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THE ROLE OF KOMBUCHA IN HEALTH: BIBLIOMETRICS ANALYSIS

Peran Kombucha dalam Kesehatan: Analisis Bibliometrik

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ABSTRAK

Kombucha adalah minuman fermentasi yang secara tradisional dibuat dari teh hijau atau hitam menggunakan kultur simbiotik bakteri dan ragi (SCOBY). Minuman ini telah dikonsumsi secara luas di Asia Timur selama berabad-abad dan kini semakin menarik minat ilmiah global karena potensi manfaat kesehatannya. Studi ini bertujuan untuk menganalisis tren publikasi ilmiah tentang fermentasi kombucha dan aspek kesehatannya melalui pendekatan bibliometrik, guna mengidentifikasi titik panas penelitian dan celah yang perlu dieksplorasi di masa depan. Studi bibliometrik kuantitatif deskriptif dilakukan menggunakan basis data Google Scholar, PubMed, dan Scopus. Kata kunci "fermentasi kombucha" digunakan untuk mengidentifikasi artikel yang diterbitkan antara tahun 2016 dan 2025, menghasilkan 30 publikasi ilmiah. Tren publikasi dan jaringan ko-munculan kata kunci divisualisasikan dan dipetakan menggunakan perangkat lunak VOSviewer. Analisis menunjukkan bahwa penelitian kombucha terutama berfokus pada kandungan probiotiknya, aktivitas antioksidan dan antimikroba, serta produksi senyawa bioaktif seperti polifenol dan asam glukuronat. Senyawa-senyawa ini berkontribusi pada efek pendukung kesehatan, termasuk detoksifikasi hati. Namun, hanya sebagian kecil (kurang dari 20%) dari publikasi yang ditinjau memberikan wawasan rinci tentang mekanisme molekuler atau studi in vivo. Meskipun fermentasi kombucha telah menunjukkan potensi biomedis yang signifikan, studi komprehensif tentang jalur biokimia spesifik, senyawa aktif, dan efek klinisnya masih terbatas, terutama di Indonesia dan negara-negara berkembang lainnya. Oleh karena itu, penelitian di masa depan perlu memperluas cakupan ke penyelidikan molekuler dan klinis untuk memaksimalkan peran kombucha sebagai terapi pendukung inovatif untuk penyakit degeneratif.

Kata kunci: *antimikroba, antioksidan, fermentasi kombucha, teh kombucha, VOSviewer*

ABSTRACT

Kombucha is a fermented beverage traditionally made from green or black tea using a symbiotic culture of bacteria and yeast (SCOBY). It has been widely consumed in East Asia for centuries and is now gaining increasing global scientific interest due to its potential health benefits. This study aimed to analyze the trend of scientific publications on kombucha fermentation and its health-related aspects through a bibliometric approach, in order to identify research hotspots and gaps for future exploration. A descriptive quantitative bibliometric study was conducted using the databases Google Scholar, PubMed, and Scopus. The keyword *"fermentasi kombucha"* was applied to retrieve articles published between 2016 and 2025, resulting in 30 scientific papers. Publication trends and keyword co-occurrence networks were visualized and mapped using VOSviewer software. The analysis showed that kombucha research mainly focuses on its probiotic content, antioxidant and antimicrobial activities, and the production of bioactive compounds such as polyphenols and glucuronic acid. These compounds contribute to health-supporting effects, including liver detoxification. However, only a small proportion (less than 20%) of the reviewed publications provide detailed insights into molecular mechanisms or *in vivo* studies. Although kombucha fermentation has demonstrated significant biomedical potential, comprehensive studies

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on specific biochemical pathways, active compounds, and clinical effects remain limited, particularly in Indonesia and other developing countries. Therefore, future research should expand into molecular and clinical investigations to maximize kombucha's role as an innovative supportive therapy for degenerative diseases.

