Literature Review
Food Science and Technology
ISSN 0101-2061 (Print)
ISSN 1678-457X (Online)
DOI: https://doi.org/10.5327/fst.00261

Trends in kombucha research: a bibliometric and technological prospection analysis

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Abstract

Kombucha is a fermented beverage that is gaining more and more attention due to its biological activities and health benefits. This study presents a bibliometric analysis and technological prospection of the kombucha beverage from 1996 to 2022, with indexed data performed in the Web of Science and the Lens databases for the bibliometric analysis, and VOSviewer was used to analyze the data and provide the bibliometric networks. To date, the United States, China, India, Brazil, and Serbia have contributed to most of the results on kombucha. Jayabalan and Malbasa, affiliated with the University of Bharathiar (India) and University of Novi Sad (Serbia), provide the most productive research. Research on kombucha is focused on the biological activities, health benefits, fermentative process, composition, and microbiology. The United States and China have the most number of patents, with the main depositors being private companies such as reGenics, Shi Weiyao, and EPC Natural Products Co Ltd. This analysis makes it possible to understand the trends and gaps in kombucha research, providing researchers with future perspectives aimed at deepening the knowledge about kombucha.

Keywords: VOSviewer; kombucha; bibliometric analysis; technological prospection.

Practical applications: The bibliometric/patentary studies provided valuable insights related to the kombucha research.

1 INTRODUCTION

Kombucha is a beverage produced by the fermentation of green or black tea (*Camellia sinensis*) sweetened with sucrose by a microbial consortium of bacteria and yeasts (symbiotic culture of bacteria and yeast). This consortium consists of acetic acid bacteria, lactic acid bacteria, and yeasts. After fermentation, the beverage presents with acidic characteristics (Amarasinghe et al., 2018). The consumption and production of kombucha were first reported in northeastern China (Manchuria), during the Tsi Dynasty ("Ling Chi") around 220 B.C., where it was valued for its detoxifying and energizing properties. With the development of trade routes, kombucha was first dispatched to Russia and then to Eastern Europe around the turn of the 20th century (Jayabalan et al., 2014).

The bacteria and yeast of the kombucha culture being the fermentation process, the yeasts being responsible for producing the invertase that hydrolyzes the sucrose molecule in glucose and fructose. This is the first opportunity for the interaction of resources between microorganisms as a source of carbon. Glucose and fructose are converted into ethanol and carbon dioxide through several fermentation steps that are characterized by cooperation and competition between microorganisms in the kombucha beverage (May et al., 2019). The bacteria present in the kombucha culture mostly belong to the bacterial genera *Acetobacter* and *Gluconobacte*r and produce acetic acid as one of the main metabolites when sucrose is used as a carbon source, resulting in a decrease in pH. The bacteria strains use glucose as energy to produce cellulose nanofibers, thereby forming a new cellulosic biofilm (Ayed et al., 2017; Bhattacharya et al., 2016).

The consumption of kombucha is associated with several health benefits. After fermentation, the final product comprises a complex chemical composition and contains several compounds, such as organic acids, vitamins, enzymes, and polyphenols (Ahmed et al., 2020; Ivanišová et al., 2020). In recent years, consumers have shown interest in consuming quality food and beverages and have understood the role of the diet in maintaining a good health, resulting in the increasing demand for beverages such as kombucha. Some authors report that the intake of kombucha provides several benefits to the body, such as detoxifying the blood, reducing cholesterol levels, normalizing intestinal activity, balancing the intestinal flora, and improving the immune system (Zou et al., 2021).

The global kombucha market is rapidly increasing with a compound annual growth rate of 23% in the period 2014–2018 and is expected to maintain its rapid growth in the next 5 years (Emiljanowicz & Malinowska-Pańczyk, 2019). The dynamic development of this beverage sector can therefore contribute to the creation of products different from the concept of functionality. Consequently, it is important to determine the key factors that affect the biological activities of this product and how altering the individual components can affect the fermentation process itself and the quality, and, consequently, the health benefits of the final commercial product (Antolak et al., 2021).

