

Mapping the Research Landscape of Nitrite, pH, and *Lactobacillus acidophilus*: A Bibliometric Analysis

Iffa Izzati Azizah¹, Dimas Prasetianto Wicaksono^{2*}, Betadion Rizki Sinaredi²

¹Undergraduate Student, Faculty of Dental Medicine,
Universitas Airlangga, Surabaya, Indonesia

²Department of Pediatric Dentistry, Faculty of Dental Medicine,
Universitas Airlangga, Surabaya, Indonesia

E-mail: iffa.izzati.azizah-2023@fkg.unair.ac.id;
dimaspw@fkg.unair.ac.id; betadion-r-s@fkg.unair.ac.id

*Corresponding author details: Dimas Prasetianto Wicaksono; dimaspw@fkg.unair.ac.id

ABSTRACT

Nitrite, pH, and *Lactobacillus acidophilus* are interrelated in microbiological systems, yet the literature linking them remains scattered across applications. This study aimed to map publication trends, the distribution of research contributions, and thematic trends on nitrite, pH, and *L. acidophilus* through bibliometric analysis. We searched the Scopus database on July 24, 2026, using the keyword combination (“nitrite” OR “nitrites”) AND “pH” AND “*Lactobacillus acidophilus*” in titles, abstracts, and keywords. Of the 14 documents retrieved, we analysed and visualised 10 that passed screening in VOSviewer. The results showed a fluctuating publication pattern without a linear increase, with a peak in 2014 (three documents) and no documents during 2016–2022. The documents originated from eight countries, with China contributing the most (three documents), and were spread across 21 affiliations and 10 source titles, with no single institution or journal dominating. The co-authorship network consisted of a single group of 14 authors from one article. Keyword co-occurrence analysis yielded 29 keywords in two clusters: microbiological and metabolic aspects (bacterial growth, fermentation, acidification, nitrate/nitrite, and pH) and probiotic and animal-model experimental research. The specific relationship among nitrite, *L. acidophilus* metabolic activity, and pH changes did not emerge as a dominant theme, indicating a need for further experimental research.

Keywords: nitrite; pH; *Lactobacillus acidophilus*; bibliometric analysis; Scopus; VOSviewer

INTRODUCTION

Nitrite is a compound that plays an important role in various fields, particularly food processing, as it can be used to inhibit microbial growth and maintain certain characteristics of fermented products. Nitrite (NO_2^-) exhibits antimicrobial activity and can be formed through the reduction of nitrate (NO_3^-) by oral bacteria. Wicaksono et al. (2020) showed that nitrite could inhibit *Streptococcus mutans* growth at 0.5 mM[1]. Meanwhile, Sato-Suzuki et al. (2020) found that nitrite production activity was higher in dental plaque than in the tongue coating and involved various bacterial genera, including *Actinomyces*, *Schaalia*, *Veillonella*, and *Neisseria*[2]. Furthermore, nitrite production by *Veillonella* is influenced by pH conditions, lactate availability, and anaerobic conditions [1]. These findings indicate that nitrite is associated with oral cavity microbiological activity and environmental conditions that influence bacterial metabolism. However, its use requires careful consideration because nitrite may pose potential health risks [3,4].

Beyond its use in food processing, nitrite can also be produced by microorganisms that reduce nitrate. This makes nitrite an important compound in microbiological and fermentation research [5,6].

In addition to nitrite, pH is a key factor influencing microbial activity and metabolism. pH changes can affect bacterial growth, metabolic activity, and bacteria's ability to survive under acidic conditions. During fermentation, lactic acid bacteria produce organic acids that decrease pH, while pH conditions also influence the activity of antimicrobial compounds such as nitrite. This bidirectional relationship between acidity and microbial activity makes pH an important parameter in various studies involving lactic acid bacteria [7,8].

One of the most widely used and studied lactic acid bacteria is *Lactobacillus acidophilus*. This bacterium produces lactic acid through its metabolism, lowering the pH of its surroundings, particularly during fermentation. *L. acidophilus*'s ability to tolerate acidic

conditions also indicates that it can remain active in low-pH environments. In oral health, acid-producing bacteria activity and the resulting pH decrease are relevant to the caries process. Kunarti et al. (2021) explained that dental caries is a multifactorial disease characterized by an imbalance between demineralisation and remineralisation of dental tissues[9]. Similarly, Dianawati et al. (2020) described how organic acids produced through the metabolism of cariogenic bacteria can lower pH below the critical threshold and trigger the demineralisation of dental tissues[10]. Yani et al. (2020) also linked dental caries to bacterial acid production from fermentable carbohydrates, which contributes to dental demineralization[11]. Although these three studies did not specifically investigate *L. acidophilus*, their findings strengthen the theoretical basis for considering acid production and pH changes as important aspects of understanding the demineralisation process associated with dental caries. Therefore, the metabolic characteristics of *L. acidophilus* and its ability to survive under acidic conditions are relevant to investigating pH changes in the oral cavity [12–15].

The relationship between nitrite, pH, and *Lactobacillus acidophilus* is particularly interesting because these three components may interact within a microbiological system. Several studies have shown that the effectiveness of nitrite is influenced by acidity, while the activity of *L. acidophilus* may contribute to pH changes through acid production. Acidic conditions can also influence the conversion of nitrite into other nitrogen-containing compounds. Therefore, research on these three components encompasses not only the relationship between nitrite and microorganisms but also the environmental conditions that influence bacterial activity and metabolism [16].