Keywords: antimicrobial, antioxidant, kombucha fermentation, the kombucha, VOSviewer

INTRODUCTION

Kombucha is a traditional fermented tea that has been known for centuries, especially in East Asia.[1] The fermentation process involves a symbiotic culture of bacteria and yeast (SCOBY) in a sweetened tea solution.[2] In Indonesia, SCOBY has been widely cultivated at the household and MSME levels to produce local kombucha, in line with the increasing demand for healthy fermented beverages.[3] This fermentation process, which generally takes several days to weeks, produces a beverage with a distinctive sour taste and complex aroma. Over the last decade, kombucha has attracted growing global attention not only as a functional drink alternative but also because of its potential health benefits.[4,5]

One of kombucha's well-known properties is its probiotic content. Microorganisms such as Acetobacter, Lactobacillus, and various yeast species are reported to contribute to maintaining a healthy gut microbiota.[6] A balanced gut microbiome is associated with improved nutrient absorption, strengthened immunity, and reduced risks of digestive disorders such as diarrhea and constipation.[7,8] Although early studies on the effect of kombucha on gut microbiome balance show promising results, stronger clinical trials are still required to confirm these findings.

In addition to probiotics, kombucha also contains polyphenols derived from its tea base, which provide antioxidant properties that may help reduce oxidative stress.[9] During fermentation, microbial activity generates various metabolites, including glucuronic acid, which plays a role in liver detoxification. The combined presence of tea polyphenols and fermentation metabolites is thought to contribute to protective effects against degenerative diseases such as cancer, cardiovascular disease, and diabetes mellitus .[10-12]

Kombucha's antimicrobial effects have also been demonstrated against common pathogens including *E. coli, S. typhi, and S. aureus*, mainly due to the production of organic acids, ethanol, and other bioactive compounds formed during fermentation. In addition, its probiotic components may help modulate immune responses by stimulating antibody production and supporting a balanced immune system.[13-16] This potential has encouraged interest in exploring kombucha as a complementary product for infection prevention.

In some animal studies, kombucha consumption has been linked to reduced LDL cholesterol, increased HDL, and improved blood glucose control, suggesting possible metabolic health benefits for individuals with metabolic syndrome, type 2 diabetes mellitus, or cardiovascular conditions.[17] However, despite these early findings, rigorous human clinical evidence remains limited.[18,19,20]

Although numerous studies have examined kombucha's functional properties, most are limited to in vitro or animal-based research. Investigations into active compounds, mechanisms of action in humans, and the effects of raw material variations, fermentation time, and microbial strains remain scarce. Moreover, potential areas such as enzymatic pathways and neuroprotective effects are rarely explored. Thus, kombucha remains a promising field for further research—not only as a functional beverage but also as a natural fermented product with therapeutic potential. In this context, the present study does not assess kombucha's direct clinical

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benefits but instead analyzes global scientific publication trends using a bibliometric approach. Through bibliometric mapping, it aimed to identify research patterns, dominant keywords, and existing gaps in the literature. The findings are expected to provide a clear overview of kombucha research development, highlighting key knowledge clusters and underexplored areas—particularly those related to molecular mechanisms and neuroprotective potentials.

METHODS

This study, conducted from March to April 2025, analyzed 1,232 scientific publications on kombucha from 2016–2025 retrieved via the Scopus database (https://www.scopus.com). Most publications originated from China, India, Poland, Brazil, and Thailand, dominated by research in food science, microbiology, and biotechnology from public universities and applied research institutions. Figure 1 shows publication trends peaking in 2023–2024, followed by a decline in 2025. Data visualization using VOSviewer produced a network map of 26 terms (Figure 2) and a density map (Figure 3) highlighting dominant keywords such as antioxidant, yeast, green tea, sugar, and activity. However, detailed studies on biochemical mechanisms or the identification of active compounds remain limited.

Despite strong publication growth and cross-national collaboration, research exploring molecular pathways and neuroprotective effects of kombucha fermentation remains scarce, indicating promising directions for future investigations.