Received 18 Jan., 2024.
Accepted 3 Mar., 2024.
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The commercial importance of kombucha is increasingly highlighted as the concern regarding the consumption of healthier foods that provide direct health benefits increases. Although kombucha is being studied extensively, there are still many promising areas of untapped potential. The technological prospection and bibliometric analysis are tools that make it possible to identify, map, and correlate the main product areas on a national and international scale, assessing the evolution of the innovation scenario and development of products that do not exist on the market. They are used, for example, to identify the groups of publications, authors, or journals that assess the growth, enabling the verification of the trends and gaps associated with the subject studied, playing a significant role in the management and decision-making in science and technology (George et al., 2021; van Eck & Waltman, 2017).

This determination process is carried out through some statistical criteria that allow the evolution of the number of publications per year, most cited authors, most used keywords, cooperation networks of authors, journals, and countries (Gonçalves et al., 2019). To assist in data processing, VOSviewer is a great tool used for the construction and visualization of bibliometric networks, allowing the creation of networks of citation relationships, bibliographic coupling, co-citation, co-authoring, and offering text mining functionality that can be used to build and visualize co-occurrence networks of terms drawn from a huge body of scientific literature (journals and researchers) (Prajapati et al., 2018).

On this basis, this study aims to perform a bibliometric analysis and technological prospection in databases, composed of articles and patents, in order to examine the trends in kombucha research. Considering the evolution over time, we focus on the geographical participation, journals, authors, and keywords using the VOSviewer for the evaluation of journal articles. In addition, we verify how these research developments have been influencing future changes and new paths for the subject studied.

2 MATERIAL AND METHODS

2.1 Determining, downloading, and refining search results in the database

The database Web of Science was used for providing comprehensive citation data for many different academic areas and large number of important publications, and serving as one of the most comprehensive repositories since its launch in 1996 to the present. The keywords "KOMBUCHA" or "KOMBUCHA TEA" were used for the search topic field, which searches for words in titles, abstracts, and authors' keywords. Thus, the results considered valid include scientific articles from peer-reviewed journals and do not include book reviews, meetings, editorials, and books. As this research was limited to investigating the main standards of publications and the main groups of ascending studies of the proposed theme, publications appearing in trade magazines and conferences were also excluded.

All data were downloaded from the Web of Science and imported into VOSviewer v.1.6.11 (Leiden University, Leiden, The Netherlands), which is commonly used to analyze and visualize the relationships among authors, countries, co-citations, and the terms used in articles. Bibliometric analysis was performed using VOSviewer (www.vosviewer.com), which is free and can be used to view bibliometric networks.

2.2 Analysis of bibliometric indicators

To perform the analysis, the authors organized their search according to the following steps: first, defining the period for carrying out the search (from January to December 2022); second, the source of the term (title, abstract, authors' keywords, and keywords), type of node (author, institution, country, keyword, category, reference citation, cited author, and cited journal), and the static cluster view; and third, mapping the networks, displaying the productive authors, institutions, and countries, frequently occurring keywords, and documented instances of co-citation, author, and journal co-citation analyses. Frequency, co-authorship, co-occurrence, and co-citation indicators were defined based on Danvila-del-Valle et al. (2019) and were calculated and analyzed using VOSviewer.

2.3 Technological prospection

The technological prospecting method was applied based on the data retrieved from patent documents from the last 20 years using the following search tools: Lens, USPTO, Patentescope, INPI, Latipat, and Espacenet. Data obtained in Lens were compiled and exported to Microsoft Excel. The search was performed between January and December 2022 using the keywords relevant to the subject under investigation. The words "KOMBUCHA" and "KOMBUCHA TEA" were crossed individually using the "AND" operator. On these platforms, combinations were searched both in the "TITLE" and "ABSTRACT" fields to increase the reach of this search. The temporal and geographical distribution of patent profits with active status was evaluated.

3 RESULTS AND DISCUSSION

3.1 Bibliometric analysis

The results obtained in the analysis carried out using VOSviewer were interpreted in terms of the titles of the most relevant journals, countries, and the most used keywords, contributing significantly to research on kombucha and reinforcing the importance of research on the subject.

