

Microorganisms in coffee fermentation: A bibliometric and systematic literature network analysis related to agriculture and beverage quality (1965-2019)

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ABSTRACT

The activity of microorganisms in coffee fermentation has a great influence on the composition of the beans and their beverage quality. In the present study, a bibliometric and systematic literature network analysis is made to examine the growth in the literature and the flow of knowledge in the field of study. The bibliometric information was retrieved from the Scopus database, obtaining 55 articles between 1965 and 2019. Frequencies, co-authorship, and co-occurrence indicators were analyzed using Microsoft Excel and VOSviewer software. Our findings show that most of the articles have been published in the last decade and mainly on microbial diversity and starter cultures. Furthermore, it was possible to identify the most productive authors, the most influential works, the main journals where articles of the most productive authors and the most influential works have been published, the most productive affiliation countries, the most used keywords, the co-authorship taking authors and countries as the unit of analysis, the keyword co-occurrence, and the spatial distribution of studies with their research topics. This is the first bibliometric and systematic literature network analysis carried out on research articles on microorganisms in coffee fermentation related to agriculture and beverage quality, which becomes a tool for researchers in making decisions for the building and development of strategic plans for future research by understanding the trends and status of existing research in the field of study in accordance with the authors, works, affiliation countries, study topics, and patterns of international collaboration and within the academic community.

Key words: Bibliometry; *Coffea*; coffee processing; cup quality; microbiology.

1 INTRODUCTION

The coffee genus (*Coffea*) belongs to the Rubiaceae family and comprises 103 species from Latin America, Africa, and Asia (Simon-Gruita et al., 2019). *Coffea arabica* L. and *C. canephora* L. species are the most economically and industrially important species grown for beverage production, where *C. arabica* represents around 70-75% of the total coffee marketed in the world (Aristizábal; Chacón; Cardona, 2017; Waters; Arendt; Moroni, 2017). The coffee beverage has been consumed for at least the last 10 centuries and is currently one of the most daily ingested drinks worldwide (Orecchio; Amorello; Barreca, 2019). In 2018 there was a production of more than 170.000 (in thousands of 60-kg bags) and coffee consumption of 168.099 in the period of 2018/19 (ICO, 2020).

To obtain the coffee drink, once the coffee cherries are harvested, they have to be processed to remove the exocarp, mesocarp and mucilage layer (pectin layer) (Figure 1) to obtain the green coffee beans, which are then dried and roasted (Huch; Franz, 2015). The processing can be done using three different types of postharvest methods (dry, wet, or semi-dry) which allow fermentation to occur (Haile; Kang, 2019a; Huch; Franz, 2015; Schwan; Silva; Batista, 2012).

Fermentation is a metabolic process that is critical for removing mucilage from parchment coffee (Haile; Kang,

2019a). Coffee fermentation is carried out by microorganisms such as bacteria, yeasts, and filamentous fungi (Pereira; Soccol; Soccol, 2016; Silva et al., 2008). Microorganisms degrade the mucilage which contains pectin, cellulose, and starch, and produce alcohols, acids, esters, and ketones (Puerta; Echeverry, 2015). Those substances produced during the fermentation process affect the composition of the beans and therefore their cupping quality (Haile; Kang, 2019a; Lee et al., 2015).

Taking into account the importance of microorganisms in the coffee fermentation process, a few literature reviews have been published. Lee et al. (2015) wrote a review article about the relationship between fermentation and coffee aroma including the microbiology of coffee fermentation. Pereira, Soccol and Soccol (2016) published a paper related to the current state of research on coffee fermentations in which it covers microbial ecology and starter cultures. Furthermore, Waters, Arendt and Moroni (2017) made a critical review about microflora associated with coffee fermentation; Haile and Kang (2019a) analyzed the role of microbes in coffee fermentation and their impact on coffee quality and De Melo Pereira et al. (2020) discussed new directions for exploiting lactic acid bacteria in coffee fermentation covering diversity, ecology, metabolism and key influences on coffee quality.

Although these reviews offer useful insights about research on microorganisms in coffee fermentation related

to agriculture and/or beverage quality, a bibliometric and systematic literature network analysis has not been completed. Bibliometric and structured network analysis has gained importance as being a prominent literature review (Bamel; Pandey; Gupta, 2020). This analysis provides information about the growth in the literature and the flow of knowledge in the field of study during the period of 1965-2019 and helps to explore, organize and analyze data that can assist researchers in the decision-making process regarding the building and development of strategic plans, answer questions about which research directions should be built in future or which ongoing research activity should be supported concerning microorganisms in coffee fermentation related to agriculture and/or beverage quality (Daim et al., 2006; Matcharashvili et al., 2014; Pereira et al., 2019). This paper is an attempt to supplement the few published literature reviews and to make significant contributions to the literature on microorganisms in coffee fermentation using a bibliometric and systematic literature network analysis.

2 MATERIAL AND METHODS

In this study, a bibliometric method including a descriptive and exploratory approach was adopted to analyze the studies conducted concerning microorganisms in the coffee fermentation process in agriculture and as an influential factor in the sensory quality of the beverage. A quantitative and qualitative approach was used to compare and analyze research data.

The construction of the bibliometric profile was conducted through different phases ranging from the definition of the initial query string to the analysis of the results based on methodologies proposed by Angulo et al. (2018); Bildosola et al. (2017); Fahimnia, Sarkis and Davarzani (2015).