Journal Eligibility Criteria

The determination of journal standards is based: (i) discussing traditional fermentation bacteria; (ii) examining benefit of Kombucha; (iii) discussing Kombucha produced by bacteria; (iv) published in Indonesian or English; and (v) in the form of review journals published in the range of 2016-2025. All journals were obtained by searching using electronic and manual search tools from PubMed and Google Scholar databases. Exclusion criteria in this study included journals that were not related to traditional fermentation bacteria.

Journal Selection

Journal selection followed the guidelines of Pigott and Polanin (2020) to identify publications meeting the established inclusion criteria. Titles and abstracts were screened to exclude irrelevant sources through a systematic identification and data analysis process. Subsequently, the selected journal articles were reviewed and evaluated in detail to ensure full compliance with the inclusion standards.[21]

Research Bias Control

The risk of bias or quality assessment in this journal review encompassed the following aspects: (i) the accuracy of information presented about kombucha fermentation and its health benefits; and (ii) the selective reporting of outcomes. The overall risk of bias was deemed minimal when all criteria were satisfactorily met.

RESULTS

This study was conducted from March to April 2025 using the Scopus database at https://www.scopus.com, which yielded 1,232 scientific articles or journal publications on kombucha published between 2016 and 2025. with the highest distribution of publications originating from countries such as China, India, Poland, Brazil, and Thailand, and dominated by research institutions in the fields of food science,microbiology, and biotechnology at public universities and applied food research institutions; Figure 1 shows the trend in the number of journals published each year, with the highest surge occurring in 2023–2024 before declining in 2025. To visualize the data distribution, VOSviewer software was used to generate a network map of 26 terms (Figure 2) and a density visualization (Figure 3) mapping key terms such as antioxidant, yeast, green tea, sugar, and activity, but it still lacks

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detailed explanations of the biochemical mechanisms or identification of specific active compounds supporting specific therapeutic benefits, such as enzyme activity pathways or anti-cancer potential. Thus, despite the large overall number of publications and intensive cross-national institutional collaboration, in-depth research linking the kombucha fermentation process to molecular mechanisms and neuroprotective effects remains relatively rare, opening up opportunities for more targeted and innovative future research.

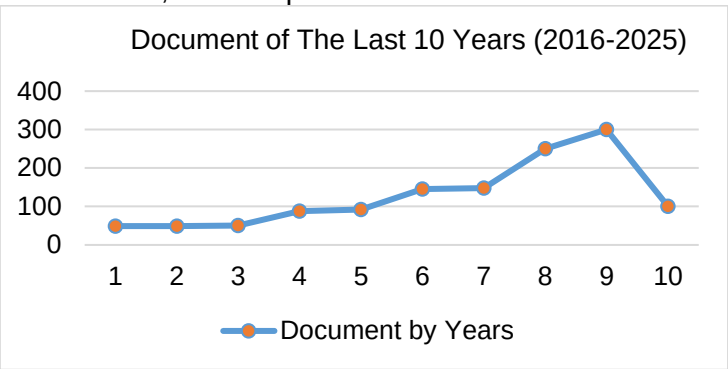

Figure 1. Total of Publications on "Kombucha Fermentation" from 2016 to 2025

Based on kombucha publication trends from 2016 to 2025, the number of studies remained below 50 per year from 2016–2018, focusing on antioxidant and antimicrobial activities. It rose to 80–90 papers in 2019–2020 as research explored new raw materials like green tea and coffee, then surged to 140–180 in 2021–2022 with expanded topics such as anti-cancer, anti-inflammatory, and in vivo studies. Publications peaked at 250–300 in 2023–2024 with emerging molecular analyses but declined to around 100 in 2025 (provisional data), highlighting the need for deeper molecular and neuroprotective research. (Source: Scopus)