Although research on nitrite, pH, and *Lactobacillus acidophilus* has been conducted in various contexts, the available literature remains dispersed across different application areas, bacterial characteristics, pH conditions, nitrite concentrations, and types of research matrices. The identified studies cover a range of topics, from the antimicrobial activity of nitrite against oral bacteria to the use of *L. acidophilus* in food fermentation and investigations into the ability of lactic acid bacteria to reduce nitrite[7,8,12–15]. These circumstances highlight the need to map the existing literature to determine how research on nitrite, pH, and *L. acidophilus* has evolved and to identify the themes that have received research attention.

Bibliometric analysis can provide an overview of a research field's development and structure based on scientific publication data. Through bibliometric analysis, publication trends can be examined by year, country, institution, author, and publication source. In addition, keyword co-occurrence mapping using tools such as VOSviewer can be used to identify relationships between concepts and thematic trends within the analysed literature. This approach enables research to not only describe

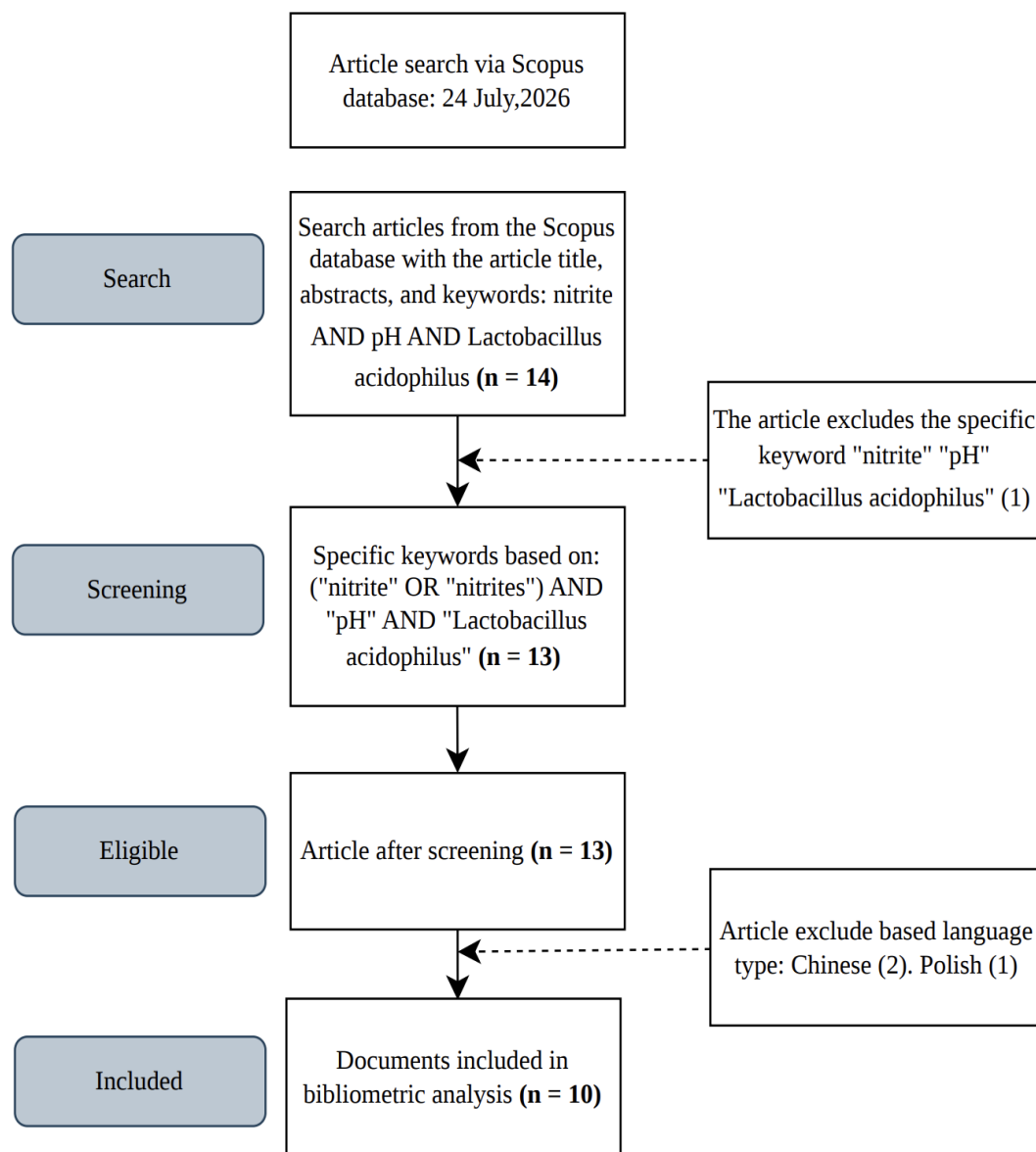
publication output but also identify patterns and interrelationships among emerging research topics within a particular field.

Based on these considerations, mapping research on nitrite, pH, and *L. acidophilus* is necessary to provide an overview of publication trends, the distribution of research contributions, and emerging thematic trends. The results of this mapping can also be used to identify underexplored research areas based on keyword relationships and the distribution of themes within the literature. Thus, bibliometric analysis is expected to provide an overview of the development of research on nitrite, pH, and *L. acidophilus*, while also serving as a foundation for determining future research directions.

- RQ1: How has research on nitrite, pH, and *Lactobacillus acidophilus* evolved in terms of annual publication output?
- RQ2: How is research on nitrite, pH, and *Lactobacillus acidophilus* distributed across countries, institutions, authors, and publication sources, and how has the co-authorship network developed?
- RQ3: What research themes and trends can be identified through keyword co-occurrence analysis, and what research gaps may guide future research directions?