3.1.1 Co-authorship analysis for the most influential authors and countries

Country co-authorship was analyzed for information on international collaboration in kombucha studies. The distribution of articles published by institutions and countries are indicators of the research productivity. It is still possible to verify the growth of the articles according to time, where four periods of time – 2014, 2016, 2018, and 2020 – are highlighted (Figure 1). These are related to the colors of each cluster, so it is observed that the cluster countries with the yellow color, with Brazil having the highest number of citations of articles, have shown an exponential growth from 2020 to 2022. The growth

in the number of published articles suggests that the theme is entering a development stage. As a result, different directions of research can be undertaken exploring new related topics, examining in greater depth hitherto less studied areas, or even aiming to address traditional questions through new frameworks. Exploring new international collaborations can also be helpful in broadening the scope of investigation (Donthu et al., 2020).

The map of collaborative networks about co-authorship, with the author's unit of analysis referring to the collaboration of two or more authors in a document and is used to understand the patterns of collaboration within the academic community (Donthu et al., 2021). Figure 2 shows how co-authorship networks with a minimum number of documents and citations of an author equal to five. The connected authors consist of 9 out of 50 authors grouped into four clusters, wherein in each cluster the relationships and partnerships between the authors can be observed. Malbasa is affiliated with the University of Novi Sad (Serbia) and Jayabalan is affiliated with the National Institute of Technology Rourkela (India), with each having 11 and 9 documents, respectively.

The works found in the literature referring to Malbasa have scope related to the research with the kombucha fermentation process, evaluation of the acid content, antioxidant activity, remaining sucrose content, and biomass yield (Malbaša et al., 2008; Malbaša et al., 2011), in addition to the research related to the fermentation of milk (Vitas et al., 2013) using as inoculum the microorganisms present in kombucha. Jayabalan's studies focus on the changes in organic acid and polyphenol content during fermentation by varying the type of tea used (Jayabalan et al., 2007) as well as evaluating the influence of heat on the biochemical constituents and free radical scavenging properties of kombucha tea (Jayabalan et al., 2014). The relationships between the authors promote the contribution and distribution of knowledge in each area, resulting in deeper knowledge, and also verify the deficits presented in the research field, thus being able to intensify research on the topic addressed and favor the growth and scientific development (Donthu et al., 2021).

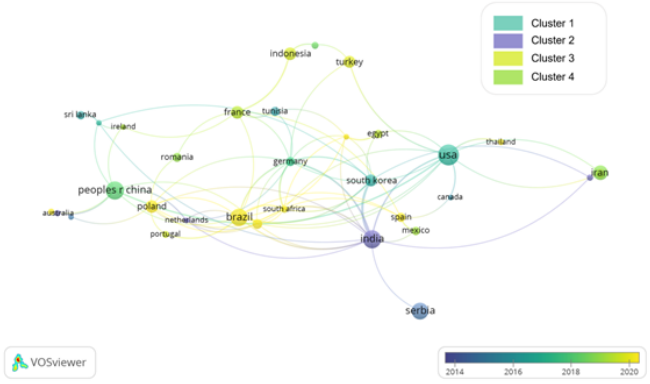

Figure 1. VOSviewer co-authoring network visualization map referring to the collaboration of two or more authors on a document based on the countries the authors are affiliated with. The size of the circle indicates the weight of the item, the lines indicate the links between the items, the distance between the items shows their relationship, and different colors indicate groupings.

3.1.2 Top most co-citation network

Co-citation analysis was used to map the most cited scientific articles on kombucha. By checking the main authors, this analysis is based on the fact that researchers attribute to a publication when referring to him as a source. Consequently, it can be concluded that the more an article is cited, the more influential it will be for the research community in the development of that area (Cruz-O'Byrne et al., 2020). In a co-citation network, five publications are connected when they match the reference list of another publication (Hu et al., 2019). The co-citation analysis represented in Figure 3 shows the connections of 70 authors divided into four clusters, where the author Jayabalan, represented in the blue cluster, stands out with 599 citations, followed by Villa-Real (193 citations), Sreeramulu in the green cluster (119 citations), and Greenwalt (144 citations) in the green cluster and marsh yellow cluster (83 citations).