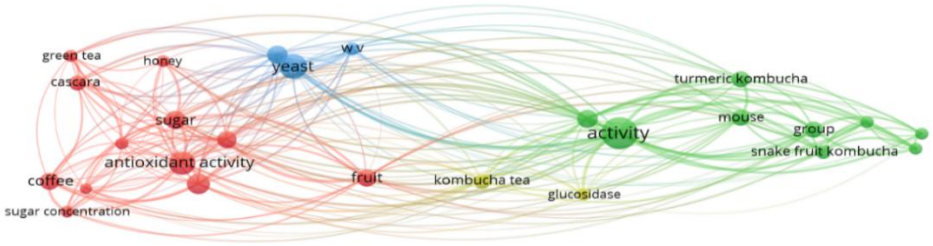

Figure 2. Keyword Network Map Visualization (Kombucha Fermentation)

Figure 2. Visualization of the keyword network map (Kombucha fermentation) from 1,232 scientific publications analyzed using VOSviewer software. The visualization reveals three main keyword clusters: (1) the red cluster, which focuses on kombucha's basic ingredients and antioxidant activity, including keywords such as sugar, coffee, green tea, and antioxidant activity; (2) the green cluster, which highlights studies on biological activity using animal models with keywords like activity, mouse, turmeric kombucha, and snake fruit kombucha; and (3) the blue cluster, emphasizing the microbiological aspects of fermentation dominated by the keyword yeast. The larger size of keywords such as antioxidant activity, yeast, and activity indicates their higher frequency and central role in kombucha research. (Source: VOSviewer and https://www.scopus.com)

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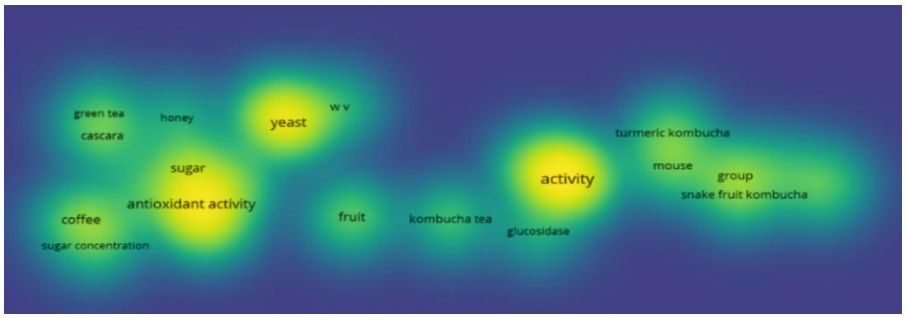

Figure 3. Visualization of The Keyword Density Map (Fermented Kombucha)

Figure 3. Visualization of the keyword density map (Fermented Kombucha) of scientific publications on fermented kombucha, generated using VOSviewer software. Yellow color indicates areas with high keyword density or frequency of occurrence, while green to blue color indicates lower frequency. It can be seen that the keywords with the highest intensity are “antioxidant activity”, ‘yeast’, and “activity”, indicating that these topics are the main focus of kombucha-related research. (Source: VOSviewer and https://www.scopus.com).

Table 1. Types of Kombucha and The Health Benefits of Kombucha Obtained from Data from The Last 5 Years

No	Types of Kombucha	Inspection Parameters	Treatment	Country	Reference
1	Kombucha	Antioxidant and antimicrobial activity	• Prevention of oxidative stress	Poland	[22]
2	Kombucha	Antioxidant and antimicrobial activity	• Strategies to prevent and manage oxidative stress-related diseases	Thailand	[23]
3	Kombucha	Antioxidant, antibacterial and antifungal activity	• Antibacterial*Salmonella enteritidis* • Antifungal Candida albicans	Brazil	[24]
4	Black Tea Kombucha	Antioxidant, antibacterial activity	• *Staphylococcus aureus MCTIC 4163, Bacillus cereus MU-A44 and Escherichia coli NCTIC 8196.*	New Zealand	[25]
5	Kombucha	Antioxidant, antibacterial and anti-inflammatory activities	• Interleukins 1β, 6 and 10	Poland	[26]
6	Kombucha	Phytochemical activity and antioxidant	• Prevention of oxidative stress	Poland	[27]
7	Green Tea Kombucha	Antioxidant, Antiproliferative, Antibacterial, and Antimalarial	• Salmonella, spp • *Plasmodium falciparum* • oxidative stress	Brazil	[28]
8	Honey Kombucha	Antioxidants	• Efforts to prevent and address diseases caused by oxidative stress	English	[29]
9	Pineapple Skin Kombucha	Antioxidants, and antimicrobials	• Mitigation and management of disorders caused by oxidative stress	Thailand	[30]