METHODS AND ANALYSIS

This study used bibliometric analysis to map the development and characteristics of research on nitrite, pH, and *Lactobacillus acidophilus* based on scientific publications indexed in the Scopus database. The analysis examined publication trends by year, the distribution of research contributions by country, institution, author, and publication source, and keyword relationships to identify thematic trends and research gaps. The literature search was conducted in Scopus on July 24, 2026, using the keyword combination ("nitrite" OR "nitrites") AND "pH" AND "*Lactobacillus acidophilus*" in the titles, abstracts, and keywords. The search was restricted to English-language publications. The inclusion criteria were: (1) scientific publications indexed in Scopus; (2) publications identified using the specified keyword combination in their titles, abstracts, and/or keywords; (3) English-language publications; (4) publications available up to the search date, July 24, 2026; and (5) document types selected according to the objectives of the bibliometric analysis. The exclusion criteria included publications that did not meet the specified keyword combination, were written in languages other than English, or did not fall within the selected document types. We exported bibliographic data from the identified publications from Scopus, analysed them descriptively, and visualised them using VOSviewer. The descriptive analysis covered publication distributions by year, country, institution, author, and publication source. In contrast, network analysis visualised relationships among research elements, including co-authorship networks and keyword co-occurrence patterns.

**FIGURE 1:** PRISMA Framework.

Based on the search conducted on July 24, 2026, using the Scopus database and the search query ("nitrite" OR "nitrites") AND "pH" AND "*Lactobacillus acidophilus*" across article titles, abstracts, and keywords, covering publications from 2006 to 2026, a total of 14 documents were retrieved (Figure 1). During screening, one article was excluded because it did not meet the keyword

requirements for "nitrite," "pH," and "*Lactobacillus acidophilus*," leaving 13 articles that matched the specified keywords. The 13 eligible articles were then screened by language. At this stage, three articles were excluded: two written in Chinese and one written in Polish. Consequently, ten documents met the inclusion criteria and were used as the dataset for the bibliometric analysis.

TABLE 1: Data Analysis.

RQ	Data Analysis
RQ1	Publication Year
RQ2	Countries, Institutions, Authors, Publication Sources, and Collaboration Networks
RQ3	Keyword Occurrence, Keyword Co-occurrence, VOSviewer, and Research Gap Interpretation

TABLE 2: Data Extraction.

Author/ Year	Title	Journal	Citation	DOI	Affiliated Countries	Author Keywords	Document Type
Wicaksono D.P et al., (2025)	The Effect of Nitrite (NO ₂ ⁻), Fluoride (F ⁻) and their combination on <i>Lactobacillus acidophilus</i>	Fluoride	0	https://www.fluoridere search.online/epub/files /337.pdf	Indonesia, Thailand	caries; fluoride; human&disease; <i>Lactobacillus acidophilus</i> ; nitrite	Article
Minhos L.F et al., (2023)	Evaluation of the Efficacy of <i>Lactobacillus acidophilus</i> in the Treatment of Cyclophosphamide-induced Hemorrhagic Cystitis in Wistar Rats	Current Pharmaceutical Biotechnology	2	10.2174/138920102366220429121953	Brazil	bladder inflammation; cyclophosphamide; hemorrhagic cystitis; <i>Lactobacillus</i> spp.; probiotics; Wistar rats	Article
Wang Y et al., (2026)	Multi-strain cultivation for improving safety and sensory properties of traditional chilli sauce	Journal of Food Science and Technology	0	10.1007/s13197-026-06754-0	China	Chilli sauce; Fermentation; Flavour compounds; Lactic acid bacteria; Nitrite	Article
Xia D.S. et al. (2006)	Antimicrobial effect of acidified nitrate and nitrite on six common oral pathogens in vitro	Chinese Medical Journal	35	10.1097/00029330-200611020-00010	China	Acidification; Nitrate; Nitrite; Oral pathogens	Article
Libera J, Dolatowski Z.J (2014)	Effect of <i>Lactobacillus acidophilus</i> (Bauer) and <i>Bifidobacterium bifidum</i> on probiotic bacteria on changes in fat in dry-fermented meat products during storage	Zywnosc. Nauka. Technologia. Jakosc / Food Science Technology. Quality	1	10.15193/ZNTJ/2014/95/160-172	Poland	Dry-fermented pork necks; Fat oxidation; Probiotics; Storage	Article
Sushma M et al. (2009)	Effect of probiotic dairy products, prebiotic honey and their combination on different types of ulcers in albino rats	Pharmacologyonline	0	-	India	Acetic acid-induced colitis; Cysteamine-induced duodenal ulcer; Prebiotic honey; Probiotic dairy product; Pylorus ligation; Ulcerative colitis	Article
Baytukenova S et al., (2025)	Application of <i>Propionibacterium</i> and <i>Lactobacillus</i> Starter Cultures in Semidry Fermented and Smoked Sausage Production: Effects on Quality, Safety, and Nitrite Reduction	International Journal of Food Science	3	10.1155/ijfo/4733962	Kazakhstan	amino acid composition; nitrite reduction; <i>Propionibacterium shermanii</i> ; semidry fermented sausage; starter cultures	Article
Ren D et al., (2014)	In vitro evaluation of the probiotic and functional potential of <i>Lactobacillus</i> strains isolated from fermented food and human intestine	Anaerobe	167	10.1016/j.anaerobe.2014.07.004	China	Adhesion; Gastrointestinal tolerance; In vitro properties; <i>Lactobacillus</i> spp.; Probiotics	Article
Tiso M.; Schechter A.N (2015)	Nitrate reduction to nitrite, nitric oxide and ammonia by gut bacteria under physiological conditions	PLoS ONE	284	10.1371/journal.pone.0119712	United States	-	Article
Bomdespach L.Q. et al. (2014)	Evaluation of the use of probiotic lactic acid bacteria in the development of chicken hamburger	International Food Research Journal	8	-	Brazil	Curing salts; <i>Lactobacillus acidophilus</i> ; Meat products; Okara	Article