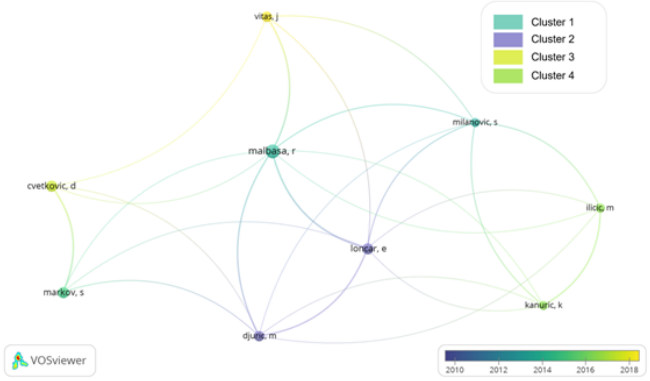

Figure 2. Visualization map of the VOSviewer co-authorship network referring to the authors who stand out in the production of scientific documents. The size of the circle indicates the weight of the item, the lines indicate the links between the items, the distance between the items shows their relationship, and different colors indicate groupings.

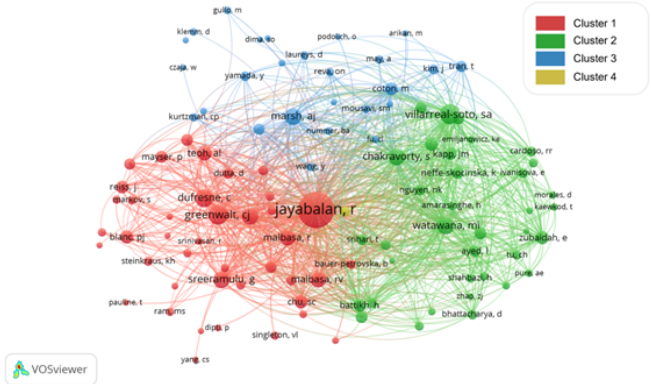

Figure 3. Visualization map of the VOSviewer network of co-citation based on the number of times authors are cited. The size of the circle indicates the weight of the item, the lines indicate the links between the items, the distance between the items shows their relationship, and different colors indicate groupings.

Figure 4 shows the most prominent journals for publications on kombucha, divided into four clusters according to the scope of each journal and the content of each scientific article. *Food Chemistry* stands out; with the highest number of citations, this journal publishes articles dealing with the advancement of food chemistry and biochemistry or the analytical methods/approach used. The topics presented in *Food Chemistry* include chemistry relating to the major and minor components of foods and their nutritional, physiological, sensory, flavor, and microbiological aspects. This attracts the interest of researchers due to its high number of citations, with a high impact factor value of 9.231 in the year of the present study.

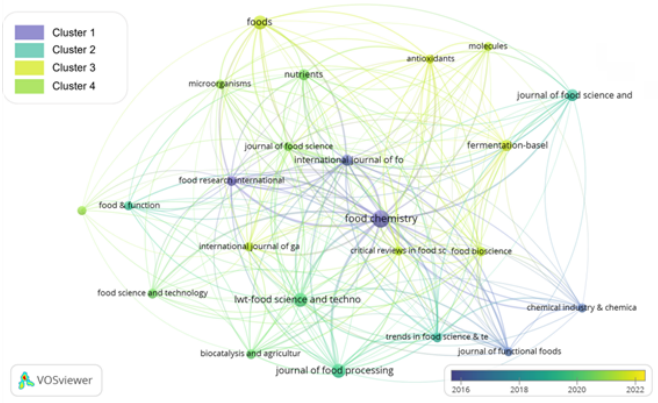

Figure 4. Visualization map of the VOSviewer network based on the most cited journals. The size of the circle indicates the weight of the item, the lines indicate the links between the items, the distance between the items shows their relationship, and different colors indicate groupings.

