its novel findings or methodologies, but the interest could have waned over time as newer research emerged. Alternatively, the study's findings might have been controversial or disputed, leading to a high initial citation count but a low citation count in recent years.

Meanwhile, Clifford et al. (2003) proposed a hierarchical scheme for the identification of chlorogenic acids using liquid chromatography-mass spectrometry. Chlorogenic acids are important antioxidants found in coffee. The methodology developed in this study could be crucial for future research into the health benefits of coffee and the effects of different coffee processing methods on the antioxidant content of the final product. This kind of innovative research introduces new concepts in coffee science and can lead to high-quality studies that garner many citations.

Nardini et al. (2002): This research investigated the absorption of phenolic acids, which are antioxidants found in coffee, in humans after coffee consumption. The study found that these compounds are indeed absorbed in the human body, which suggests that they could contribute to the health benefits associated with coffee consumption. This research adds to our understanding of how the beneficial compounds in coffee interact with the human body, which could explain its high citation count.

4.5 Research focuses and their development trends

The surge in research focused on the processing and analysis of coffee can be attributed to several key factors. Firstly, advancements in technologies such as chromatography and spectrometry have significantly enhanced researchers' ability to analyze the chemical composition of coffee during various stages of processing. These sophisticated analytical tools provide deeper insights into how different processing methods affect the final flavour and quality of coffee (Freitas et al., 2024). Secondly, there is a growing emphasis on optimizing coffee production processes. Keywords like 'process', 'processing', and 'roasting' highlight efforts to refine brewing and roasting techniques. This optimization aims not only to improve the efficiency of coffee production but also to enhance the sensory qualities of the end product, meeting consumer expectations for consistent and high-quality coffee (Raveendran & Murthy, 2022). Thirdly, the demand for quality control in the coffee industry has intensified. As consumers become more discerning about the coffee they consume, there is a heightened need for rigorous analysis and evaluation throughout the production chain (Barreto et al., 2023). Researchers are thus focusing on developing innovative processing methods that ensure coffee meets stringent quality standards consistently.

This trend reflects an increasing global awareness of coffee's potential health benefits and risks. The rise in health-focused research can be attributed to several key factors: firstly, a growing health consciousness worldwide has prompted extensive investigation into the antioxidant, anti-inflammatory, and antimicrobial properties of coffee. Researchers are exploring how these bioactive compounds in coffee contribute to overall health and well-being, including their potential role in reducing the risk of diseases and improving mental health (Barrea et al., 2021; Grosso et al., 2017). Secondly, there is an emerging trend of collaboration between food scientists and medical researchers, aiming to comprehensively understand coffee's physiological impacts. This interdisciplinary approach has led to continuous discoveries of positive health effects associated with moderate coffee consumption, further fuelling research interest (Gökcen & Sanlier, 2019). This finding aligns with broader themes of sustainability and the circular economy, as the health benefits of bioactive compounds are increasingly linked to the valorization of coffee by-products (e.g., spent grounds and silverskin), which reduces waste while creating value-added products like functional foods or supplements (Ballesteros et al., 2014; Kondamudi et al., 2008). Thirdly, the consistent findings of beneficial health impacts have reinforced ongoing research efforts, encouraging deeper exploration into coffee's potential therapeutic properties. Overall, the substantial growth in health-related coffee research underscores a concerted effort to integrate scientific advancements with consumer health considerations, shaping both academic inquiry and public perception of coffee as a dietary component.

5 CONCLUSIONS

This bibliometric analysis highlights key trends in coffee science, including composition, processing, health effects, and sustainability, with chlorogenic acids and coffee by-products as highly cited themes. Future research should prioritise consumer-driven strategies, technological innovation, and interdisciplinary, international collaboration for sustainable industry growth. Emerging tools such as artificial intelligence and machine learning may enable more dynamic, predictive bibliometric analyses, while climate change impacts, including shrinking growing areas and yield losses, remain critical for resilient coffee production systems.

6 AUTHOR CONTRIBUTION

Conceptual Idea: Sukweenadhi, J.; Ho, Y. S. Methodology design: Sukweenadhi, J.; Ho, Y. S. Data collection: Ho, Y. S. Data analysis and interpretation: Sukweenadhi, J.; Ho, Y. S. Writing and editing: Sukweenadhi, J.

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8 DATA AVAILABILITY STATEMENT

Data available upon request to authors.

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