2.1 Definition of the initial query string, initial data download and searching results refinement

According to Galvis and Sánchez (2014), the definition of search strategies includes the determination of the database to be consulted and the search expressions in the selected database. Elsevier's Scopus database was selected and the keywords "coffee" "fermentation" "microb*" "microorganism" "fungi" "bacter*" and "yeast" were used in "TITLE-ABS-KEY" search field with limitations to articles published until 2019, obtaining the query string:

TITLE-ABS-KEY (coffee AND fermentation AND (microb* OR microorganism OR fungi OR bacter* OR yeast) AND DOCTYPE ("ar") ANDNOT PUBYEAR > 2019.

The initial query string provided 243 results. These registers were downloaded to conduct a data cleaning and a quality evaluation of them according to the object under study. All the summaries were read to identify those articles whose studies on microorganisms in coffee fermentation are related to agriculture and/or the sensory quality of the coffee beverage. Those unrelated items were discarded.

2.2 Definition of the final query string

Taking into account the keywords of the discarded articles, a new search query string was created to exclude those articles. The following query string was obtained:

TITLE-ABS-KEY (coffee AND fermentation AND (microb* OR microorganism OR fungi OR bacter* OR yeast) ANDNOT (review OR husk OR waste OR residue OR spent OR spoilage OR by-product OR silverskin OR skin OR "pulp extract" OR "level of caffeine" OR "value of coffee pulp" OR "coffee bean extract" OR "I. green coffee" OR "II. roasted coffee" OR "plant tissue" OR "fermentation

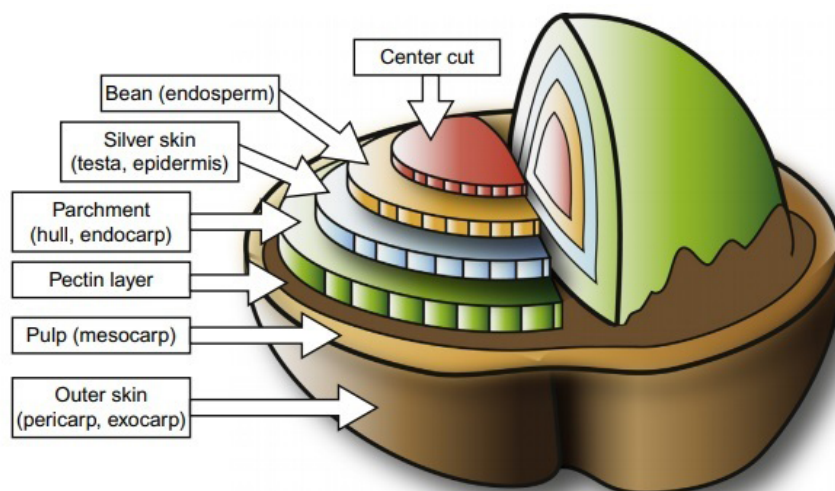


Figure 1: The anatomy of a coffee cherry.

Source: Gibson and Newsham (2018).

extract" OR "Solid-state fermentation of coffee pulp" OR "cocoa fermentation" OR theobromine OR bread OR milk OR beer OR cheese OR rice OR wheat OR kombucha OR kefir OR noni OR mutation OR "gut microbiota" OR intestin* OR disease OR decolour* OR pancar OR oak OR silage OR weevil OR chitin OR insecticidal OR acrylamide OR "production of 5-hydroxy" OR "ethanol production" OR "production of ethanol" OR oil OR biogas OR desempenho OR ohmic)) AND DOCTYPE ("ar") ANDNOT PUBYEAR > 2019.

2.3 Final data download

Once the final search query string was defined, on April 25, 2020, a list with 55 articles was obtained whose studies on microorganisms in coffee fermentation are related to agriculture and/or the sensory quality of the beverage. All data of said articles were downloaded.

2.4 Definition, calculation, and analysis of bibliometric indicators

Frequency, co-authorship, and co-occurrence indicators were defined based on Aguirre and Bolton (2014); Angulo et al. (2018); Bamel, Pandey and Gupta (2020); Durieux and Genenois (2010); Fahimnia, Sarkis and Davarzani (2015); Garechana et al. (2014); Pereira et al. (2019). The frequency indicators were calculated and analyzed using the dynamic tables function in Microsoft Excel. These results were later used to build tables and figures. Co-authorship and co-occurrence indicators were calculated and analyzed by figures using VOSviewer software.

Frequency indicators analysis includes chronological distribution of studies (1965-2019), classification of the most productive authors, the top of the most influential works, the affiliation countries with the greater number of articles, and the top of the most used keywords. The co-authorship indicator comprehends authors and countries. The co-occurrence indicator encompasses author and index keywords.

The analysis of the results was divided into five topics: 1. Chronological distribution of studies; 2. Top of the most productive authors and co-authorship network; 3. Top of the most influential works; 4. Top of the most productive affiliation countries and country co-authorship network; 5. Top of the most used keywords and keyword co-occurrence network.

3 RESULTS

3.1 Chronological distribution of studies

Figure 2 presents the publication frequency in chronological order. Results show that the number of articles

published annually increased from 1 in 1965 to 55 in 2019; this last year (2019) being the one with the highest number of articles published. Time periods 1966-1991, 1993-2000 and years 1999, 2000, 2003, 2005, 2009, 2012 did not present documents.

3.2 Top of the most productive authors and co-authorship network

From 170 authors, the 5 most prolific authors in research on microorganisms in coffee fermentation concerning agriculture and/or the sensory quality of the beverage were identified (Table 1). These authors make an important contribution to the growth and evolution of the field of study (Bamel; Pandey; Gupta, 2020). Besides, knowing about pioneers in a particular domain helps decide whom to contact for research, policymaking, and help with organizational issues in a specific field (Rey; Ribeiro; Palacios, 2016).