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No	Types of Kombucha	Inspection Parameters	Treatment	Country	Reference
10	Kombucha	Antioxidants	• Approaches to preventing and managing oxidative stress-induced conditions	China	31
11	Kombucha Tea: Black Tea, Broken Glass Tea, and Polyherbal Tea	Antioxidants	• Preventing and managing diseases linked to oxidative stress	Malaysia	32
12	Kombucha	Anti-cancer, antibacterial and antioxidant	• Gastric cancer targets 4H9M, 2DQ7 and 1TVO	India	33
13	Kombucha	Anticancer	• Inhibitor of digestive enzyme activity and adipocyte differentiation of OP9 cells	China	34
14	Kombucha	Antimicrobial and anticancer properties of cellless isolated metabolites from a Gluconobacter oxydans strain found in kombucha.	• Gastric cancer and colorectal cancer	Poland	35
15	Vine tea kombucha	Anti-cancer, antibacterial and antioxidant	• Liver Cancer	China	36
16	Kombucha	Anti-inflammatory	• Cerebral ischemia	Iran	37
17	Kombucha	Antioxidant and antileukemia	• Antioxidants against Leishmania parasites	Cameroon	38
18	Kombucha	Anticancer	• Factors such as HIF-1α, VEGF, IL-8, COX-2, as well as caspase-3, -8, and -9 enzymes, PARP, Bax protein, Bcl-2, p53, p21, MMP-2, MMP-9, and β-actin.	English	39
19	Kombucha Thunbergia laurifolia	Antioxidants	• Prevention of oxidative stress	Thailand	40
20	Lemon verbena Kombucha	Antioxidants	• Prevention of oxidative stress	Iran	41
21	Kombucha Tea	Antiviral and Anti Antiproliferation	• HEPG-2 Cells (Liver Cells) • Hepatitis A virus (HAV), Rift Valley fever virus (RVFV), and Herpes simplex virus (HSV)	Chad, Africa	42
22	Kombucha Tea	Anti-inflammatory	• Kombucha exhibits hypoglycemic properties • Antilipidemic, • Antibacterial, • Antioxidants, and • Detoxification	Africa	43
23	Kombucha	Anti-inflammatory,Antibacterial, Antioxidant	• Its anti-inflammatory effect on RAW264 cells (macrophage cells)	China	44

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No	Types of Kombucha	Inspection Parameters	Treatment	Country	Reference
			• *L929 cells (subcutaneous tissue)*		
24	Butterfly Pea Flower Kombucha	Antifungal	• Inhibits Candida albicans fungus	Indonesia	[45]
25	Kombucha	Treatment of diabetes, hypertension, and cardiovascular, Anitkanker	• Kombucha offers multiple health benefits, including blood detoxification and reductions in cholesterol, blood pressure, kidney calcification, inflammation, arthritis, rheumatism, gout, obesity, menstrual issues, menopausal symptoms, insomnia, stress, and nervous disorders. It also supports liver, glandular, and immune function; boosts interferon production; improves hair, skin, and nail health; enhances vision; regulates bowel activity; balances intestinal flora; and helps prevent bladder infections. • Human cancer cell lines used included MCF7 (breast), HT-29 (colon), A549 (lung), U2OS (bone), and 786-O (kidney). Studies found that kombucha showed cytotoxic effects on 786-O and U2OS cells, reduced MMP-2 and MMP-9 activity in 786-O cells, and decreased MMP-2 activity in A549 cells.	Thailand	[46]
26	Vegetable, fruit and plant kombucha	Anti-cancer, anti-triplidemia, and anti-hypertensive	• The anti-inflammatory effect was demonstrated through inhibition of the production of various proinflammatory mediators, including IL-1α, IL-6, TNF-α, and NO, on lipopolysaccharide (LPS)-induced inflammatory responses in RAW264 macrophage cells.	Bangkok	[47]
27	Kombucha	Glycemic index and insulin index monitoring	• Hyperglycemia Reduction	Australia	[48]