RESULT AND DISCUSSION

RQ1: How has research on nitrite, pH, and *Lactobacillus acidophilus* evolved in terms of annual publication output?

A Scopus search using the keyword combination ("nitrite" OR "nitrites") AND "pH" AND "*Lactobacillus acidophilus*" in the Article Title, Abstract, and Keywords fields, restricted to English-language publications, retrieved 10 documents. The publication year distribution indicates that the earliest publication in the dataset appeared in 2006, while the most recent publication was published in 2026. The publication-year metadata for these 10 documents was used to describe publication trends over time

TABLE 3: Number of Publications based on Year.

Year	Number of Publications
2006	1
2009	1
2014	3
2015	1
2023	1
2025	2
2026	1
Total	10

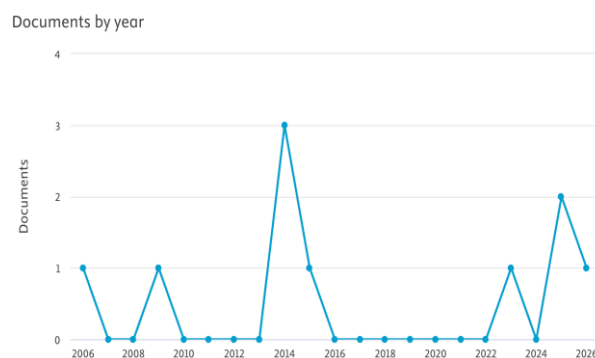


FIGURE 2: Distribution of Publications on Nitrite, pH, and *Lactobacillus acidophilus* by Publication Year (Source: Scopus Database)

Based on Table 2, the number of publications shows an inconsistent pattern over the years. The earliest publication in the dataset was recorded in 2006, followed by one publication in 2009. The highest number of publications was observed in 2014, with three publications (30%). Subsequently, only one publication was identified in 2015, and no publications were found in the dataset between 2016 and 2022. Publications reappeared in 2023, then increased to two in 2025 and one in 2026.

The annual publication distribution indicates that research identified through the keyword combination of nitrite, pH, and *Lactobacillus acidophilus* followed a fluctuating pattern from 2006 to 2026. Of the 10 publications, the highest number was recorded in 2014, with three publications (30%).

Meanwhile, 2006, 2009, 2015, 2023, and 2026 each accounted for one publication, whereas 2025 accounted for two publications. This distribution indicates that publications on this topic have not increased linearly over time.

The 2014 publication peak should be interpreted in the context of the characteristics and research focuses identified during that period. Publications from this year included studies on the probiotic potential and characteristics of *Lactobacillus* species, as well as the application of lactic acid bacteria in food products. Therefore, the increase in publications in 2014 does not directly indicate the consolidation of research specifically focused on the relationship between nitrite, pH, and *L. acidophilus*. Instead, these findings suggest that researchers explored these three concepts across several distinct contexts[17–19].

The absence of publications in the dataset during the 2016–2022 period also indicates a temporal gap in the literature that met the search criteria. However, this finding should be interpreted with caution. The absence of publications during a particular period does not necessarily indicate a complete lack of research on the topic, as bibliometric findings are strongly influenced by the database, search fields, keywords, publication language, and selection criteria employed. In this study, we limited the dataset to English-language documents indexed in Scopus and identified them using the keyword combination ("nitrite" OR "nitrites") AND "pH" AND "*Lactobacillus acidophilus*". Therefore, the temporal patterns identified reflect publication trends within this study's search strategy rather than the full available literature on the topic.

In the more recent period, publications reappeared in 2023, increased to two publications in 2025, and were followed by one document in 2026. One 2025 publication specifically evaluated the effects of nitrite on *L. acidophilus*, while the 2026 publication examined the use of multi-strain cultures involving *L. acidophilus* in food fermentation. These findings indicate that all three research concepts continue to appear in recent literature, although the dataset still contains relatively few publications.

Overall, the temporal distribution of the 10 publications indicates that research on nitrite, pH, and *L. acidophilus* has not shown consistent publication growth. The identified literature appears sporadically, with publications concentrated in certain years, particularly 2014 and 2025–2026. This pattern may indicate that research connecting these three concepts remains fragmented across contexts and has not yet shown sustained publication activity within a particular period. These findings provide a basis for further analysis of the distribution of countries, institutions, authors, publication sources, and keyword relationships in the subsequent research questions.

RQ2: How is research on nitrite, pH, and *Lactobacillus acidophilus* distributed across countries, institutions, authors, and publication sources, and how has the co-authorship network developed?

Documents by country or territory
Compare the document counts for up to 15 countries/territories.