It is evident from Table 1 that the most productive authors have an affiliation from Brazil, where Schwan, R.F. headed the list with the largest number of publications, followed by de Melo Pereira, G.V., Silva, C.F. and Soccol, C.R.

The top 5 most productive authors have a combined publication number of 24 papers in 17 journals. 16.7% of the articles are in "Food Research International", followed by "Food Microbiology" (12.5%), "Acta Scientiarum. Agronomy" (8.3%), "Fermentation" (8.3%), and "International Journal of Food Microbiology" (8.3%).

Regarding co-authorship with the authors' unit of analysis, it refers to the collaboration of two or more authors in a document and is used to understand patterns of collaboration within the academic community (Newman, 2004). Figure 3 shows the co-authorship networks with a minimum number of documents and citations of an author equal to one. Connected authors consist of 53 out of 170 authors grouped into 6 clusters.

The red is the largest cluster that represents the authors with the greatest collaboration among the articles studied, this cluster is composed of 14 authors. Followed by the green cluster and the dark blue one made up of 10 authors. It is also evident that the red cluster is near to yellow and light blue, and the green cluster is near to dark blue and purple.

3.3 Top of the most influential works

In addition to the analysis of the most productive authors, it is important to identify the most influential works that have shaped the knowledge structure of a domain (Bamel; Pandey; Gupta, 2020). Table 2 shows the top 5 most influential articles in terms of their citations. The most influential articles were published in the period 2001-2008.

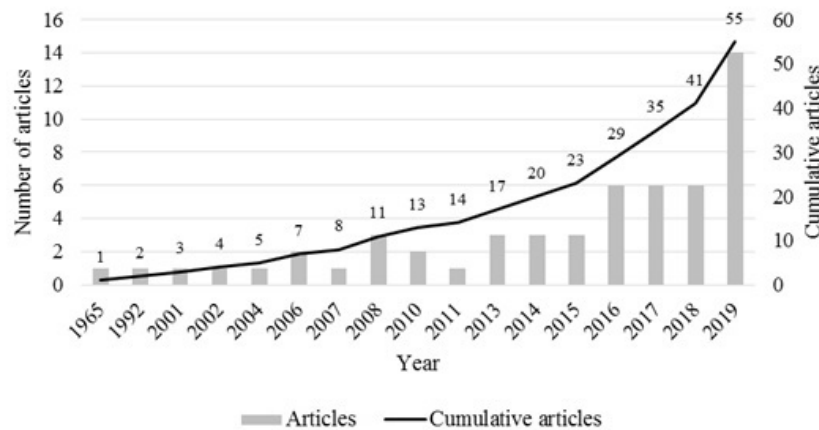


Figure 2: Chronological distribution of microorganisms studies in coffee fermentation related to agriculture and beverage quality (1965-2019).

Table 1: Top 5 most productive authors. Source: Author's analysis of Scopus data.

No.	Author	Number of articles	AV (%)	Affiliation	Journals
1	Schwan, R.F.	15	27.3	Universidade Federal de Lavras, Lavras, Brazil	Food Microbiol. (3), Food Res. Int. (3), Acta Sci. Agron. (2), Int. J. Food Microbiol. (1), World J. Microbiol. Biotechnol. (1), Braz. J. Microbiol. (1), LWT - Food Sci. Technol. (1), Ann. Microbiol. (1), Front. Microbiol. (1), J. Sci. Food Agric. (1)
2	de Melo Pereira, G.V. (De Melo Pereira, G.V.) (Pereira, G.V.d.M.)	10	18.2	Universidade Federal do Parana, Curitiba, Brazil	Fermentation (2), Food Microbiol. (1), Int. J. Food Microbiol. (1), Food Res. Int. (1), Int. J. Food Sci. Technol. (1), Food Technol. Biotechnol. (1), Food BioSci. (1), Micro. Res. Ann (1), Sci. Rep. (1)
3	Silva, C.F.	9	16.4	Universidade Federal de Lavras, Lavras, Brazil	Food Microbiol. (3), Food Res. Int. (1), World J. Microbiol. Biotechnol. (1), Int. J. Food Microbiol. (1), Braz. J. Microbiol. (1), Acta Sci. Agron. (1), Ann. Microbiol. (1).
4	Soccol, C.R.	9	16.4	Universidade Federal do Parana, Curitiba, Brazil	Fermentation (2), Int. J. Food Microbiol. (1), Food Res. Int. (1), Int. J. Food Sci. Technol. (1), Food Technol. Biotechnol. (1), Food BioSci. (1), Micro. Res. Ann (1), Sci. Rep. (1)
5	Miguel, M.G.d.C.P. (da Cruz Pedrozo Miguel, M.G.) (Miguel, M.G.P.d.C)	8	14.6	Universidade Federal de Lavras, Lavras, Brazil	Food Res. Int. (3), Food Microbiol. (1), Int. J. Food Microbiol. (1), LWT - Food Sci. Technol. (1), Ann. Microbiol. (1), J. Sci. Food Agric. (1)

AV: Represents the Article Value calculated as the ratio of "number of individual articles" by "total articles".

3.4 Top of the most productive affiliation countries and country co-authorship network

From 20 countries, the affiliation country with the largest number of articles published is Brazil with 26 papers (47.3%), followed by France (10.9%), Switzerland (7.3%), Belgium (7.3%), China (7.3%) and South Korea (7.3%).

Country co-authorship was analyzed to obtain information on international collaboration in studies on microorganisms in coffee fermentation related to agriculture and/or beverage quality. Twelve out of the 20 countries had at least 1 publication, these countries were grouped into 4 clusters (Figure 4).