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No	Types of Kombucha	Inspection Parameters	Treatment	Country	Reference
28	Black Kombucha Tea	Fat profile and anti-inflammatory	• RAW 264.7 mouse macrophage cells (ATCC, accession number TIB-71)	Spanish	[49]
29	Grape Kombucha Tea	Anti-aging	• Measurement of blood glucose, total cholesterol, and PGC-1α expression in Swiss albino mice consuming a high cholesterol and fat diet (CFED).	Indonesia	[50]
30	Kombucha Green Tea Banana	Noncommunicable diseases (NCDs)	• The analyzed parameters included blood glucose, total cholesterol and its fractions, triglyceride levels, antioxidant activity, and liver enzyme activities — aspartate aminotransferase (AST) and alanine aminotransferase (ALT).	Brazil	[51]

A bibliometric analysis of the Scopus database (2016–2025) identified 1,232 publications on fermented kombucha, peaking in 2023–2024. As shown in Table 1, most studies examined antioxidant (20) and antimicrobial (10+) activities across countries such as China, India, Brazil, and Indonesia. Others explored anti-cancer (8+) and anti-inflammatory (5) potentials using animal models and cancer cell lines (MCF7, HT-29, A549, U2OS, 786-O). Fewer than five studies analyzed molecular mechanisms (e.g., HIF-1α, VEGF, IL-8, COX-2, MMP-2/9), revealing gaps in mechanistic and neuroprotective research.

VOSviewer visualization identified 26 keywords in three clusters: (1) raw materials and antioxidants (“sugar”, “coffee”, “green tea”); (2) biological activity (“mouse”, “turmeric kombucha”); and (3) fermentation microbiology (“yeast”). The density map highlights “antioxidant activity,” “yeast,” and “activity” as core themes, indicating that kombucha research remains dominated by antioxidant and antimicrobial studies, with limited exploration of biochemical pathways or clinical validation.

DISCUSSIONS

From 2016 to 2025, research on kombucha reported in 30 reviewed journals revealed that its most studied health benefits include antioxidant, antimicrobial, antifungal, and anticancer properties. The antioxidant activity is primarily attributed to the polyphenols in tea used as the fermentation substrate. Antimicrobial and antifungal effects are linked to organic acids such as acetic and glucuronic acids, which inhibit pathogenic bacteria like E. coli, S. aureus, and S. typhi. The anticancer potential of kombucha has also drawn attention, with several studies demonstrating its ability to inhibit liver and breast cancer cell proliferation in vitro—although human clinical evidence remains very limited. [25,49]

Kombucha’s bioactive compounds are central to its health benefits. Organic acids act as natural antimicrobials, probiotics like Acetobacter and Lactobacillus support gut balance and immunity, while vitamins B, C, and polyphenols neutralize free radicals and reduce oxidative stress linked to chronic diseases. This synergy makes kombucha a potent functional beverage.[46,47] Although the general benefits of kombucha have been widely studied,

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some aspects of research still offer scientific novelty. One of these is in-depth research into the enzymatic activity of kombucha microbes that may support liver detoxification and anti-inflammatory activity.[47]