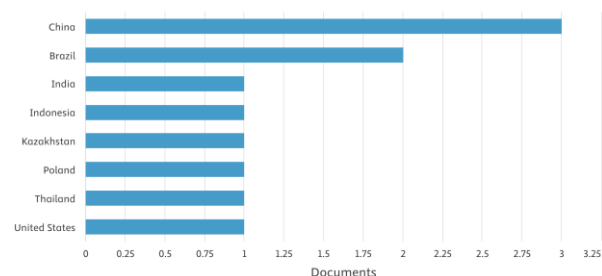


FIGURE 3: Number of Articles by Country or Territory (Source: Scopus Database)

Based on the authors' affiliations recorded in the Scopus metadata, the 10 publications in the dataset originated from several countries across Asia, the Americas, and Europe. China had the most publications, with three, followed by Brazil with two. Meanwhile, Indonesia, India, Poland, Thailand, Kazakhstan, and the United States each contributed one publication.

The distribution indicates that the dataset's publications on nitrite, pH, and *L. acidophilus* originated from eight countries. China contributed the most, with three publications (30%), followed by Brazil with two (20%). The remaining six countries each contributed one publication (10%). Thus, publication output in the dataset was not concentrated in a single country, although certain countries, particularly China, contributed more research.

The geographical distribution indicates that research on nitrite, pH, and *L. acidophilus* spans a relatively diverse range of countries, although the number of identified publications remains limited. Contributions from eight countries suggest that research on these three concepts has been conducted across several distinct research settings.

China contributed the most to the dataset, with three documents. These publications covered different research contexts, including the functional characteristics of *Lactobacillus* strains[20], nitrite activity in bacteria-related environments[21], and food fermentation[17]. This indicates that China's contribution to the identified research topic is not limited to a single research subfield.

Brazil ranked second, with two publications. These publications addressed different research contexts: applying lactic acid bacteria in food products[18] and using *L. acidophilus* in an experimental model[22]. Meanwhile, Indonesia, India, Poland, Kazakhstan, and the United States each contributed one publication to the dataset. Kazakhstan publication focused on lactic acid bacteria starter cultures for nitrite reduction in fermented meat products[23]. However, the number of publications per country

cannot be directly used to conclude that a particular country has greater scientific excellence or higher overall research productivity. Such interpretations should account for the fact that this analysis is based on only 10 documents retrieved through a specific Scopus search strategy. Therefore, the geographical distribution is more appropriately interpreted as a pattern of national contributions within this study's dataset rather than as a representation of each country's overall research productivity in this field.

TABLE 4: Number of Documents by Institution/Affiliation.

No	Institution/Affiliation	Number of Documents
1	Universidade Estadual Paulista Júlio de Mesquita Filho	2
2	Beijing Hospital	1
3	Tianjin Pharmaceutical Research Institute Company Limited	1
4	Academy of Animal Science and Veterinary Medicine in Jilin Province	1
5	Bhakti Wiyata Institute of Health Sciences	1
6	University Center of Grande Dourados	1
7	Chiang Mai University	1
8	National Institutes of Health (NIH)	1
9	National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK)	1
10	University of Life Sciences in Lublin	1
11	Capital Medical University	1
12	Universitas Airlangga	1
13	Academy of Military Sciences	1
14	Institut Teknologi Sepuluh Nopember	1
15	Universidade Federal da Grande Dourados	1
16	Jilin Agricultural University	1
17	Tianjin University of Science & Technology	1
18	Saken Seifullin Kazakh Agrotechnical University	1
19	Sri Padmavati Mahila Visvavidyalayam	1
20	Korkyt Ata Kyzylorda State University	1
21	K. Kulazhanov Kazakh University of Technology and Business	1

Based on the affiliation analysis in the Scopus database, 21 institutions/affiliations were identified across the 10 research documents. Universidade Estadual Paulista Júlio de Mesquita Filho had the most documents (2), while the remaining 20 affiliations each had one document.

The distribution indicates that institutional contributions to research on nitrite, pH, and *Lactobacillus acidophilus* are relatively dispersed. No institution demonstrates substantial publication dominance, as the most productive institution contributed only two of the ten identified documents. Most institutions were associated with only one document, suggesting the dataset represents research from various institutional groups, each with a relatively limited contribution.

The diversity of affiliations also indicates that the identified research originated from a range of academic and institutional settings, including universities, hospitals, research institutes, and

government or national research institutions. This finding aligns with the multidisciplinary nature of the identified publications, which span microbiology, food science, health, and experimental research.

However, the number of documents associated with each affiliation cannot be used as a direct indicator of an institution's research quality, excellence, or capacity. These findings only describe the distribution of institutional contributions across the ten documents retrieved using this study's search strategy. Furthermore, a single publication may list multiple affiliations; therefore, the total affiliation frequency should not be interpreted as the total number of documents.

TABLE 5: Author Productivity, Citations, and Collaboration Strength.

No	Author	Documents	Citations	Total Links Strength
1	Du, Shouwen	1	167	13
2	Jin, Ningyi	1	167	13
3	Li, Chang	1	167	13
4	Li, Xiao	1	167	13
5	Li, Yi	1	167	13
6	Liu, Cunxia	1	167	13
7	Liu, Hongfeng	1	167	13
8	Qin, Yanqing	1	167	13
9	Ren, Dayong	1	167	13
10	Sun, Yang	1	167	13
11	Tian, Mingyao	1	167	13
12	Wang, Maopeng	1	167	13
13	Ye, Fei	1	167	13
14	Yin, Ronglan	1	167	13

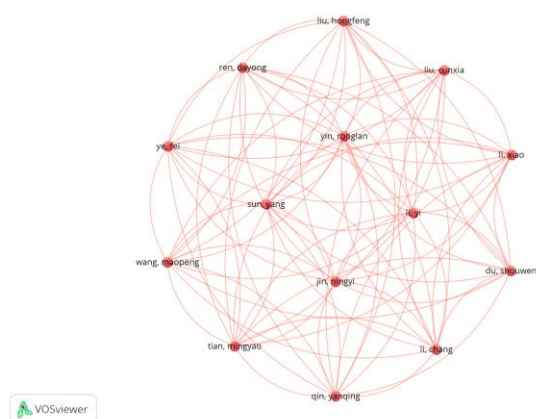


FIGURE 4: Author Collaboration Network.