3.5 Top of the most used keywords and keyword co-occurrence network

A keyword frequency of occurrence and a co-occurrence analysis were made to identify the main lines or themes of study. A total of 620 different author and index keywords were extracted from the list of 55 publications on microorganisms in coffee fermentation. In addition to the keywords "Coffee" and "Fermentation", in terms of highest occurrences in all the documents, the key terms "Yeast" or "Yeasts" (37) are on the top followed by "Bacteria" (24), "*Coffea arabica*" (17), "Starter culture" or "Starters culture" or "Starter cultures" (17), "Metabolism" (14), "Microbiology" (14), "*Coffea*" (13), "Coffee fermentation" (12), "Chemistry" (11), "Isolation and purification" (10) and "*Pichia*" (10).

Figure 5 illustrates the keyword co-occurrence network. It refers to the frequency of occurrence between two terms in a document. In this case, the minimum occurrence of a keyword was defined to be 5 and both author and index keywords were taken into account. Fifty-seven out of the 620 keywords met the established criteria. Of these 57 key terms, were excluded “Article”, “Non-human”, “Humans”, “Human” and “Priority journal” to perform a comprehensive analysis, obtaining

a total of 52 keywords. In our analysis, four clusters were obtained.

With 17 keywords, the red cluster is the largest one, followed by green (14), blue (12), and yellow one (9). The largest size of the nodes belongs to the key terms “Coffee” and “Fermentation” of the blue cluster, representing the keywords that have the highest frequency of occurrence (Van Nunen et al., 2018). This cluster is interconnected with the others through these two keywords.

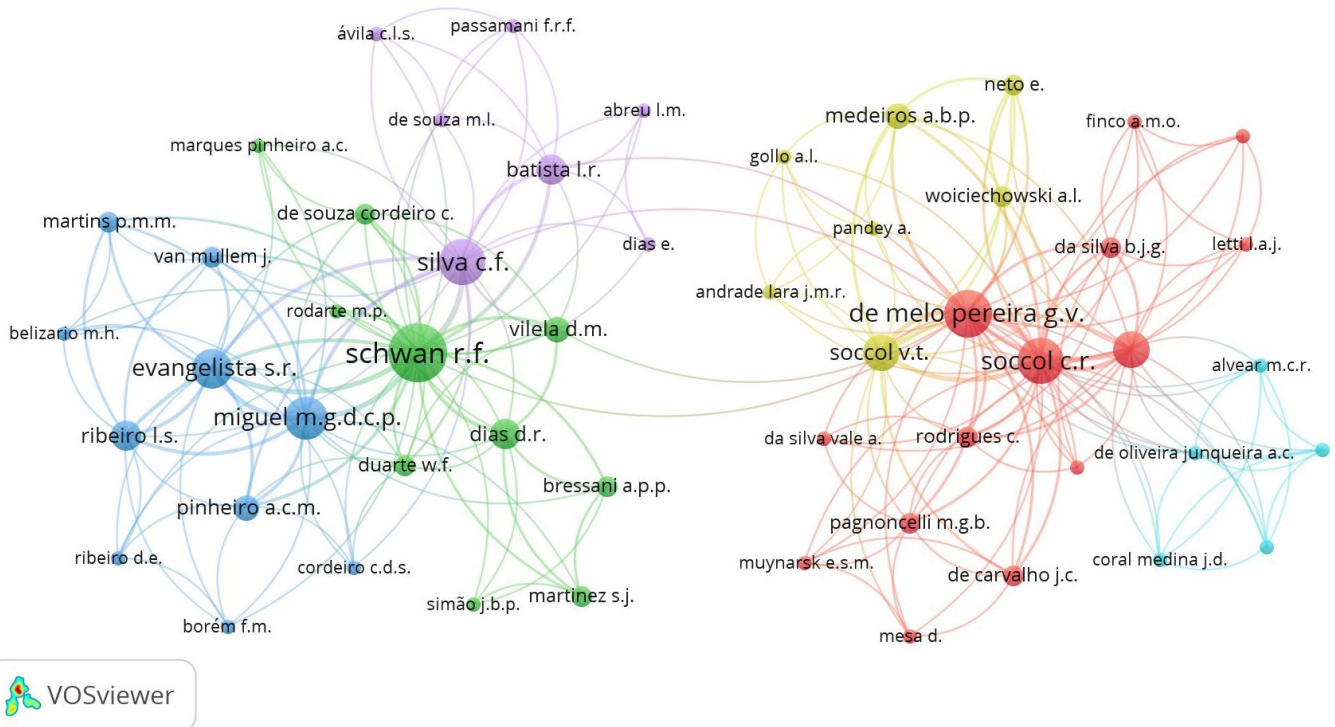


Figure 3: VOSviewer network visualization map of co-authorship.

Table 2: Top 5 most influential works. Source: Author’s analysis of Scopus data; ¹Scopus, ²Google Scholar on April 27, 2020, ³Web of Science on April 27, 2020.

No.	Author (year)	Title	Journal	NC ¹	NC ²	NC ³
1	Masoud et al. (2004)	Yeast involved in fermentation of <i>Coffea arabica</i> in East Africa determined by genotyping and by direct denaturing gradient gel electrophoresis	Yeast	89	79	137
2	Silva et al. (2008)	Succession of bacterial and fungal communities during natural coffee (<i>Coffea arabica</i>) fermentation	Food Microbiology	80	71	137
3	Avallone et al. (2001)	Microbiological and biochemical study of coffee fermentation	Current Microbiology	79	68	132
4	De Bruyne et al. (2007)	<i>Leuconostoc holzapfelii</i> sp. nov., isolated from Ethiopian coffee fermentation and assessment of sequence analysis of housekeeping genes from delineation of <i>Leuconostoc</i> species	International Journal of Systematic and Evolutionary Microbiology	75	68	91
5	Masoud and Kaltoft (2006)	The effects of yeasts involved in the fermentation of <i>Coffea arabica</i> in East Africa on growth and ochratoxin A (OTA) production by <i>Aspergillus ochraceus</i>	International Journal of Food Microbiology	74	72	117

NC: Number of Citations.