Another journal that stands out in citations with kombucha research is *LWT – Food Science and Technology,* an international journal that publishes innovative articles in such areas as food chemistry, biochemistry, microbiology, technology, and nutrition, with an impact factor value of 6.056. This journal has been of great relevance, and given the high number of citations, researchers tend to seek these journals so that their knowledge reflected by means of articles reaches the highest number of citations and is thus disseminated with greater intensity in the community scientific.

Other practical implications can be observed for the evaluation of the scientific article when submitted to a journal. The implication is that the material submitted by journals with lower concepts comes from the low-average impact journals than the material submitted by journals with higher concepts. Thus, when the level of analysis is relative to the journal, these items seem to have a similar impact concerning the medium in which they are published (Ampese et al., 2021).

As shown in Table 1, the 10 most cited articles between 2002 and 2022 show that Jayabalan had 30% of the most cited articles in recent years, thereby confirming the contribution of this author in articles on kombucha published in the last 20 years. The 10 most cited articles (Table 1) generally have as scientific content the composition, microbiology, fermentation, biological activities, and the health benefits of kombucha consumption, thereby verifying that these topics have been the main discussion raised in the academic community on the topic addressed.

Table 1. Top 10 articles most cited between 1996 and 2022 about kombucha, authors, and journals provided by the Web of Science database.

Ranking	Authors	Journal	Title	Average citation per year	References
1	Dufresne, Farnworth	*Food Research International*	Tea, kombucha, and health: a review	8.41	Dufresne; Farnworth, 2000
2	Jayabalan	*Food Chemistry*	Changes in content of organic acids and tea polyphenols during kombucha tea fermentation	10.61	Jayabalan et al., 2007
3	Jayabalan	*Comprehensive reviews in food science and food safety*	A review on kombucha tea-microbiology, composition, fermentation, beneficial effects, toxicity, and tea fungus	19.50	Jayabalan et al., 2014
4	Teoh	*International Journal of food microbiology*	Yeast ecology of kombucha fermentation	8.11	Teoh et al., 2004
5	Raspor	*Critical Reviews in Biotechnology*	Biotechnological applications of acetic acid bacteria	9.57	Raspor; Goranovič, 2008
6	Marsh	*Food Microbiology*	Sequence-based analysis of the bacterial and fungal compositions of multiple kombucha (tea fungus) samples	15.38	Marsh et al., 2014
7	Chen	*Journal of Applied Microbiology*	Changes in major components of tea fungus metabolites during prolonged fermentation	5.18	Chen; Liu, 2000
8	Sreeramulu	*Journal of Agricultural and Food Chemistry*	Kombucha fermentation and its antimicrobial activity	5.00	Sreeramulu et al., 2000
9	Jayabalan	*Food Chemistry*	Changes in free-radical scavenging ability of kombucha tea during fermentation	7.64	Jayabalan et al., 2008
10	Greenwalt	*Journal of Food Protection*	Kombucha, the fermented tea: microbiology, composition, and claimed health effects	4.86	Greenwalt et al., 2000

3.1.4 The most used keywords and keyword co-occurrence network

The VOS method was applied to group keywords into groups, thereby forming clusters that are identified by different colors. Each highlighted word is represented by a circle, with the diameter and size of the label denoting the number of occurrences in titles and/or abstracts (van Eck & Waltman, 2017). The colors in each group represent the binding terms; the size of a label represents the number of publications on kombucha and the terms that are most related to the topic studied, and the distance between the two terms represents the degree to which they are associated.

The keywords provided by the authors of the paper that occurred more than five times in the WOS core database were enrolled in the final analysis. It was found that all these frequently used keywords are interrelated and compatible. The keywords of the 467 publications evaluated in this study were analyzed using VOSviewer (Figure 5). A total of 110 keywords divided into five clusters were identified as having occurred in the title and/or abstract fields in all articles. The keywords that stood out the most were kombucha (213 times), tea (139 times), fermentation (135 times), health (67 times), polyphenols (61 times), and tea fungus (40 times).