Based on Figure 4, VOSviewer displays the largest connected set, consisting of 14 authors grouped into a single cluster. The authors of the other nine documents are not connected to this component. The network contains 91 links, indicating a highly interconnected co-authorship network. Node size represents the number of documents, while the lines between nodes indicate co-authorship relationships. All authors within this component have one document each and the same total link strength (TLS) value of 13.

With 14 authors, the maximum possible number of pairwise connections is calculated as $[14 \times (14 - 1)] / 2 = 91$. Since the number of links equals this maximum, the network is fully connected. All authors in this component contributed to the same document, namely Ren et al. (2014). Therefore, the network structure reflects co-authorship within a single article rather than collaboration between research groups. The authors of the remaining nine documents do not form a connected network with this group.

This also explains why all authors have a total link strength (TLS) of 13. Each author is connected to the other 13 authors, resulting in identical TLS values. This finding indicates that no single author serves as an exclusive central hub for collaboration. Instead, all authors in this group have equal connectivity.

However, these findings should be interpreted with caution. A document count of one for each author does not mean each author has published only one article in their academic career. Rather, this value indicates that each author has one document included in the 10-publication dataset analysed in this study. Therefore, these results cannot be used to conclude the authors' overall academic productivity.

Furthermore, high network connectivity does not necessarily indicate collaboration between research groups or extensive international collaboration. Based on the observed network pattern, the dense connections most likely reflect a single group of authors who jointly contributed to one publication within the dataset. This matters because the dataset analysed in this study is relatively small, comprising only 10 documents. With so few publications, the co-authorship network structure may be dominated by the author group associated with one or a few specific articles.

Therefore, this study's co-authorship findings are better interpreted as identifying a group of authors who co-authored a publication, rather than providing a comprehensive overview of the development of global collaboration in the field of nitrite, pH, and *Lactobacillus acidophilus*. The authors of the other documents in the dataset do not form connected networks, indicating that cross-group collaboration is not yet evident in the identified literature.

Documents per year by source

Compare the document counts for up to 10 sources.

[Compare sources and view CiteScore, SJR, and SNIP data](#)

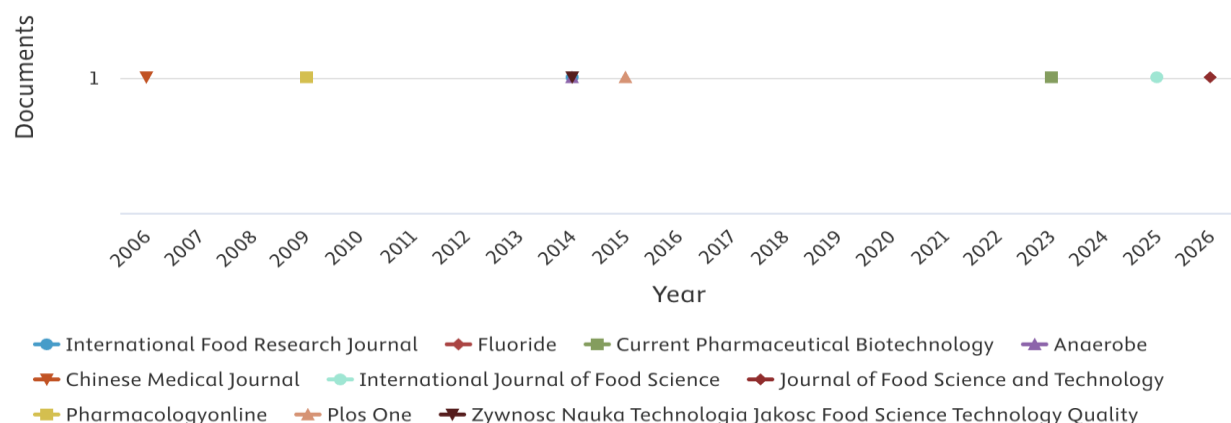


FIGURE 5: Documents by Year by Source (Source: Scopus Database)

Based on the bibliometric analysis of the 10 publications retrieved from Scopus, research on nitrite, pH, and *Lactobacillus acidophilus* was distributed across 10 different source titles. Each source title contributed only one document, indicating that no journal dominated publication productivity in the analysed dataset. The source titles included Anaerobe, Chinese Medical Journal, Current Pharmaceutical Biotechnology, Fluoride, International Food Research Journal, International Journal of Food Science, Journal of Food Science and Technology, Pharmacologyonline, PLOS ONE, and Żywność. Nauka. Technologia. Jakość / Food Science Technology Quality.

The distribution of publications across 10 source titles indicates that research on the relationship between nitrite, pH, and *Lactobacillus acidophilus* is not concentrated in a single journal. Each journal contributed only one publication to the dataset; therefore, no core journal demonstrating a dominant publication output on this topic could be identified. This pattern may reflect the multidisciplinary nature of the research topic, which lies at the intersection of microbiology, health sciences, medicine, pharmacy, and food science.