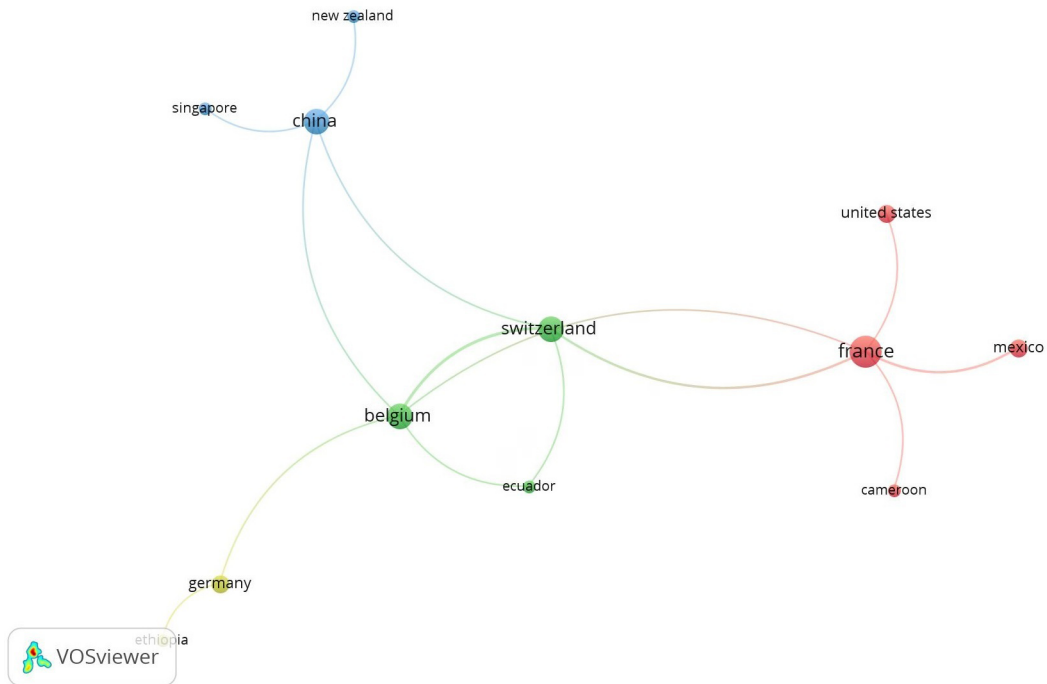


Figure 4: VOSviewer network visualization map of country co-authorship.

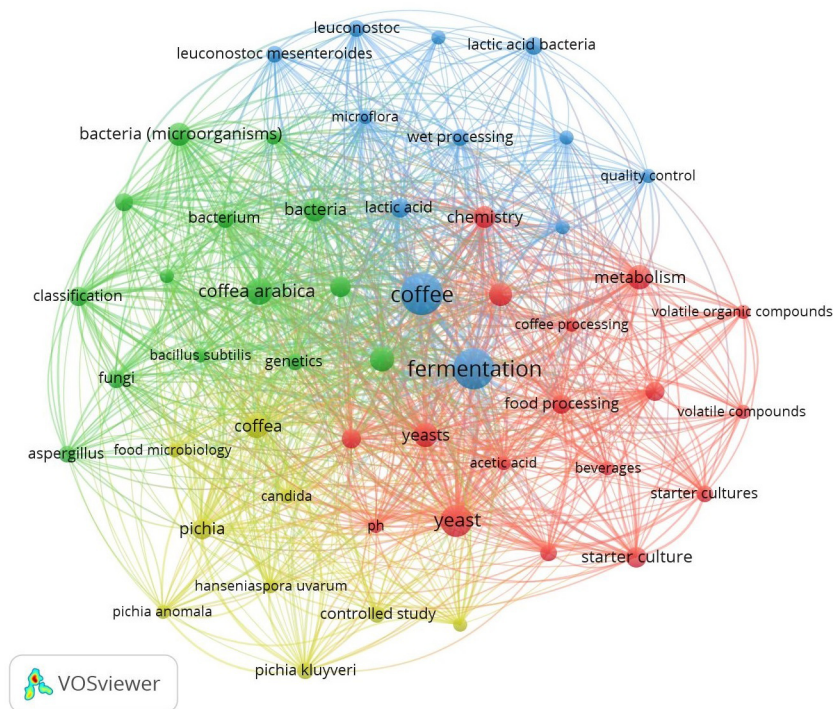


Figure 5: VOSviewer network visualization map of keyword co-occurrence.

3.6 Spatial distribution of studies and research topics

This section refers to the countries where the studies were applied, which are different from the affiliation countries of the authors. The same article may have different locations or more than one research topic. Spatial

distribution of studies and research topics are presented in Table 3.

Brazil is the country where more studies have been carried out on microorganisms in coffee fermentation, addressing a variety of topics that lead to complete information in the field of study. Followed by Colombia, Indonesia, Korea, China, Mexico, and Ethiopia, which have some studies but there are information gaps.

Table 3: Spatial distribution of studies and research themes. Source: Author's analysis of Scopus data.