The analysis of the keywords revealed eight study groups cluster 1 (kombucha, fermentation, and bacterial cellulose), where the related words are characterized by having content related to the biological activities present in kombucha and related to the products generated during the fermentation process; cluster 2 (tea) types of tea (black and/or green), substances present in tea and their properties; cluster 3 (polyphenols) are words related to the biological activities associated with the consumption of kombucha, such as antioxidant activity, organic acids, probiotics, among others; cluster 4 (health) are words related to the components present in kombucha, caffeine, catechins, cytotoxins, and other components researched on the kombucha beverage; and cluster 5 highlights the most frequently occurring words when searching for tea fungus in the kombucha brewing process. The keywords present in an article reflect the main focus of the work and aid in the search for other researchers, in addition to providing information on the main content of an article, and can also be used to identify research trends in a specific domain (Lee et al., 2020).

As observed by Antolak et al. (2021), the words that occur most frequently in research on the kombucha theme were kombucha, tea, and fermentation, thereby confirming that the current research on kombucha has been limited to the fermentation processes and the growing demand for information on kombucha beverage. However, it is important to determine the main factors that affect the biological activities of this product and how altering the individual components can affect the fermentation process itself and, consequently, the health benefits of the final commercial products.

3.1.5 Technological prospection

Intellectual property, specifically patents, has proved to be a powerful tool for disseminating biotechnological inventions. Patentable biotechnological inventions involve products such as nucleotide and amino acid sequences, microorganisms, processes, or methods to modify such products, and uses for the manufacture of medicines, inventive activity, and industrial application (Giugni & Giugni, 2010).

With this analysis carried out in some patent databases, it was possible to observe the number of patent documents deposited between 2000 and 2022, in addition to the restrictions on documents with the keyword present in the title, abstract, or both. In this research, the Lens platform had the highest number of patents filed in relation to the other bases evaluated, with a total of 245 published patents available, being chosen for the later steps of the study. However, it is worth mentioning that these data underwent a selection, with reading of the abstracts, to collect only information from the patents related to the food area.

The data presented in Figure 6 show the development of patent applications on the topic of kombucha from 1998 to 2022, thereby demonstrating the growing diffusion of this technology. This trend is associated with the population's increased interest in healthy products that provide health benefits, in addition to essential nutrition, and have dramatically advanced to prevent

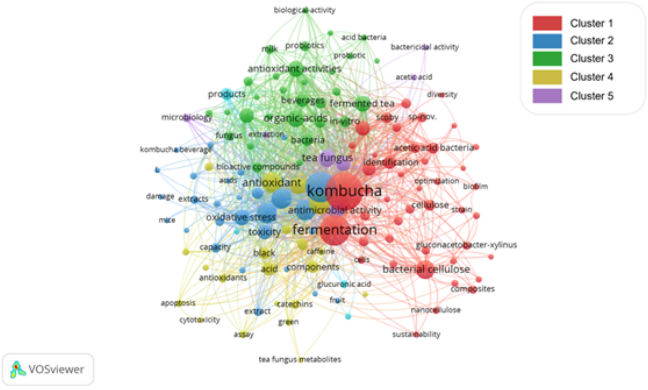

Figure 5. VOSviewer network view co-occurrence map of keywords that are the most frequent in Kombucha research. The size of the circle indicates the weight of the item, the lines indicate the links between the items, the distance between the items shows their relationship, and different colors indicate groupings.