The diversity of source titles also indicates that research on nitrite and *Lactobacillus acidophilus* has emerged across various scientific contexts.

Therefore, the distribution of journal sources in this study is better interpreted as reflecting the spread of publications across disciplines rather than indicating a specific publication hub. However, this interpretation should be approached with caution because the analysed dataset consists of only 10 documents, meaning that the observed distribution of publication sources may not represent the entirety of the scientific literature on this topic.

RQ3: What research themes and trends can be identified through keyword co-occurrence analysis, and what research gaps may guide future research directions?

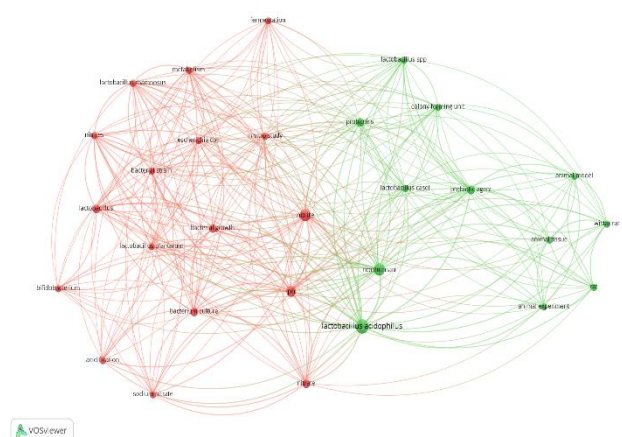


FIGURE 6: Keyword Co-occurrence Network.

TABLE 6: Keyword Co-occurrence Analysis.

Cluster	Keyword	Thematic Interpretation
Cluster 1	fermentation	Fermentation and Metabolic Product Formation
	<i>Lactobacillus rhamnosus</i>	<i>Lactobacillus</i> Species Used in Research
	metabolism	Bacterial Metabolic Activity
	nitrites	Nitrite and Its Interactions with Bacterial Systems
	<i>Escherichia coli</i>	Comparative/Supporting Microorganisms in Research
	in vitro study	In Vitro Experimental Approaches
	bacterium	General Studies on Bacteria
	<i>Lactobacillus</i>	Bacterial Genera of Research Interest
	bacterial growth	Bacterial Growth and Responses
	<i>Lactobacillus plantarum</i>	Other <i>Lactobacillus</i> Species
	<i>Bifidobacterium</i>	Other Bacteria Relevant to Microbiological Research
	bacterium culture	Bacterial Culture
	acidification	Acidification Processes and Changes in pH Conditions
	sodium nitrate	Nitrate Compounds as Sources or Precursors of Nitrite
	nitrite	Nitrite as the Primary Research Focus
Cluster 2	pH	pH as an Environmental and Metabolic Parameter
	nitrate	Nitrate and Its Relationship with Nitrite
	<i>Lactobacillus acidophilus</i>	Key Species Relevant to the Research Focus
	<i>Lactobacillus</i> spp.	Studies on Various <i>Lactobacillus</i> Species
	<i>Lactobacillus casei</i>	<i>Lactobacillus</i> Species in Probiotic Research
	probiotics	Applications of <i>Lactobacillus</i> in Probiotic Contexts
	probiotic agent	The Role of <i>Lactobacillus</i> as a Probiotic Agent
	colony forming unit	Bacterial Viability Quantification and Assessment
	animal experiment	Animal-Based Experimental Research
	animal model	Use of Animal Models
	animal tissue	Observations in Animal Tissues
	Wistar rat	Animal Models Used in Research
	rat	Rodent Models
	nonhuman	Non-Human Research Subjects

Using keyword co-occurrence analysis in VOSviewer with a minimum occurrence threshold of two, we identified 29 keywords. We grouped them into two clusters, with 314 links and a total link strength of 502. The mapping revealed relationships among keywords representing microbiological aspects, bacterial metabolism, nitrate/nitrite, and acidity, as well as keywords associated with probiotics and animal-model experimental research.

Cluster 1 was dominated by keywords related to *Lactobacillus* microbiological activity and characteristics, particularly metabolism, fermentation, bacterial growth, acidification, bacterial culture, and in vitro studies. This cluster also demonstrated clear associations with nitrite, nitrites, nitrate, sodium nitrate, and pH. Therefore, the first cluster represents a research theme focused on bacterial metabolic responses and activity in relation to nitrate/nitrite compounds and acidic conditions.

Meanwhile, Cluster 2 primarily comprised keywords such as *Lactobacillus acidophilus*, *Lactobacillus* spp., *Lactobacillus casei*, probiotics, probiotic agent, and colony-forming unit. This cluster was also associated with animal experiment, animal model, animal tissue, Wistar rat, rat, and nonhuman. This pattern indicates a research group more focused on applying *Lactobacillus* as a probiotic and evaluating its biological effects through experimental approaches, including animal models.

Overall, the co-occurrence map shows that nitrite and pH sit within a network associated with themes of *Lactobacillus* metabolism and growth. At the same time, *Lactobacillus acidophilus* occupies a central position in the network. This indicates that the three main research components, nitrite, pH, and *L. acidophilus*, connect to several broader research themes.

TABLE 7: Total Link Strength by Keyword.