Location (Country)	Number of articles	Q	D		SC	SQ	PCA	B	O	References	
			C-D	C-I							
Brazil	25	X	X				X			Silva et al. (2008)	
		X	X							Silva, Batista and Schwan (2008)	
						X		X		X	Silva et al. (2013)
		X	X	X							Vilela et al. (2010)
										X	Muynarsk et al. (2019); Rodarte et al. (2011)
		X			X	X	X	X			De Carvalho Neto et al. (2018a); De Melo Pereira et al. (2014, 2015); Evangelista et al. (2014a, 2014b); Martinez et al. (2017)
		X	X	X				X			Evangelista et al. (2015)
		X				X	X	X			Martins et al. (2019); Pereira et al. (2016)
		X			X			X		X	De Carvalho Neto et al. (2017)
									X		Souza et al. (2017)
						X		X			De Carvalho Neto et al. (2018b)
				X	X	X		X	X		
Colombia	5									Ribeiro et al. (2017a); Tinoco et al. (2019)	
					X	X	X			Cândido et al. (2019); Ribeiro et al. (2017b)	
						X		X			Da Silva et al. (2019); Martinez et al. (2019)
		X								X	Boizet et al. (1992)
							X	X			Mejia et al. (2016)
Indonesia	4								X	Ludlow et al. (2016)	
		X	X				X			Muzaifa et al. (2018)	
		X								X	Muzaifa et al. (2019)
Korea	3				X	X	X			Wang et al. (2019)	
		X	X	X	X				X	Kim, Yeon and Jang (2016); Kwak, Jeong and Kim (2018)	
China	3		X	X						Haile and Kang (2019b)	
			X	X			X			Hong-Hong et al. (2013)	
		X		X			X				Feng et al. (2016)
Tanzania	3			X						Zhang et al. (2019a)	
		X								Masoud et al. (2004)	
		X					X	X	X	X	Masoud and Kaltoft (2006)
Mexico	3		X				X			Massawe and Lifa (2010)	
			X			X	X	X			Avallone et al. (2001)
			X			X	X	X			Avallone et al. (2002)
Ethiopia	3								X	Ludlow et al. (2016)	
									X	De Bruyne et al. (2007); Schillinger et al. (2008)	
India	2	X			X	X	X			Ludlow et al. (2016)	
		X					X	X			B et al. (2019)
										Velmourougane, (2013)	

Continua...

Table 3: Continuation.

Kenya	2	X		X	X	X	Ludlow et al. (2016)
						X	Haile and Kang (2019c)
United States	2	X	X		X		Frank, Lum and De La Cruz (1965)
						X	Ludlow et al. (2016)
Ecuador	2			X		X	De Bruyn et al. (2016)
		X		X	X		Zhang et al. (2019b)
Cameroon	1			X			Hamdouche et al. (2016)
Thailand	1	X	X				Nasanit and Satayawut (2015)
Costa Rica, Guatemala, Honduras, Nicaragua, Peru, Rwanda, Uganda, Yemen	1					X	Ludlow et al. (2016)

Q: Quantification of microorganisms; D: Approximation of microbial diversity; C-D: Culture dependent-methods; C-I: Culture-independent methods; SC: Starter Cultures; SQ: Sensorial Quality; PCA: Physical, Chemical, or Physicochemical Analysis; B: Biocontrollers; O: Others.

4 DISCUSSION

This study offers a bibliometric profile of published research articles on microorganisms in coffee fermentation related to agriculture and beverage quality between 1965 and 2019. Key findings are summarized as follows.

The **first** is the increasing behavior of these studies over time, showing that the field of study is receiving considerable attention from researchers. To understand the evolution and topics, a detailed content analysis of the studies was performed.

Quantification of microorganisms through culture-dependent methods in the coffee fermentation process was carried out in 54.5% of the articles which corresponded to 30 documents, where the majority studied fungi and/or yeast (86.7%) and 80.0% studied bacteria. 31.0% of the 30 documents related the number of microorganisms with the sensory quality of the beverage (B et al., 2019; De Melo Pereira et al., 2015; Evangelista et al., 2014a; Martinez et al., 2017; Martins et al., 2019; Massawe; Lifa, 2010; Mejia et al., 2016; Muzaifa et al., 2018; Velmourougane, 2013).

An approximation of microbial diversity using culture-dependent methods was executed in 15 articles, corresponding to 27.3% of the studies. 80.0% of these articles studied bacteria and 73.3% fungi and/or yeast. Within these 15 papers, only 2 (14.3%) related microbial diversity to beverage quality (Avallone et al., 2002; Mejia et al., 2016). The use of culture-independent methods with the same objective was conducted on 30.9% of the documents (17 articles) where 76.5% studied bacteria and 82.4% fungi and/or yeast. 29.4% of these documents related diversity to the final quality of the beverage

(De Melo Pereira et al., 2015; Evangelista et al., 2014b; Martinez et al., 2017; Ribeiro et al., 2018; Zhang et al., 2019a).

Inoculation of microorganisms (starter cultures) in coffee fermentation was performed in 40.0% of the studies corresponding to 22 articles; being the yeasts of *Saccharomyces* genus the most used as starter cultures (B et al., 2019; Cândido et al., 2019; Evangelista et al., 2014a; Evangelista et al., 2014b; Kwak; Jeong; Kim, 2018; Martinez et al., 2017; Martins et al., 2019; Ribeiro et al., 2017a; Ribeiro et al., 2017b; Tinoco et al., 2019), followed by bacteria belonging to the *Lactobacillus* genus (Avallone et al., 2002; B et al., 2019; De Carvalho Neto et al., 2018a; Kim; Yeon; Jang, 2016; Pereira et al., 2016) and yeasts of *Pichia* genus (De Melo Pereira et al., 2015; Evangelista et al., 2014a; Evangelista et al., 2014b; Massawe; Lifa, 2010). The importance of these studies lies in the fact that the use of starter cultures in coffee fermentation improves the beverage sensory quality by providing better control of the process (Evangelista et al., 2014a). 77.3% out of 22 documents related starter cultures to cup quality.