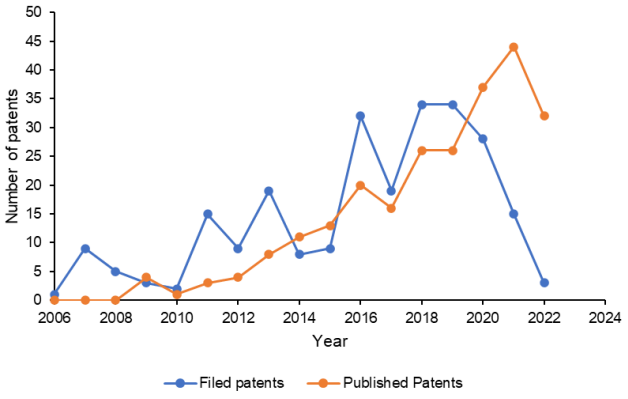

Figure 6. Temporal evolution (2006–2022) of the production of patent documents involving kombucha.

disease and promote people's well-being and quality of life (Jayabalan et al., 2014). The number of patent (Figure 6) applications according to the Lens platform on the topic "kombucha" between 1998 and 2022 makes it possible to observe the growing relevance of the subject in the scientific field. The number of requests began to show growth from 2003 onward when requests went from 5 to 20 documents. In 2011, this number doubled to 40 patent applications; and in 2016, a 50% increase in the number of patents can be seen compared to previous years, with the peak being in 2019. It is interesting to note that Figure 6 shows a drop in patent publications in the period from 2020 to 2022. This fact can be explained by the COVID-19 pandemic that occurred during this period, making it difficult for research to be carried out.

Regarding the number of patents by country, the United States has the highest number of patents deposited, followed by European countries and China with 168, 37, and 19 documents, respectively. This emphasis on the United States and China may be related to the fact that these countries are developed, and understanding and progress both in research and the growth of new products end up taking broader paths. The kombucha market is becoming well known worldwide, including family businesses (small companies), which have gained considerable prominence in this field. It is estimated that there are approximately 235 kombucha companies spread across Europe, North America, and Asia, potentially reaching $3.5–5 billion by 2025 (Clarke, 2018). Furthermore, it is possible to highlight the main patent depositors such as reGenics (33), a private Norwegian biotechnology company, and Shi Weiyao (12), which registered its patents more frequently in the United States and China. Its main competitors in the food and beverage, pharmaceutical, and basic materials chemistry markets are EPC Natural Products Co Ltd, which is a world leader in natural flavor innovation and flavor modulators.

4 CONCLUSIONS

The approach used allowed a quantitative statistical analysis of many articles on the topic of kombucha. The visualization network analysis adopted in this study helped to map, mine, investigate, organize, and present the referred domain in the kombucha theme. The findings revealed that

- In the investigated research theme, the volume of publications in the early years follows an exponential growth path compared to the last years of publications with the kombucha theme, demonstrating the progress and the growing interest in the study;
- To date, 16 countries have contributed research results on kombucha, most notably Serbia and India, with the most productive authors being Jayabalan (University of Bharathiar, India) and Malbasa (affiliated with the University of Novi Sad, Serbia);
- The areas of research that have shown the most prominence with kombucha are mainly biological activities, health benefits, fermentation, composition, and microbiology. This analysis made it possible to understand the trends and gaps in kombucha research, providing researchers with future perspectives aimed at deepening knowledge about kombucha;
- The analysis carried out presents encouraging data on the patenting of the kombucha beverage, reflecting the effects of the increase in research, resulting in new processes and products. The top depositors being reGenics, Shi Weiyao, and EPC Natural Products Co Ltd.;

Finally, the data captured in this study were limited to journal articles and patent documents; therefore, they may not do justice to the complete collection of literature available on kombucha. Therefore, it is necessary to consider in future studies other types of publications, thereby expanding data collection and releasing more information to readers about the latest discoveries in the field of kombucha.

ACKNOWLEDGMENTS

The first author is grateful to the FACEPE (Foundation for Science and Technology of the State of Pernambuco, Brazil) for the PhD scholarship (grant IBPG-0385- 5.07/21) and the financial support that made this research possible. All the authors are grateful to the Universidade Federal do Agreste de Pernambuco (UFAPE). This research was funded by the Coordination for the Improvement of Higher Education Personnel (CAPES, Brazil) under scholarship number 001, the National Council for Scientific and Technological Development (CNPq, Brazil) under grant number 315249/2021-8, and Foundation for Science and Technology of the State of Pernambuco (FACEPE, Brazil) under grant number APQ-0726-5.07/21.

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