Based on the bibliometric analysis, current kombucha research primarily centers on antioxidant and antimicrobial activities, along with variations in fermentation ingredients such as green tea, coffee, honey, and fruits, which are closely linked to keywords like sugar, yeast, and antioxidant activity. This trend aligns with previous studies emphasizing kombucha's potential in reducing oxidative stress, preventing microbial infections, and exerting anticancer effects. However, significant gaps remain—particularly the limited exploration of molecular mechanisms, such as how kombucha's bioactive compounds affect cellular signaling pathways or gene expression, and the lack of research on its neuroprotective potential against oxidative damage. These gaps highlight important opportunities for future studies to deepen understanding of kombucha's mechanistic actions and its protective role in the nervous system.[36] Research on Indonesia's local microbial variations and unique fermentation substrates also opens up opportunities to find SCOBY strains with more specific bioactive activities.[50]

Several bibliometric findings in the latest Tables 24 and 29 indicate that Indonesia has shown a notable upward trend in kombucha-related publications over the past five years, positioning it among the more active research contributors in Asia. However, the exact publication figures require clarification to substantiate this trend. Data from databases such as Scopus or Google Scholar can be used to determine the annual number of kombucha studies authored by Indonesian researchers, providing a clearer picture of Indonesia's growing role in this research field.[45,50]

Data from Scopus and Google Scholar indicate that Indonesian researchers publish dozens of kombucha-related studies each year, reflecting a steady rise in research output. This trend is largely driven by studies utilizing local natural ingredients, the popularity of herbal beverages, and the growth of small and medium-sized enterprises (MSMEs) in the fermented drink sector. Similarly, countries such as Australia, China, India, and Brazil are also actively engaged in kombucha research, focusing both on health benefits and the advancement of the functional beverage industry. [48, 51]

Indonesia has a rich diversity of medicinal plants and spices—such as ginger, turmeric, lemongrass, and moringa leaves—that can be integrated into the kombucha fermentation process. Combining SCOBY with these local ingredients enhances the drink's nutritional value, flavor, and bioactivity, while promoting innovation in fermented beverages with a uniquely Indonesian identity and strong export potential. Moreover, utilizing local plant resources can empower farmers and MSMEs, positioning kombucha not only as a functional health drink but also as a driver of local resource–based economic growth.[42]

As public interest in kombucha continues to grow, the standardization of raw materials and fermentation processes has become increasingly crucial. Standardization ensures product quality, safety, and consistency in delivering health benefits—especially if kombucha is to be developed as a medically recognized functional beverage. Key aspects include regulating the substrate type, fermentation duration, SCOBY microbial composition, and contamination control. Establishing these standards will help producers comply with functional food regulations, broaden market access, and support advanced research, including clinical trials, to scientifically validate kombucha's claimed health benefits.[47]

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The strengths of this study include extensive data coverage with 1,232 publications spanning nearly a decade, a comprehensive bibliometric analysis using VOSviewer to map keyword trends and research clusters, and the identification of key countries and institutions actively conducting kombucha research. However, its limitations lie in the descriptive nature of most findings, the lack of methodological quality assessment of primary studies, limited data on human clinical trials, and the absence of direct linkage between bibliometric results and standardized, evidence-based health outcomes.

CONCLUSION

Based on the publication trend over the past decade, which has increased by approximately 15–20% per year, kombucha has been extensively studied for its antioxidant, antimicrobial, anti-inflammatory, antiproliferative, and potential anticancer properties, with Indonesia ranking among the top five countries in Asia actively publishing related research. Kombucha contains key bioactive compounds such as organic acids, probiotics, polyphenols, and vitamins B and C, which contribute to its roles as an antioxidant, liver detoxifier, gut microbiota balancer, and immune booster. Dominant keywords describing its function include natural probiotics, fermented functional drink, detoxification, and antioxidants.

Despite its potential, most studies remain in vitro or animal-based, highlighting the need for human clinical trials to assess its effects on oxidative stress, microbiota balance, immunity, and metabolic regulation. Moving forward, the development of kombucha using Indonesian local plant substrates should be optimized through standardized raw materials and fermentation protocols to ensure consistent, safe, and evidence-based public health applications.

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