In 5.5% of the articles, studies on microorganisms as biocontrollers of fungi of *Aspergillus* genus in coffee fermentation was carried out, which are producers of Ochratoxin A (OTA) (Masoud; Kaltoft, 2006; Massawe; Lifa, 2010; Souza et al., 2017). OTA is classified by the International Agency for Research on Cancer (IARC) as a possible carcinogen in humans (IARC, 1993) and there are several reports on the occurrence of OTA in coffee samples from different origins, whose contamination directly influences food security (FAO, 2006).

Other contributions to microbiology and species identification in coffee fermentation were made; Boizet et al. (1992) taxonomically characterized the bacteria *Leuconostoc*

mesenteroide through DNA-DNA hybridization, morphology, and composition of protein structures, De Bruyne et al. (2007) identified a new species of *Leuconostoc* genus (*L. holzapfelii*), Schillinger et al. (2008) developed a gender-specific PCR analysis method for rapid and reliable differentiation between two heterofermentative lactic acid bacteria (genera *Leuconostoc* and *Weissella*), and Muynarsk et al. (2019) determined the genetic sequence of *Pediococcus acidilactici*.

Second, the results of the most productive authors show the leadership of Schwan and other authors from Brazil. Studies performed by these authors include the quantification of microorganisms, determination of microbial diversity by culture-dependent and -independent methods, and the inoculation of starter cultures in the coffee fermentation process.

Analyzing the co-authorship network shown in Figure 3, studies of the clusters focus mainly on starter cultures and microbial diversity, except the light blue cluster. The red cluster is composed of authors belonging to Federal University of Paraná, Brazil, demonstrating their co-authorship occurs mainly with members of the same affiliation, and it is led by de Melo Pereira G.V. and Soccol, C.R. Red cluster is interconnected in the network with all the others, except for the dark blue. In terms of the number of articles, de Melo Pereira participates in all the articles of the cluster followed by Soccol C.R. and de Carvalho Neto, D.P.

Authors of the green cluster have different Brazilian affiliations and it is headed by Schwan, who has the largest number of co-authorship links with other researchers and he is also the most cited (403 citations) and the most productive author (Table 1). This cluster has the highest number of documents (15) and in terms of the highest number of publications, also includes authors such as Dias, Vilela, Bressani, and so on.

The Dark blue cluster includes authors such as Evangelista, Miguel, Ribeiro L.S., and so on. In terms of publication years, this cluster has publications in the period of 2013-2019, excepting 2016. In terms of the number of articles and citations, Miguel has the highest indicator. This cluster is linked with the green and purple ones.

With seven authors, on one side is the yellow cluster that is rooted in Soccol V.T. who participates in the six documents of the cluster and has the maximum number of citations of the cluster members, followed by Medeiros, A.B.P. This cluster is only connected with the red one and its articles were published in the period 2014-2019, one document per year. On the other side is the purple cluster led by Silva, C.F. who also participates in all papers of the cluster and has the highest number in terms of citations. This cluster also has members such as Batista, Abreu, Dias, and so on.

The light blue cluster is the smallest one, only connected with the red cluster. This cluster has only one document, therefore the authors belonging to the cluster participate in it. The study carried out by these authors makes an important

contribution to the field of study by being the first description of the microbial diversity (fungi and bacteria) using culture-independent methods in Colombian coffee beans (De Oliveira Junqueira et al., 2019).

The **third** finding is concerning the most influential works. The study realized by Masoud et al. (2004) has the greatest influence in studies on microorganisms in coffee fermentation. This one was the third contribution after Avallone et al. (2001) and Frank, Lum and de la Cruz (1965) regarding the quantification of yeasts through culture-dependent methods and the first contribution to the determination of yeast diversity in the coffee fermentation process using culture-independent methods. The second most influential individual article written by Silva et al. (2008) adds important knowledge about quantification and diversity through the morphological characterization of bacteria and fungi in coffee fermentation using culture-dependent methods.

Other important works were carried out by Avallone et al. (2001) regarding the quantitative and qualitative study of fungi, bacteria and yeasts in the fermentation process, De Bruyne et al. (2007) with the discovery of a new species *Leuconostoc holzapfelii* isolated from coffee fermentation, and Masoud and Kalsoft (2006) with the inoculation of yeasts in the fermentation process as biocontrol on OTA production.

Fourth, the top of the most productive affiliation countries and country co-authorship network. The leadership of Brazil when compared to the other countries is consistent as it is the largest coffee producer worldwide and France, which is second in terms of their number of articles, is the largest importer of roasted coffee and the seventh importer of green coffee (FAO, 2018).

According to the country co-authorship network, although Brazil presents the largest number of articles, it is not co-authored with another country in the field of study. Figure 4 shows that the red cluster composed of 4 countries (France, United States, Mexico, and Cameroon) is the largest one in the country co-authorship. France has the highest weight which is evident with the size of the label. France's international collaboration encompasses European, American, and African countries. In terms of their items, the red cluster is followed by the green one (Switzerland, Belgium, and Ecuador), blue (China, New Zealand, and Singapore) and yellow (Germany and Ethiopia).