No	Keyword	Occurrences	Total Link Strength
1	<i>Lactobacillus acidophilus</i>	8	91
2	Nonhuman	6	88
3	Nitrite	6	78
4	pH	5	77
5	Bacterium culture	3	57
6	Bacterial growth	3	53
7	<i>Lactobacillus</i>	3	50
8	Probiotic agent	3	50
9	Bacterium	2	47
10	<i>Escherichia coli</i>	2	47
11	<i>Lactobacillus plantarum</i>	2	47
12	<i>Lactobacillus rhamnosus</i>	2	47
13	Metabolism	2	47
14	Nitrites	2	47
15	Nitrate	3	43
16	Probiotics	3	42
17	Colony-forming unit	2	39
18	<i>Lactobacillus</i> spp.	2	39
19	<i>Lactobacillus casei</i>	2	36
20	In vitro study	2	35
21	Acidification	2	32
22	Sodium nitrate	2	32
23	Fermentation	2	26
24	Animal experiment	2	25
25	Animal model	2	25
26	Animal tissue	2	25
27	<i>Bifidobacterium</i>	2	25
28	Rat	2	25
29	Wistar rat	2	25

Based on Table 6, *Lactobacillus acidophilus* was the most frequently occurring keyword, appearing in eight documents, with the highest Total Link Strength (TLS) of 91. Subsequently, nonhuman and nitrite each appeared six times, with TLS values of 88 and 78, respectively. The keyword pH appeared five times, with a TLS value of 77. Other keywords occurred two to three times, with TLS values ranging from 25 to 57. These counts were derived from the author and index keyword fields rather than from abstract text.

The mapping results indicate that the identified literature does not form a single homogeneous research theme but is instead divided into two interconnected thematic clusters. Cluster 1 is dominated by themes related to bacterial metabolic activity and growth. The co-occurrence of the keyword metabolism, fermentation, acidification, bacterial growth, and pH indicates that research on *Lactobacillus* is frequently associated with changes in acidic environmental conditions as a consequence of its metabolic activity. This aligns with *Lactobacillus*'s ability to ferment and produce acidic metabolites, suggesting that metabolic activity may be linked to changes in environmental pH.

The presence of nitrite, nitrate, nitrites, and sodium nitrate within the same cluster indicates that these nitrogen compounds have been investigated in relation to microbiological activity. Nitrite's proximity to pH and to terms associated with bacterial growth and metabolism suggests that the relationship between nitrite compounds, bacterial activity, and acidity is an emerging theme in the analysed literature. However, these bibliometric findings show only thematic associations based on keyword co-occurrence and cannot directly establish a causal relationship between nitrite and changes in pH.

Cluster 1 also includes several species, such as *Lactobacillus plantarum* and *Lactobacillus rhamnosus*, in addition to *Lactobacillus* at the genus level. This finding indicates that research on nitrate/nitrite and *Lactobacillus* metabolic characteristics is not limited to a single species. Therefore, the presence of *Lactobacillus acidophilus* in the research network should be understood in the broader context of the *Lactobacillus* literature. This is important because some of the knowledge related to metabolism, growth, and environmental responses may be derived from studies involving *Lactobacillus* species other than *L. acidophilus*.

In contrast to Cluster 1, Cluster 2 demonstrates a stronger focus on probiotics and experimental research. The occurrence of probiotics, probiotic agent, *Lactobacillus casei*, and *Lactobacillus* spp. indicates that *Lactobacillus* has also been extensively studied for its biological functions and its application as a probiotic microorganism. The association with colony-forming unit reflects research interest in bacterial growth or viability as a study parameter.

Furthermore, the occurrence of animal experiments, animal model, animal tissue, Wistar rat, and rat indicates literature that uses in vivo approaches to evaluate the biological effects of *Lactobacillus* or related interventions. This finding extends the research context beyond direct microbiological observations to biological evaluations in living organisms. However, because the analysed dataset includes only 10 documents, this cluster is better regarded as one of the research directions identified in the dataset rather than a dominant representation of the entire body of research on *L. acidophilus*.

An interesting finding from this mapping is the connection between the two clusters through the main research keywords. *Lactobacillus acidophilus* is positioned within the group associated with probiotics and experimental research, while also being linked to nitrite, pH, and metabolic terms across the overall network. This pattern indicates that the literature on *L. acidophilus* encompasses several aspects, including microbiological characteristics, metabolism, acidity conditions, and biological functions.

Thus, the RQ3 findings indicate that research themes related to nitrite, pH, and *Lactobacillus acidophilus* have developed along two main directions: (1) microbiological and metabolic aspects, encompassing bacterial growth, fermentation, acidification, nitrate/nitrite, and pH; and (2) biological and applied aspects, encompassing probiotics and experimental research using animal models. The mapping also shows that although nitrite, pH, and *L. acidophilus* appear in the same network, evidence for the specific relationship among these three components requires further examination by synthesising the individual studies' findings, as co-occurrence analysis does not establish causal relationships.

CONCLUSION

Based on the bibliometric analysis of 10 publications retrieved from the Scopus database, research on nitrite, pH, and *Lactobacillus acidophilus* remains relatively limited and dispersed across various publication sources. Keyword analysis identified 29 keywords grouped into two clusters, comprising 314 links and a total link strength of 502, with *Lactobacillus acidophilus*, nitrite, and pH as the most prominent keywords. Thematic mapping revealed research focuses on *Lactobacillus* metabolism and growth, fermentation, acidification, nitrate/nitrite, and pH, alongside themes related to probiotics and experimental research. Although the three main components appear in the research network, the

dataset does not show a dominant theme linking nitrite, the metabolic activity of *Lactobacillus acidophilus*, and changes in pH. Therefore, further research, particularly through experimental approaches, is needed to clarify these relationships.

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