France and Belgium have the highest individual links (5) and total link strength (7). France, in addition to being linked with the countries of its cluster, is linked with Switzerland and Belgium. On the other hand, Belgium, in addition to its cluster items, is connected with France, China, and Germany. Switzerland also has 7 total link strength, not only linking with the countries of its cluster but also with China and France. The countries with the lowest total link strength (1) are New Zealand, Singapore, Ethiopia, the United States, and Cameroon.

Fifth, the results of the most used keywords and keyword co-occurrence network. The red cluster includes keywords such as “Yeast”, “Metabolism”, “Coffee fermentation”, “Chemistry”, “Starter culture”, “Food handling”, “Food processing”, “Volatile compounds”, “Beverages”. This analysis indicates that the focus of the cluster is the management of the coffee fermentation process as an influential factor in the chemical composition of the beverage and the use of microbial inoculums to influence these beverage characteristics.

The green cluster has as its central axis the keyword “*Coffea arabica*” surrounded by others such as “Microbiology”, “Bacteria”, “Fungi”, “Isolation and purification”, “Classification”, “Genetics” and “Microbiota”. This cluster has research publications focused on quantification and determination of microbial diversity in the fermentation process of *C. arabica* species using culture-dependent and -independent methods.

The blue cluster has the most common keywords; “Coffee” and “Fermentation”. Those keywords are connected in the cluster with other words such as “Lactic acid”, “Lactic acid bacteria”, “*Leuconostoc*”, “Microflora”, “Wet processing”, “Quality control” and “Sensory analysis”. It appears that this cluster focuses on the study of lactic acid bacteria, such as *Leuconostoc*, in the wet fermentation process of coffee and its influence on the sensory quality of the beverage.

The yellow cluster is made up of keywords such as “*Coffea*”, “*Pichia*”, “*Candida*”, “Controlled study” and “*Hanseniaspora uvarum*”. Research in this cluster appears to focus on control of the fermentation process of the *Coffea* genus through yeast inoculums mostly used as starter cultures.

The last finding corresponding to the **sixth** is on the location of the studies and the topics addressed. Brazil is the country where the greatest number of studies on the coffee fermentation process have been applied. The main research carried out in this country are on chemical composition, quantification of microorganisms, approximation of microbial diversity through culture-independent methods and starter cultures. Two approaches are evident; the use of starter cultures to promote the sensory quality of the beverage, and the study of microorganisms (quantification and diversity) related to the physicochemical characteristics. In the other countries listed in Table 3, although some studies have been done, there are information gaps that must be filled. Research involving the quantification of microorganisms, determination of microbial diversity, and physicochemical analysis in the fermentation process are the most common.

5 CONCLUSIONS

This article consolidates research on microorganisms in the coffee fermentation process. The study is directly related to agriculture and/or food, specifically in the beverage quality by

using a bibliometric and structured network. To supplement the few published literature reviews, the chronological distribution of studies, the most productive authors, most influential works, most productive affiliation countries, most used keywords, co-authorship network with the authors, and countries as the unit of analysis and keyword co-occurrence were analytically and objectively identified.

The findings demonstrate that the largest number of studies were conducted in the last decade and that the number of articles increased as more advanced technologies have been developed. While in the past decades, research was mainly performed regarding the quantification of microorganisms and the identification of these using culture-dependent methods, in this decade, studies are focused on the study of microbial diversity through identification by culture-independent methods and the use of starter cultures in the coffee fermentation process.

It was possible to identify that Schwan, Rosane is the author with the highest influence in the growth and evolution of domain knowledge of research about microorganisms in coffee fermentation in terms of productivity, co-authorship, and citations. Her work is mainly focused on subject areas such as Agricultural and Biological Sciences, Immunology and Microbiology, and Biochemistry, Genetics and Molecular Biology.

The most influential work, in terms of citations, is the article written by Masoud et al. (2004), being the fourth paper published on microorganism in coffee fermentation related to agriculture and/or beverage quality. This result is not surprising since as of 2019 there are only 55 articles with research in that field of study and being one of the first executed, it has become a fundamental reference for the following studies. Further, recently published works have not had a chance to gain as much influence since citations have yet to accrue. The articles of the most productive authors and the most influential works have been published mainly in journals such as “Yeast” and “Food Microbiology”.

It was also identified that affiliations from Brazil are the most productive in the field of study but they do not present international collaboration; they only present co-authorship among its members. Affiliation countries such as France, Belgium, and Switzerland have the highest co-authorship indicator. Lastly, the most used keywords and keyword co-occurrence network provided useful information about the main research topics in the field of study. The most used key terms are “Coffee”, “Fermentation”, “Yeast” or “Yeasts”, “Bacteria”, “*Coffea arabica*” and “Starter culture” or “Starters culture” or “Starter cultures”. The keywords “Coffee”, “Fermentation”, “Yeast” or “Yeasts”, “*Coffea arabica*”, “Microbiology” and “Metabolism” have the highest co-occurrence indicator.

Although studies have been carried out on microorganisms in the coffee fermentation process related

to agriculture and food (beverage quality), and there is considerable progress in the field of study, it is necessary to continue researching in different parts of the world, since the presence of microorganisms and the behavior of the fermentation process is specific to each place and geographic niche; culminating in the reason why each region has distinctive flavored coffees (De Oliveira Junqueira et al., 2019). It is also important to continue conducting research related to using culture-independent methods to break-down the barriers that arise when interpreting results obtained by culture-dependent methods, as well as studies on selection and inoculation of starter cultures according to specific regional conditions. It would be also convenient to consider studies that allow developing tools to carry out a good fermentation process that can guarantee coffee growers an added value to production, high quality of the beverage, and a reduction in the risk of offering the grain with undesirable defects.

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